# THE JOHN DAY FORMATION IN THE PICTURE GORGE QUADRANGLE, OREGON

by

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# THE JOHN DAY FORMATION IN THE PICTURE GORGE QUADRANGLE, OREGON

## INTRODUCTION

### Location

The Picture Gorge quadrangle is located in the middle portion of the John Day Basin in north-central Oregon. The quadrangle includes the area between 44° 35' 36" and 44° 28' 40" north latitude, and between 119° 42' 43" and 119° 34' 22" west longitude. The Wheeler-Grant County line traverses the area in a north-south direction so the western half of the quadrangle is in the southeastern part of Wheeler County and the eastern half of the quadrangle is situated near the middle of the western boundary of Grant County. The geographic location and relative area are shown on Plate I.

Two main paved highways cross the quadrangle--the John Day Highway, which enters the area on the north and extends due south to Picture Gorge, and the Ochoco Highway, which enters on the western border of the quadrangle and trends in an easterly direction to Picture Gorge. The two roads join at Picture Gorge in the southern half of the quadrangle. From Picture Gorge Junction north along the John Day Highway it is 20 miles to the town of Kimberly; to the southeast along the same highway it is 6 miles to Dayville; and west along the Ochoco Highway it is 30 miles to

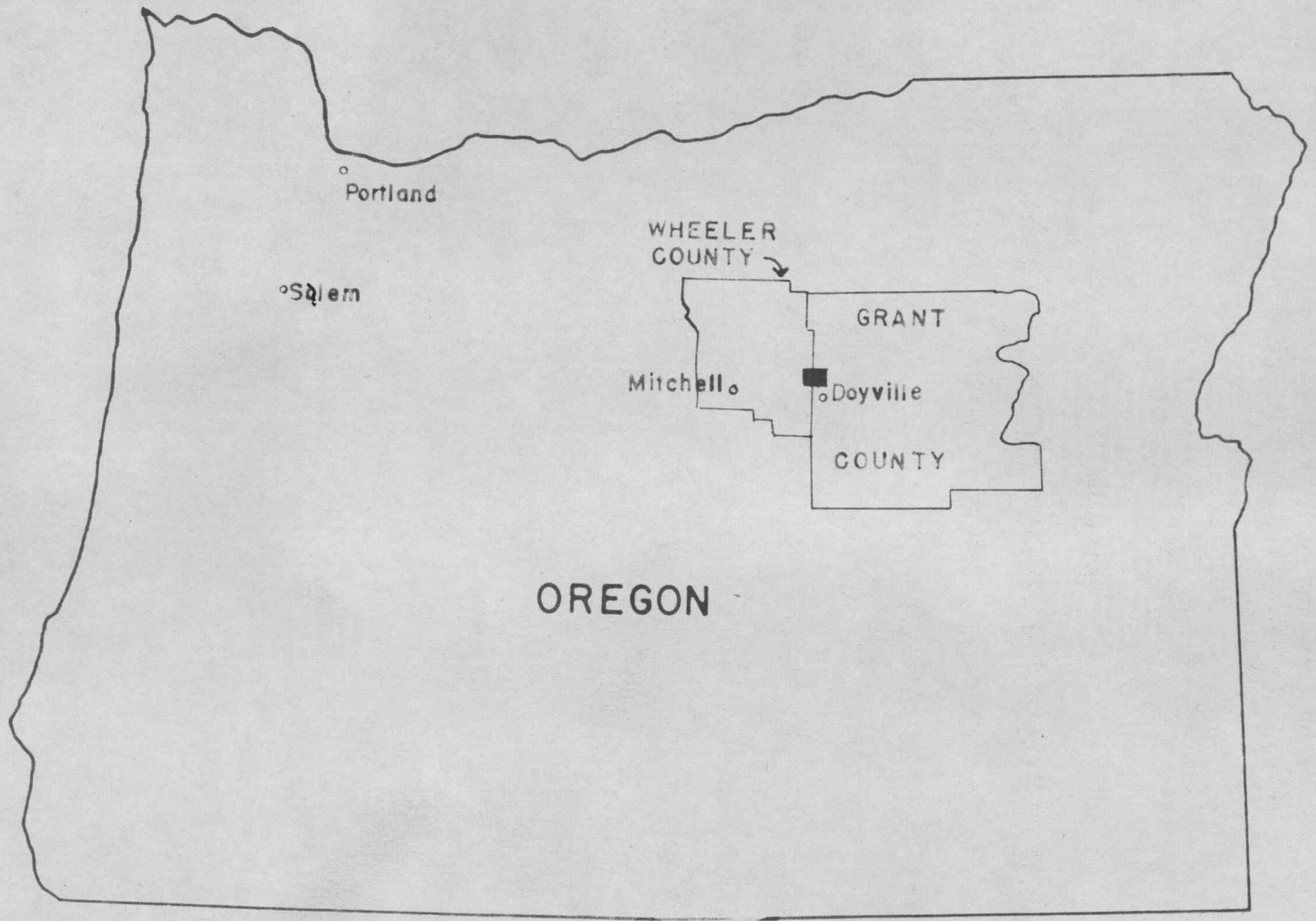



PLATE II

Index map showing location of Picture Gorge Quadrangle, Oregon the town of Mitchell.

## Size

The area originally referred to as Picture Gorge quadrangle in the survey of 1925 included 56 square miles. The Dayville quadrangle surveyed in 1932 took in that part of the area south of the $44^{\circ}$ 30' north latitude line which was formerly incorporated within the Picture Gorge quadrangle proper. The area south of this latitude is not included in this investigation, and all references to the Picture Gorge quadrangle that appear later in the text include only that part of the quadrangle which lies north of the $44^{\circ}$ 30' north latitude line and outside the Dayville quadrangle.

The actual area as thus reduced is approximately 46 square miles. It includes all of Butler Basin, a small part of Big Basin, and the western tip of the John Day Valley.

## Purpose of the Investigation

The primary purpose of the investigation of the Picture Gorge area was to make a detailed study of the John Day formation, particularly the lithology of the various units that comprise the formation, with a view toward determining the mode and environment of its origin. Many paleontological investigations of the John Day fossil flora and fauna have been made without the aid of precise geological information. As a result many of the findings have been of little value as the collectors did not correlate their fossil localities with the corresponding lithology and geological horizons. Most collections have been classified roughly as coming from the lower, middle, or upper John Day formation and many times this classification was done solely on the basis of the color of the matrix! Those vertebrate fossils which had green matrix were considered to be from the middle John Day and those with light buff color were supposed to be from the upper John Day beds. As a result of this haphazard color classification the stratigraphic succession of the fauna of the John Day formation has become confused.

This investigation of the John Day formation at Picture Gorge does not attempt to determine the stratigraphy for the entire formation but merely to delineate the stratigraphy at one of the main type localities.

In addition to the stratigraphic problem the origin of the John Day tuff beds has been in controversy--whether they were laid down in a large Oligocene-Miocene lake or laid down as an aeolian deposit of ash. Possibly only a regional study of the formation can settle this problem finally, but the present study of the tuff beds in the Picture Gorge area seems to supply definite clues.

Besides these stratigraphic problems the areal geology and the structural relations of the rocks of the Picture

Gorge quadrangle were investigated in reconnaissance detail. This was done to complete the information on the general setting of the John Day formation in this area.

## Methods of Investigation

The field work in connection with the John Day formation was done in as detailed scope as the existing topography of the area permitted. A complete and detailed sampling of the formation was done and each sample was located by use of the plane table and alidade. A complete vertical profile was made from the top to the bottom of the formation as exposed in the area. The profile was taken in sections at different points in the area and not at any one particular place as a complete section of the John Day formation is not afforded at any one exposure. Additional and duplicate profiles were not attempted as the topography is too rough to afford access to additional areas for sampling in a vertical series. Duplicate sampling laterally along the beds, for the most part, was not feasible and not necessary as the beds seemed to show little variation in the lateral direction.

The areal geology was done by the writer with the help of several undergraduates. Most of the areal mapping was of a reconnaissance nature.

The laboratory study of the tuff was made as detailed as possible so as to get a complete petrographic description of each bed in the formation. The tuffs were treated as sediments and sedimentary petrography methods were used almost exclusively in their study. Heavy mineral separations were carried out for each sample along with a quantitative wet sieve analysis for the separation of the material larger than 200 mesh (0.074 mm.). Time did not permit detailed counting of the heavy minerals although the quantities for each sample were estimated by eye. Thin sectioning of the tuffs was done only to determine their texture as very few of the constituent minerals were present in any one thin section.

Detailed investigation of the other formations occurring in the Picture Gorge area was not attempted. They are discussed within the text only on the basis of their general appearance and field relations.

## Previous Investigations

The discovery of fossil mammalian remains in the John Day Basin in 1861 by a company of soldiers led Thomas Condon, amateur geologist, then pastor of The Dalles Congregational Church, to make the first recorded investigation of the John Day formation. Condon's work on the John Day formation was not of a systematic nature but rather merely a random collection of the vertebrate fossils. His observations were first published in the Overland Monthly, May, 1871. Condon (7, p.393) considered the John Day tuffs to represent a huge Tertiary lake deposit. His discussion in part follows: "A lake existed here through the whole Tertiary period; and a continued lake depression surrounded by elevated ridges of hills, rising into mountain magnitude, implies the deposit of continued sediment.........the winds would always blow into the waters of the lake their burden of leaves and the flood of the winter wash in some fragments of the bones of the animals that characterized the period." Until recent time some geologists following Condon's original hypothesis maintained that the John Day beds were of lacustrine origin.

In 1875 O.C. Marsh first used the name John Day to designate the Miocene lake beds described by Condon. Of the John Day Basin Marsh (15, p.52) wrote: "The typical localities of this Miocene lake basin are along the John Day River, and this name may be very properly used to designate the lake basin." Marsh also was interested primarily in the vertebrate material to be found within the beds. Professor Joseph LeConte first discussed the structural relations of the John Day formation. In his paper, "The Great Lava Flood of the West," LeConte (13, p.170) states the relation of the lava (Columbia River Basalt) to the John Day beds in part as follows: "The lava of this region (John Day Basin) is less thick, (than the Columbia River Basalt exposed along the Columbia River) only about 600 to 700 feet thick; and being underlaid by the remarkable fossiliferous Miocene lake deposit of the John Day Valley...."

Clarence King in 1878 made some observations on the John Day formation in connection with his report "Exploration of the 40th Parallel." King (12, p.423) first described petrographically the type of material that makes up the John Day formation. His description is as follows: "These Oregon beds (John Day formation) are all in inclined positions, earlier than the basaltic eruptions, (Columbia River lava) and the main material of his (O.C.Marsh) whole series, as I have determined by microscopic studies, is of trachytic pumice, tuffs and hyaline sands."

The first detailed description of the John Day formation was made by John C. Merriam (17, p.270-314) in 1901. His article "A Contribution to the Geology of the John Day Basin" gives a general stratigraphical, structural and paleontological discussion of the John Day formation.

In conjunction with Merriam's work on the John Day formation, Frank C. Calkin's paper (3, p.109-314), "A Contribution to the Petrography of the John Day Basin," discusses in detail the petrographic nature of the John Day formation.

Since Merriam's and Calkin's work on the John Day formation no other detailed work has been done expressly on this formation, although there are many references to the formation in recent literature. Among others the following list of authors have included a discussion of the John Day formation: I.C. Russell (21, p.58), J.P. Buwalda (2, p.1-10), J.F. Bowman (1, p.28-36), E.T. Hodge (11, p.40) and R.W. Chaney (4, p.30).

# GEOGRAPHY

## Topography

The Picture Gorge area is located within the physiographic province known as the Columbia River Plateau, in which the dominant control of the topography is exerted by the Columbia River lavas. The plateau surrounding this particular area, for the most part, has been extremely dissected by the headward erosion of the John Day River and its tributaries, leaving only small areas, if any, which can be referred to as part of the original Columbia River Plateau. The folding and faulting of the Columbia River lavas in this region also have contributed to the obscuring of the original plateau. Of special importance to the local relief of the Picture Gorge area are the resistant ignimbrite flows of the Rattlesnake formation. This welded tuff forms extensive "rim-rock" areas in the John Day Valley which are expressed as weathering escarpments and residual buttes along the flanks of the valley.

The relief of the area is extreme and averages about 2000 feet for the Picture Gorge area. The lowest elevation is found along the John Day River as it leaves the northern portion of the quadrangle at a level of about 2100 feet. The maximum elevation is found in the SE 1/4 of Sec. 36, R.26 E., T.11 S., on the upthrow side of a large fault block which rises to 4802 feet.

Picture Gorge, the most imposing topographic feature of the area, has been cut into Columbia River lavas by the John Day River and Rock Creek to form a sharp, rugged canyon with nearly vertical walls rising 800 feet above the stream bed. The erosive action of both streams within the lavas isolated a large triangular-shaped block of lava which stands out as a butte. To the south of the gorge several large oblong mesas capped by Rattlesnake "rim-rock" interrupt the otherwise smooth valley floor of the John Day River.

To the north of Picture Gorge the country opens up into a large landslide basin known as Butler Basin. The basin is surrounded by landslide scarps of Columbia River lavas underlain by the softer John Day tuff beds and displays hummocky surfaces typical of a landslide area. Sheep Rock, a large lava-capped butte and landmark, stands in the southeast part of the basin as an erosional outlier entirely separate from the main receding landslide escarpment of the Columbia River lavas.

On the northern limits of Butler Basin Middle Mountain forms a very imposing barrier where Columbia River lavas have been folded into a syncline and then faulted so as eventually to create a large mountain transverse to the John Day River.

The remainder of the Picture Gorge area consists of dissected remnants of the Columbia River lavas which here have a gentle dip to the south.

## Drainage

The entire area is drained by the East Fork of the John Day River, which rises to the east in one of the ridges of the Blue Mountains 30 miles to the east of Canyon City and flows in a general westerly direction to the vicinity of Dayville. The course from here to Picture Gorge, a distance of five miles, is northwesterly. At the gorge the river turns sharply to the north where it is superimposed in nearly a straight line on the Columbia River Basalts, presumably following an original depression formed by the Middle Mountain syncline. The history of the course of the John Day River will be discussed in detail later in the text. The river continues northward from Middle Mountain to its junction with the North Fork near the town of Kimberly.

Streams to which frequent reference will be made in subsequent discussion are Cottonwood Creek, flowing from the south to meet the East Fork at the Mascall Ranch; Rattlesnake Creek, entering at the mouth of Picture Gorge, and Little Rattlesnake, its tributary; Rock Creek, which drains the uplands southwest of Picture Gorge quadrangle; and Mountain and Birch Creeks, the main tributaries of Rock Creek. These streams all drain the region south and southwest of the sharp northward bend in the East Fork at

Picture Gorge. Deer Gulch, flowing west meets the East Fork at Humphrey Ranch, Squaw Creek entering the East Fork on the northern flank of Middle Mountain, and Dick Creek, which drains the southern portion of Big Basin, are streams that drain the highlands flanking the East Fork north of the gorge. Most of the streams tributary to the East Fork in this area are intermittent; in fact during extremely dry seasons the East Fork itself occasionally declines to brook-like proportions.

## Climate

The climate of the John Day Basin is semi-arid with extreme daily and seasonal variations of temperature. The average annual rainfall at Dayville is 11.68 inches over a 15 year period. Throughout the summer months the weather is quite variable and may bring unexpected periods of abnormal rainfall. The daily range of temperature in the summer months is commonly about 30 degrees. The winter months are marked by extremely low temperatures and an increase in precipitation, mostly as snow, which accumulates to depths of several feet in the higher regions.

## Vegetation

The vegetation of this region is generally sparse and consists of hardy desert types typical of much of eastern Oregon. Along the perennial streams and surrounding large springs, however, the vegetation is more lush and varied.

The species found near plentiful water include alder (*Alnus tenufolia*), birch (*Betula fontinalis*), hackberry (*Celtis occidentalis*), dogwood (*Cornus occidentalis*), poplar (*Populus trichocarpa*), gooseberry (*Ribes aureum*), wild rose (*Rosa pisocarpa*), willow (*Salix lasiolepis*), and cat tail (*Typha latifolia*). The desert types found on the uplands and on the drier flats include juniper (*Juniperus occidentalis*), sagebrush (*Artemesia tridentata*), and bunch grass (*Agropyrum spicatum*). Growing on the high portions of the upland areas are mountain mahogany (*Cercoarpus ledifolius*) and western yellow pine (*Pinus ponderosa*).

This area is not suitable for cultivation except small fields of hay and grain grown on the flood plains of the John Day River. The uplands furnish excellent grazing for both cattle and sheep. Animal husbandry therefore is the chief industry in the region.

# GENERAL GEOLOGY

## Synopsis of the Geologic Formations

The rocks of the Picture Gorge quadrangle to be considered in this paper are dominantly of volcanic origin. In order of age these are: John Day formation, Columbia River Basalt formation, Mascall formation, and Rattlesnake formation. All of these volcanic rocks are Tertiary in age. All of the Tertiary formations heretofore described from the John Day Basin are exposed in the area except the Eocene rocks which are generally referred to as the Clarno formation. Within several miles of this area, however, several extensive exposures of the Clarno formation are present.

The oldest rocks in the area are limited in extent and include highly metamorphosed marine sediments of uncertain age which are unconformably overlain by a massive indurated conglomerate tentatively referred to the Cretaceous period. All of the rocks in the area, except possibly some of late Quaternary age, have been deformed by folding and faulting, including landslides. The youngest deposits of the area are for the most part the unconsolidated deposits laid down by streams. Reworked volcanic ash is found in these unconsolidated deposits.

The different geologic formations that have been distinguished in the field work are represented on the

TABLE 1

Summary of Exposed Rock Formations in the Picture Gorge Quadrangle, Oregon

| Age | Formation | Character | Thickness (feet) |
|---|---|---|---|
| Quaternary | | Alluvial gravel, silt, and ash. Landslide areas. | 2-30 |
| Pliocene | Rattlesnake fr. | Poorly consolidated silts and gravels. Welded-tuff overlain by fanglomerates. | 100-200 |
| | unconformity | | |
| Upper Miocene | Mascall fr. | Water-laid rhyolite tuff and some inter-bedded gravels. | 100-450 |
| | unconformity | | |
| Middle Miocene | Columbia River Basalts | Olivine and normal basalt flows. | 800-1200 |
| | unconformity | | |
| Lower Miocene | Upper and Middle John Day fr. | Variegated andesite tuffs. Ignimbrite bed separating the two members. | 600-700 |
| Upper Oligocene | Lower John Day fr. | Red trachyte tuff, in part, water-laid. Basalt flows near the base. | 100-600 |
| | unconformity | | |
| Upper Cretaceous | Cretaceous(?) conglomerate | Highly indurated conglomerate and some sandstone lenses. | 200-300 |
| | unconformity | | |
| ? | meta-sediments | Metamorphosed marine sediments. Lime-stone, quartzite, and schist. | 3000 ? |

geologic map (Plate V). The character and relations of the formations exposed in the Picture Gorge quadrangle are shown on Table 1.

Pre-Cretaceous Meta-sediments

Name. The basement rocks of the Picture Gorge area are as yet unnamed. No formational designation or age correlation is known. The discussion in this paper will refer to these rocks merely as Pre-Cretaceous meta-sediments.

Distribution and Topographic Expression. The areal distribution of the Pre-Cretaceous is limited. The actual area involved is a thin strip 1 mile long varying in width from several hundred to 1000 feet. The total amounts to half a square mile. The meta-sediments are exposed along the base of a large fault scarp which is expressed by Windy Point and the basalt ridges farther east. To the west of the main exposure the meta-sediments pinch out along the fault and to the east the exposure is covered by slump material and alluvium.

The Pre-Cretaceous rocks form three small ridges transverse to the main fault and are the only rocks exposed along the south edge of the fault in Big Basin. The relatively greater hardness of these rocks in comparison with that of other formations tends to make their outcrop more rugged in topographic expression.

Lithology. The Pre-Cretaceous rocks are composed of a series of highly metamorphosed marine sediments. Preservation of the banding and bedding is recognizable in many of the outcrops. The rock types found include schistose limestone, green schistose quartzite, silicified sericite schist, chlorite-muscovite schist, granulated quartzite, and small amounts of serpentine.

The granulated quartzite and schistose limestone are the most abundant rock types. The other types are intercalated in minor amounts within the quartzite and limestone. The entire formation has undergone several episodes of fracturing and drag folding, but subsequently it has been silicified so that all of the fractures have been healed. Usually the quartzites show extreme fracturing and the softer schists show small scale drag folding.

The quartzite ranges from blue to red to green in color. The blue and red varieties show extreme fracturing while the green has a schistose structure. Under the microscope the red and blue quartzite exhibits mortar structure and is seen to be cut by a network of healed fractures. The green schistose quartzite has well defined schistosity which is expressed by the elongation and parallelism of the quartz grains. Thin "streams" of chlorite follow the trend of schistosity.

The limestone varies in outward appearence from a massive rock to schistose rock. Under the microscope the limestone exhibits extreme crushing with very little recrystallization except for the few veins of secondary calcite cutting the rock. In the hand specimen the limestone is a light grey-blue to light grey rock.

The silicified sericite schist is a rust-brown platy rock that is cut by a series of intersecting fractures which have been healed by secondary quartz. Under the microscope the rock shows the sericite schist to be completely impregnated with secondary quartz. The brown coloration is due to replacement of pyrite metacrysts by limonite.

The chlorite-muscovite schist is a light green soft rock which has not undergone silicification. This rock type usually found as small intercalated lenses associated with limestone is very limited in extent. Under the microscope the main constituents are chlorite and muscovite and both show excellent schistose structure.

All of the rocks except the mortar quartzite show secondary foliation parallel to the bedding. This foliation generally strikes S. 50° E. and dips 56° to the northeast.

Thickness. The thickness of the exposed meta-sediments as scaled and computed from the map is approximately 3000 feet. This figure is undoubtedly far below the actual thickness as only a small portion of the formation is exposed. Also the outcrops are limited and nearly vertical so that it is almost impossible to determine the actual structure of the beds, whether repeated by folding, etc.

Stratigraphic Relations and Age. As stated earlier, these rocks are the basement complex of the Picture Gorge area. A profound angular unconformity separates the meta-sediments from the overlying Cretaceous(?) conglomerates. The Cretaceous(?) beds dip 21°, S. 10° W. whereas the meta-sediments dip 56°, N. 40° E. The age of the meta-sediments is unknown as no fossils have been found within the beds. The lithology of the meta-sediments is different from any of the already described Jurassic, Triassic, and Paleozoic formations for this region. J.P. Dobell (9, p.18) reported meta-sediments of similar lithology and stratigraphic position in the Antone district. The age of the meta-sediments in the Antone district is also doubtful, although the two series are similar enough to seem to belong to the same formation.

## Cretaceous(?) Conglomerate

Name. The Cretaceous(?) rocks of the John Day Basin as yet have no formational designation. The supposedly Cretaceous exposures found in the Picture Gorge area will be referred to as the Cretaceous(?) conglomerates.

Distribution and Topographic Expression. The conglomerates outcrop in limited areas along the John Day River from Base School northward to the northern boundary of Sec. 31, T. 11 S., R. 26 E. Just south of this section on both sides of the river several hundred feet of conglomerate

Fig. 1 Highly indurated Cretaceous (?) conglomerate

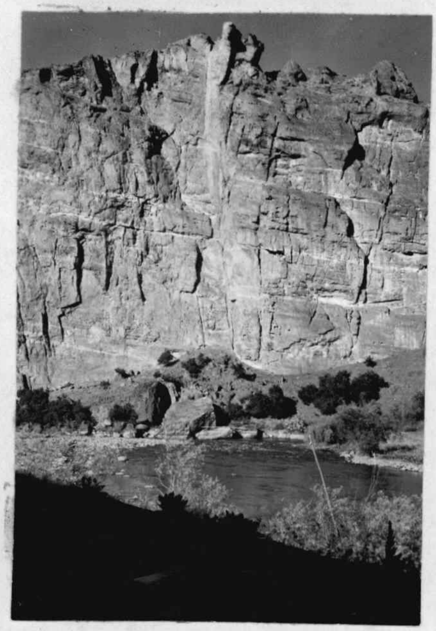


Fig. 2 Cretaceous(?) conglomerate exposed along the John Day River. Note intercalated sandstone lenses.

have been exposed by the downcutting of the John Day River (Fig. 2). This affords the best exposure of the Cretaceous(?) rocks in the area. The conglomerate extends eastward from this point on the river for a distance of 3½ miles. This exposure extends eastward from the river in a strip which varies in width from 1/4 to 1/2 mile. The total areal extent of the Cretaceous(?) in the Picture Gorge quadrangle is approximately one square mile.

The conglomerate assumes varied topographic forms. Where the overlying beds have been stripped from the conglomerate it forms low rounded hills. Where the conglomerate has been eroded below this level it forms steep sided canyons and gullies flanked by sharp ridges that have been eroded into irregular hoodoo forms (Fig. 3). The best example of the extreme erosional forms is seen in Deer Gulch. Much of the Cretaceous(?) conglomerate in Picture Gorge area has been covered by landslide and slump.

Lithology. The Cretaceous(?) rocks of the Picture Gorge area consist entirely of massive, highly indurated conglomerate with occasional lenses of sandstone. The size range of the particles composing the conglomerate is extreme. Cobbles as large as 150 mm. and sand grains down to 0.25 mm. in size are found together within the conglomerate. The material is poorly sorted as all gradation of size can be found within one small area. The complete section shows no gradation upward from a basal conglomerate to finer

Fig. 3 Erosional forms of Cretaceous(?) conglomerate along Deer Gulch.

Fig. 4 Exposure of Cretaceous(?) sandstone lense which produced fossil leaves, Deer Gulch.

material, but instead the entire thickness is composed of the unsorted cobbles, pebbles, and grit interbedded with medium-grained sandstone. A typical exposure of the conglomerate is illustrated in Figure 1.

The conglomerate has been highly impregnated with silica which is the main cementing agent in the matrix. The conglomerate is so highly indurated that when the rock is broken the fracture face is smooth. The cobbles and pebbles are well rounded and exhibit both spheroidal and discoid shapes which suggest a shoreline environment of origin. The outside surfaces of the cobbles and pebbles are usually very smooth and invariably covered with a thin film of iron oxide stain. Where the Cretaceous(?) comes in contact with the Lower John Day red beds both the sandstone lenses and the pebbly conglomerate are stained deep red or purple.

Inspection of the cobbles and pebbles composing the conglomerate shows that the rock types represented are from many of the older formations in the region. Some of the rock types, however, are completely strange and foreign to any of the known and described pre-Cretaceous rocks. Quartzite is the most abundant rock in the conglomerate. It is accompanied by minor amounts of porphyritic purple andesite, granite, rhyolite, metamorphosed siltstone, quartzite breccia, diorite, and some basic intrusive rocks. The quartzite can be identified as coming from the underlying meta-sediments in the Picture Gorge area and the metamorphic siltstone as derived from the Triassic series. The other rock types are not like any of the older exposed formations.

The sandstone lenses vary in thickness from 6 inches to 5 feet. The bedding of the conglomerates is obscured except where these sandstone lenses are locally interbedded. The lenses are not persistant and usually pinch out within a distance of several hundred yards. The sandstone is light grey to green and is either friable or indurated by secondary calcite. All of the fragments appear to be angular and present a fairly uniform size of about 0.25 mm.

A well defined set of vertical joints transects most of the conglomerate. These joints cut through the conglomerate without respect to cobbles or sandstone lenses.

Thickness. The total thickness of the conglomerates as scaled and computed from the geologic map is approximately 300 feet. This figure varies somewhat at different localities as folding and subsequent erosion have given the conglomerate an uneven thickness.

Stratigraphic Relations and Age. The Cretaceous(?) conglomerate is separated from the underlying meta-sediments by a distinct structural unconformity as mentioned earlier in the text. The Cretaceous(?) beds in turn had been folded prior to John Day time and so are also separated from the Lower John Day red beds by a marked structural unconformity. North of Turtle Cove the Lower John Day formation rests on tightly folded Cretaceous(?) whereas in Butler Basin the Lower John Day rests on only slightly warped Cretaceous(?).

The age of the known Cretaceous elsewhere in the John Day Basin as determined by Merriam (17, p.283) is Upper Cretaceous. The Cretaceous of the John Day Basin is correlated with the Chico formation of northern California although the faunas do not indicate a connecting Cretaceous seaways. Abundant fossil invertebrate material has been collected south of the Picture Gorge quadrangle in the northern portion of the Dayville quadrangle.

The conglomerates of the Picture Gorge area as yet have yielded no invertebrate fossils although some poorly preserved fossil leaves were found in one of the sandstone lenses. The leaf locality is in the south branch of Deer Gulch in the S.E. 1/4, N.W. 1/4 of Sec. 32, R. 26 E., T. 11 S. and illustrated in Figure 4. The leaves as yet have not received a complete study although the presence of sassafras suggests the age to be Cretaceous as the invertebrate fossil localities to the south also have yielded the same extinct species of sassafras. Until a complete paleontological and petrographic study of the Cretaceous in the John Day Basin is made the age of the conglomerates in the Picture Gorge will remain questionable.

## John Day Formation

<u>Name and Scope</u>. The variegated tuffs overlying the Cretaceous(?) in the Picture Gorge quadrangle were named the John Day formation in 1875 by O.C. Marsh (15, p.52). The John Day formation as used in this text includes not only the easily identified red, green, and buff tuffs but also intercalated basalts in the lower red beds, and the extensive ignimbrite flow which separates the middle and upper member of the John Day formation.

<u>Areal Distribution and Topographic Expression</u>. The John Day formation outcrops over extensive areas within the Picture Gorge quadrangle. The best exposures of the formation invariably are under a protective cap rock of Columbia River Basalts. Sheep Rock and Turtle Cove areas exhibit the most extensive outcrops of the John Day formation in the area. Other smaller exposures may be seen in Butler Basin at the base of the landslide scarps.

The typical expression of the John Day formation is badland topography. The lower red beds form low rounded hills and the middle and upper members have a more rugged aspect. Differential erosion of the hard and soft layers has produced a myriad of terraces, fluted columns and hoodoos.

<u>Lithology</u>. In this area the John Day formation can be divided into five distinct units: (1) the basalts found near the base of the John Day intercalated in the red beds;

(2) the lower red beds which form a distinct petrographic unit and have the characteristic red coloration; (3) the middle green tuff beds which include all of the tuff between the red beds and the ignimbrite flow; (4) the ignimbrite flow of distinct petrographic character; (5) the upper buff tuff beds which include all of the material between the ignimbrite flow and the overlying Columbia River Basalts.

The basalts consist of two flows which are interbedded with siliceous shales, calcareous tuff, and waterlaid tuff. The basalts are diabasic in texture and have been greatly altered by weathering. Secondary cold water deposits occur in veins and in amygdaloidal cavities within the basalts.

The lower red beds are composed of highly weathered trachytic tuff which is interbedded with several beds of light colored andesitic tuff. The lower portion of the red beds are partly waterlaid although the bulk of the material is of aeolian origin.

The middle green beds are dominantly andesitic in composition and generally have the characteristic green color although much of this member is buff instead. They consist of a series of fine grained tuff beds that repeatedly alternate from hard calcareous to soft friable layers. The whole middle series apparently was laid down under aeolian conditions.

The ignimbrite flow that separates the middle from the upper John Day member is a rhyolite welded-tuff. This welded-tuff consists of a glassy rock at the base grading upward into a more porous and vesicular tuff at the top. The source of the ignimbrite was local although the actual vent or fissure has not been located. The material is similar to the acid flows of "nuees ardentes" eruptions.

The upper John Day member differs little from the underlying middle member except for its dominant buff color. Petrographically the upper member is a fine-grained andesitic tuff. The upper member also consists of a series of alternating hard and soft tuff beds, but generally the hard layers are less indurated than those in the underlying middle member. The upper tuffs also are exclusively of aeolian origin.

Thickness. The total thickness of the John Day formation as measured by plane table and alidade is 825 feet. Extreme erosion of the soft tuffs has made the actual thickness of the John Day in some areas as low as 100 feet.

Stratigraphic Relations and Age. The John Day formation is separated from the underlying Cretaceous(?) conglomerate by a marked structural unconformity. This relation is best seen north of Turtle Cove and in areas north of the Picture Gorge quadrangle where the folded Cretaceous(?) conglomerate is overlain by almost horizontal beds of the Lower John Day. The overlying Columbia River Basalts in turn also rest on the John Day unconformably. The soft John Day tuffs were highly eroded and slightly warped before the extravasation of the lavas. The development of this unconformity apparently was contemporaneous with the deposition of the tuffs and the initial outpouring of the lavas as the first two flows of the Columbia River Basalt are interbedded with the andesitic tuffs of the Upper John Day formation. This interbedding of the John Day tuffs and the Columbia River Basalts can be seen at two different localities within the Picture Gorge quadrangle. The best exposures of the interbedding may be seen at the base of the cap rock on Sheep Rock and near the highway junction within Picture Gorge.

The age of the John Day formation has long been a subject of controversy mainly because of poorly located fossil vertebrate material and the widely divergent opinions of the paleontologists who have worked on this material. Recent work by Schultz and Falkenberg (22, p.83) on the fossils has shown that the Middle and Upper John Day are the equivalent of the Harrison formation in Nebraska and Wyoming. This places the middle and upper members in the lower Miocene. A vertebrate fossil recently found in the Lower John Day formation within the Picture Gorge area indicates that this division of the John Day belongs in the Upper Oligocene. A description of this material is given in the appendix. If this correlation is borne out by other workers the Oligocene-Miocene boundary will have to be placed within the John Day formation, probably between the Lower John Day and the Middle John Day.

## Columbia River Basalts

Name. The huge volume of basic lavas that covers most of eastern Oregon and parts of southern Washington and western Idaho are named the Columbia River Basalts. The basalts found above the John Day formation in this area are part of this great lava flood.

Areal Distribution and Topographic Expression. The dominant rock formation of this area is the Columbia River Basalts. These basaltic lavas almost completely surround Butler Basin except for the northeastern corner. They also form the northern boundary of the John Day Valley to the south of Butler Basin. Picture Gorge affords an excellent exposure of the lavas where the John Day River and Rock Creek have down cut through the entire thickness of the Columbia River Basalts (Fig. 5). The lavas have an areal extent of 23 square miles which is approximately half of the total area in the Picture Gorge quadrangle.

Not only are the Columbia River lavas the most widespread rocks of the area but they also exercise the greatest control on the existing topography. The relative hardness of the lavas has produced striking contrast in relief. Butler Basin is surrounded on the east, west, and south by precipitous landslide scarps of the Columbia River lavas.

Fig. 5 Columbia River Basalt flows exposed in Picture Gorge.

Fig. 6 Fan-shaped joints and columnar joints in a single flow of Columbia River Basalt.

Middle Mountain to the north of Butler Basin is a large syncline capped by Columbia River Basalt that forms an imposing barrier transverse to the John Day River. Where the plateau surface of the lavas is exposed the expression is relatively smooth except for some small gullies and canyons cut by consequent streams. Picture Gorge is the most imposing topographic expression of the Columbia River lavas in the area. This gorge is approximately 800 feet deep at the junction of Rock Creek and John Day River where the complete section of lavas is exposed. In the southeastern corner of the area several fault block ridges composed of Columbia River Basalt stand out as sharp hog-backs trending in a NW-SE direction.

Lithology. The Columbia River Basalts consist of a series of individual lava flows that are superimposed one upon the other. The individual flows vary in thickness from 30 feet to 100 feet and can be readily recognized in the field by the red zone at the top. This top zone represents the soil that had accumulated after the underlying flow was poured out and before the succeeding flow was implaced. The soil layers vary in thickness from 3 inches to several feet. Each was invariably baked red by the succeeding lava flow. The two basal flows, in this area, lack soil zones but they border a considerable thickness of interbedded tuff. These interbedded tuffs show excellent thinly laminated bedding and contain a great amount of fossil wood and carbonaceous material. Microscopic examination of this tuff shows that it is the same type of material as the underlying andesitic tuffs of the John Day formation. These tuff beds at their upper contact with the lavas are not baked red but took on a purplish cast resembling manganese compounds.

Directly beneath the "fossil" soil zone on the basalts are flow-breccia zones that range in thickness up to 20 feet. The breccia consists of angular basaltic and scoriaceous particles imbedded in a well indurated matrix of finer basaltic particles.

Directly below the breccia zones the basalt is highly vesicular and grades down to a felsitic dark grey rock in the middle portion of the flow. At the base of each flow the rock is again vesicular.

Most of the individual flows below the breccia zone show excellent columnar jointing which is usually normal to the horizontal surface of the flow. The jointing has two distinct forms: (1) large hexagonal columns which extend the full thickness of the flow and (2) small irregular hexagonal joints which have little or no symmetry with respect to the plane of the flow (Fig. 6). These irregular joints assume fan shapes and swirl patterns, and are apparently due to the faster cooling of the individual flow units.

Megascopic inspection of the basalts reveals little consistency in the many flows examined although as a whole the basalts are usually light to dark grey and have a subconchoidal fracture.

The most common type found is a fine-grained dark grey basalt. Olivine can be seen with the aid of the hand lens as irregular patches within a finer grained ground-mass.

A distinctive flow was noted near the base of the series in Middle Mountain. This flow is highly weathered and exhibits none of the characteristic structures of the other flows. Its color is black and it lacks the characteristic top breccia and red baked contact. On close inspection with the hand lens the rock appears to have a diabasic texture. As it is highly decomposed one finds it difficult to procure a hand specimen.

Several flows near the top of the Columbia River Basalts in this area have a porphyritic texture and are much lighter in color. The middle portion of these flows is more vesicular than in those farther down in the series. The phenocrysts are basic plagioclase set in a felsophyric groundmass. Olivine was not detected with the hand lens although it may be present in the rock.

Many of the vesicular cavities within the flows are filled with amygdules of secondary zeolites and chalcedony.

Thickness. The irregular topography of the John Day tuffs at the time of the extrusion and subsequent erosion has made the thickness of the Columbia River Basalts extremely uneven. The total number of flows counted in Picture Gorge is 19 while just north of the gorge toward the town of Kimberly the number of flows increases to 25. The thickest section of basalt in the area is along the west scarp of Butler Basin where the thickness is approximately 1200 feet. Picture Gorge exposures on the other hand have a thickness of only 800 feet.

Stratigraphic Relationships and Age. The Columbia River Basalts are separated from the John Day tuffs by an unconformity that is both erosional and structural, due to the warping and erosion of the John Day beds prior to the extrusion of the Columbia River Basalts. The overlying Mascall tuffs are separated from the Columbia River Basalts by a slight structural unconformity. At some exposures this relationship is so slight that the Mascall appears to be conformable on the basalts. The actual discordance in dip ranges from 1 to 5 degrees.

The exact age of the Columbia River Basalts is difficult to determine due to its complete lack of fossils. The underlying John Day is considered Lower Miocene, in part, and the overlying Mascall formation is considered Upper Miocene. This brackets the Columbia River Basalts within the Middle Miocene.

## Mascall Formation

Name. The fossiliferous tuff formation that overlies the Columbia River Basalts in the southern portion of the Picture Gorge area has been named the Mascall formation from its typical occurrence on the Mascall Ranch just south of Picture Gorge.

Areal Distribution and Topographic Expression. The Mascall beds are abundantly exposed in the southern portion of the Picture Gorge area. The type locality of the Mascall formation is west of the southern entrance of Picture Gorge. This exposure gives an excellent picture of the relationships between the Columbia River Basalts and the Mascall formation and also between the Mascall and the succeeding Rattlesnake formation (Fig. 9). East of the type locality the Mascall flanks the John Day Valley as small outcrops at the base of the Columbia River Basalt dip slope. West of the type locality the Mascall beds are exposed along the southern border of Rock Creek Valley and in a small area along the northwestern side of the valley near the McDonald Ranch. Most of the area south of Rock Creek is underlain by the Mascall formation. Small isolated patches of the Mascall tuffs are exposed north of the Mascall Ranch near the Hole In The Ground, Willow Springs, and Kennedy Cabin.

Typical exposures of the Mascall formation (Fig. 7) are rounded and slumped hills. Where the Mascall is protected by the overlying ignimbrite of the Rattlesnake formation the tuffs are dissected into deep gullies separated

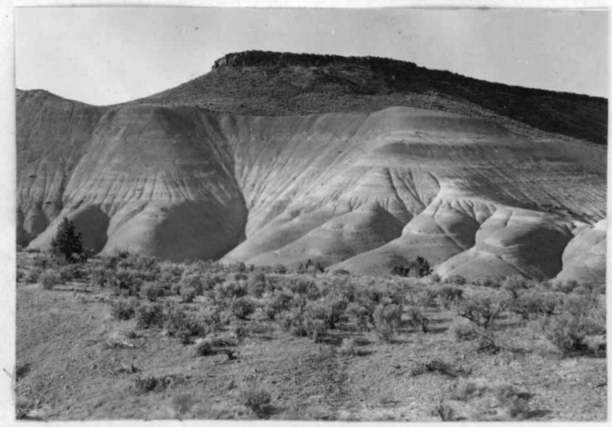


Fig. 7 Typical exposure of the Mascall formation along Rattlesnake Creek.

Fig. 8 Contact between Mascall tuff and Rattlesnake gravels.

by rounded ridges. A thick indurated layer of tuff interbedded in the Mascall forms a prominent bluff just south of Picture Gorge. This layer generally forms a small ridge or terrace in the outcrop.

Lithology. The Mascall formation is composed almost exclusively of water-laid and wind-laid tuffs accompanied by some interbedded gravels. Generally the tuffs of the Mascall are friable and poorly consolidated. The tuffs therefore are easily eroded by rain wash and when highly saturated with water the surface of the outcrops yields numerous miniature mudflows. The bedding of the Mascall is manifested by gradational changes in color and by alternating hard and soft beds. Some of the water-laid tuff beds show excellent laminations which resemble varves. Coarse textured beds near the top are crossbedded.

The color of the beds is generally in pastel shades of buff, white, and yellow. These color transitions are never sharply defined in the field as the slope wash obscures the bedrock.

Table 2 gives the generalized section of Mascall formation taken at the type locality along Rattlesnake Creek.

Microscopic inspection of the individual specimens was not attempted but inspection of the tuffs by use of the hand lens shows most of the material to be fairly fresh and unweathered except for several beds which seemed to be altering to bentonite. Calkins (3, p.167) stated that the

Table 2

Generalized Section of the Mascall Formation in the S.E. 1/4 Sec. 19, N.E. 1/4 Sec. 30, T. 12 S., R. 26 E.

| Unit | Thickness feet |
|---|---|
| Buff and white sandy tuff and intercalated gravel lenses | 100 |
| Buff friable tuff | 30 |
| Brown indurated water-laid tuff | 4 |
| Soft brown aeolian(?) tuff | 20 |
| Grey vitric indurated tuff | 2 |
| Buff friable medium-grained tuff | 20 |
| Light buff indurated tuff | 4 |
| Brown bentonitic tuff | 10 |
| Indurated brown tuff with secondary manganese | 20 |
| Brown bentonitic tuff | 10 |
| Water-laid brown sandy indurated tuff | 3 |
| Brown friable tuff | 7 |
| Resistant light buff tuff forming prominent ridges and serving as an excellent marker bed | 50 |
| Friable brown aeolian(?) tuff | 60 |
| Grey coarse to fine aeolian(?) tuff | 1 |
| Compact light buff tuff | 25 |
| Laminated light buff water-laid tuff | 2 |
| Alternating brown, yellow and buff soft and indurated tuff | 30 |
| | 435 |

Mascall tuffs were acid in character. The thin grey pumiceous bed was analyzed by Calkins (3, p.167) and classified as a rhyolite-tuff.

At several places in the Mascall formation secondary manganese occurs in nodules and as joint fillings. Psilomelane with thin coatings of pyrolusite on the surface is generally most abundant. The quantity present is so slight that it does not warrant economic consideration.

Thickness. The thickness of the Mascall formation at the type locality is 1435? [illegible] 435 feet. This figure does not agree with that of Stock, Merriam, and Moody (19, p.52) who have stated that the thickness of the Mascall at this point is 2090 feet. Their figure seems incorrect as the smaller thickness stated here was measured with the plane table and alidade. The thickness of the Mascall is variable from place to place on account of subsequent erosion of the soft tuff and the irregularities of the surface of the original basin of deposition. At some localities the thickness is less than 100 feet.

Stratigraphic Relations and Age. The underlying Columbia River Basalts are separated from the Mascall formation by a slight angular unconformity. The overlying Rattlesnake formation is separated from the Mascall by a distinct angular unconformity and the contact between the two formations is uneven indicating some erosion (Fig. 8). The difference in dip between the two formations is $13^{\circ}$.

An abundant fossil vertebrate fauna and flora removed from the Mascall has contributed to the determination of the geologic age of the beds. Merriam and Sinclair (18, p.197) consider the fauna to be the equivalent of the Upper Miocene beds of Pawnee Creek, Colorado and of Deep River, Montana.

## Rattlesnake Formation

Name. The loose gravels, silts, and welded-tuff that overlie the Mascall formation in this area were named the Rattlesnake formation by Merriam (17, p.310) in 1901. It includes the gravels underlying the welded-tuff as well as the gravels overlying this bed.

Areal Distribution and Topographic Expression. The Rattlesnake formation is limited in extent in the Picture Gorge area although those exposures which are present in the area are excellent for a study of the material. The exposures are limited to the southwestern portion of the area. The best exposure of the formation occurs at the type locality along Rattlesnake Creek (Fig. 9) where it overlies the Mascall formation. Other exposures are seen along Birch Creek and Little Rattlesnake Creek. Several small patches of the welded-tuff outcrop near the "Hole in the Ground" as a northward extension of the Rattlesnake in this area.

The typical expression of the Rattlesnake is in

Fig. 9 Type locality of the Mascall and Rattlesnake formations showing the angular unconformity that exists between the two formations along Rattlesnake Creek.

Fig. 10 Contact between welded-tuff and silt of the Rattlesnake formation. Note small rock particles within the welded-tuff.

flat-topped mesas which are protected by the welded-tuff. This welded-tuff forms extensive "rim-rock" all along the John Day Valley as the Rattlesnake generally overlies most of the other formations in the area. Where the welded-tuff is lacking or is overlain by gravels the topographic expression of the formation is entirely different. The gravels form low rounded hills where the welded-tuff has been stripped off and where the overlying gravels and fanglomerates are present the expression is usually slightly rounded or comparatively flat.

Lithology. The Rattlesnake formation comprises two distinct types of rock. The lower portion of the formation is composed of rounded gravels and interbedded silts. Capping these gravels and in some places interbedded within the gravels is a welded-tuff bed. The deposition of gravels was continuous during Rattlesnake time and did not cease after the deposition of the welded-tuff.

The gravels consist of fairly well-rounded pebbles, cobbles, and boulders of basalt, although gravels inspected to the east of Picture Gorge area are generally composed of metamorphic siltstones, vein quartz, gabbro, and other "older" rock types. This indicates that the highlands surrounding the Picture Gorge area during Rattlesnake time were primarily basaltic while the highlands to the east consisted primarily of older pre-Tertiary rocks. The bedding of the gravels is generally obscure except where they are locally interbedded with brown tuffaceous silt. Some exposures show torrential cross-bedding and occasionally cut-and-fill structures of former stream channels. The gravels overlying the "rim-rock" are generally coarser and have very little interbedded silt. These gravels or fanglomerates form confluent alluvial fans and underlie much of the present surface to the south of the Picture Gorge area.

The silts interbedded in the gravels generally are massive and show little or no bedding. The rock is a medium-grained, tuffaceous, rust-brown silt. Some exposures of the silt show white layers of locally interbedded white volcanic ash.

The welded-tuff of the Rattlesnake formation is a striking rock in that it is composed primarily of pyroclastic material but has what appears to be rudimentary flow structure. The outcrops show rough columnar jointing in the middle portion which grades into platy jointing near the top. The weathered surface of the rock is light pink to brown while the fresh rock is generally grey in color. At the base of the exposures is a layer of about 3 to 4 feet of sandy, friable tuff which carries numerous angular and rounded particles of basalt (Fig. 10). Toward the top of the bed the tuff becomes increasingly more welded and begins to show pseudo-flow structure which is expressed by large flattened fragments of pumice. Some specimens collected near the top of the welded-tuff bed are so highly welded that they are almost wholly glassy.

Close inspection of the tuff reveals an occasional phenocryst of feldspar but generally the material is composed of highly vesicular pumice and glass shards which are generally aligned horizontally. Calkins (3, p.169) classified this tuff as a rhyolite.

The source of this welded-tuff which extends over much of central Oregon has never been located. The origin of this welded-tuff has long been a problem. The only plausible explanation of the pseudo-flow structure accompanied by obvious vitroclastic texture is that this material must have been extruded in a highly gaseous state and subsequently welded after extrusion by hot latent gases within the tuff. Several previously described welded-tuffs (8, p.205) similar to that found in the Rattlesnake formation have been named ignimbrites and it appears that the welded-tuff of the Rattlesnake very properly may be named a rhyolitic ignimbrite. This type of volcanic extrusion has been called "nuées ardentes" as the material travels along suspended in a glowing gaseous cloud. Surface slopes of only a few degrees are needed for this type of extrusion to flow and it has been reported that speeds up to 50 miles per hour are attained. The extrusion of the Rattlesnake ignimbrite probably was completed within a matter of hours or at the most a few days in a single outburst as there is no evidence of recurring extrusions.

Thickness. The total thickness of the Rattlesnake formation is highly variable from one location to another. The basal gravels exposed along Rattlesnake Creek attain a thickness of 150 feet while the basal gravels along Birch Creek are in few places more than 50 feet thick. The Rattlesnake ignimbrite near the "Hole in the Ground" rests directly on the Mascall formation without any trace of the basal gravels. The overlying fanglomerates, those gravels resting on top of the ignimbrite, also vary in thickness from place to place. In the Picture Gorge area these gravels are relatively thin or completely lacking while to the south and to the east these gravels attain thicknesses up to several hundreds of feet. The ignimbrite is relatively uniform in thickness and averages about 30 to 40 feet. The total thickness of the Rattlesnake formation in the Picture Gorge area is about 200 feet.

Stratigraphic Relations and Age. The Rattlesnake is separated from the Mascall by a distinct angular unconformity. At the type locality the Mascall dips 15°, S. 20° W. and the Rattlesnake dips 2°, S. 40° W. The ignimbrite rests conformably upon the basal gravels except for local erosional unconformities. The overlying fanglomerates also rest conformably on the ignimbrite.

The age of the Rattlesnake as determined by Merriam (19, p.58) is Pliocene. Fossil vertebrate remains have been recovered from the basal silts and gravels and also from the gravels overlying the ignimbrite. The upper limits of the Rattlesnake are doubtful as the fanglomerates have not produced many vertebrate fossils. The cessation of the accumulation of these fanglomerates probably marks the close of the Pliocene and the cutting of canyons through the fanglomerates probably marks the beginning of the Pleistocene in this area.

## Quaternary Deposits

The quaternary deposits of the Picture Gorge area consist of small terrace and floodplain deposits of gravel, sand, and silt along the John Day River and the minor tributaries. Included with these deposits is a widespread white, friable, re-worked volcanic ash. Merriam (17, p.313) states that some of the terraces in this region have produced mammalian fossils which have been referred to the Pleistocene. The white volcanic ash as yet has not yielded any fossils. These ash deposits occur typically along the banks and junctions of streams. Undoubtedly in recent times a thin ash fall blanketed the entire region but since has been stripped off the surrounding terrain and deposited in small pockets distributed throughout the area. This ash fall probably came from some volcanic eruption in the northern Cascade Mountains as it thins considerably and is almost nonexistent 50 miles to the south while the deposits thicken northward from Picture Gorge area. Calkins (3, p.169) made a complete chemical analysis of the ash and suggests that it may have come from an andesitic magma.

# STRUCTURE

## Pre-Cretaceous Deformation

The small area of exposed pre-Cretaceous meta-sediments in the northeastern corner of the area indicates an intense period of deformation before the inundation of the Cretaceous seas. The extreme amount of metamorphism, crushing, drag-folding, and silicification found in these rocks shows that the pre-Cretaceous deformation was of regional proportions.

The attitude of the meta-sediments is nearly vertical as the average dip is about 56°, N. 40° E. The schistosity follows the original bedding of the former sediments and is accompanied by small scale drag-folds. These folds do not exceed 6 inches from crest to crest and are found only in the softer schists.

## Post-Cretaceous Folding

Tertiary faulting and folding has obscured the regional structure of the Cretaceous(?) conglomerate and the underlying meta-sediments, although the Cretaceous(?) conglomerates exposed in the Picture Gorge area appear to be gently warped into a large monoclinal fold. The axis of the fold trends northeast-southwest and plunges to the southwest along the axis. North of Picture Gorge area along the lower reaches of Dick Creek the Cretaceous(?) conglomerates have been strongly folded into a series of isoclinal folds whose axes trend northeast-southwest. The distance between the axes of the folds is relatively small and does not exceed 1000 feet from one anticlinal crest to the next anticlinal crest. These flexure folds have the same axial trend as the larger monoclinal fold in Butler Basin and it appears that the major post-Cretaceous tectonic movement resulted from compressional forces applied in a northwest-southeast direction.

### Post-Columbia River Basalt Folding

The folding following the extravasation of the Columbia River Basalts has had a profound effect on the development of the John Day Basin. This warping has more or less controlled the deposition of the post-Middle Miocene formations in this region. In the Picture Gorge area there is evidence of two large folds of this age.

Middle Mountain in the north portion of this area is a large syncline (Fig. 11) trending N. 15° E. The John Day River flows directly through the axis of the syncline near the Humphrey Ranch. The east limb of the syncline is terminated on the south and northeast by post-Mascall faulting and the west limb extends to the west to form an anticlinal limb about 6 miles out of the area. The average dip of the west limb is 11°, S. 70° E. while the dip on the east limb is slightly greater and averages 13°, S. 70° W. Reconstruction of the fold would form a large plunging synclinal

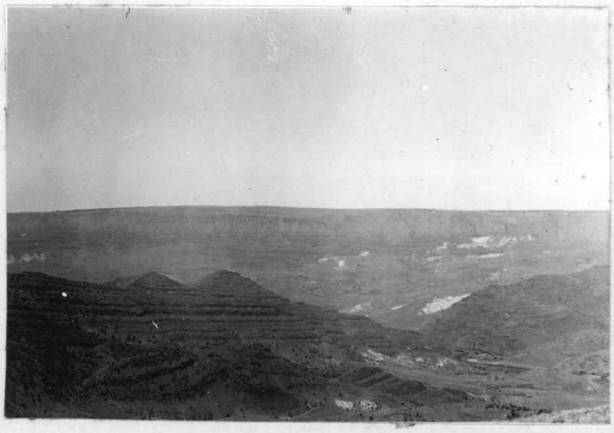


Fig. 11 Middle Mountain syncline in the foreground and the Columbia River Plateau in the distance.

Fig. 12 Breccia zone of the Middle Mountain fault. John Day tuff on the right and Cretaceous(?) conglomerate on the left.

trough some 15 miles wide.

The dip slope of the Columbia River Basalts in the southern portion of the area represents another broad flexure. The average dip of this structure is 18°, S. 10° W. although post-Miocene and post-Rattlesnake faulting has increased the initial dip of the structure. The axis of this broad synclinal warp trends east-west and extends as far east as John Day. This synclinal warp delineates the original structure which has controlled the formation of the present John Day Valley and also has controlled the deposition of the Mascall and Rattlesnake. The south limb of the syncline is not present in the Picture Gorge area but remnants of the northerly dip can be seen to the south in the Dayville quadrangle.

The opposing directions of the axes of the Middle Mountain and John Day synclines indicates that the forces responsible for the post-Columbia River Basalt warping were vertical forces of unknown origin, as the ordinary folding usually is the result of horizontal forces that produce parallel aligned axes.

The post-Columbia River Basalt folding has produced an excellent set of joints within the John Day tuff beds and in some cases a series of normal faults. Several of these small normal faults extend through the basalt and can be seen on the east ridge of Middle Mountain.

## Middle Mountain Fault

One of the main structural features of the Picture Gorge area is the Middle Mountain fault which trends in an east-west direction in the northern portion of the area. This fault is a normal gravity fault that in some places has branched out into several almost parallel faults to form small graben blocks. The only expression of this in the area is on the east side of Middle Mountain where the fault branches to the northwest near the south quarter corner of Sec. 28, R. 26E., T. 11 S. Middle Mountain has been downfaulted on the south by the major fault and on the north by the minor branch fault. The downthrow side of the faults in each case is towards Middle Mountain, thus forming a small graben of the Middle Mountain syncline although since faulting this graben block has undergone an inversion of relief and now stands out as a large mountain transverse to the axis of the syncline.

To the east of Middle Mountain the upthrow side of the major fault exposes the meta-sediments, Cretaceous (?) conglomerates, John Day formation, and Columbia River Basalts. Landslides in the Columbia River Basalts and John Day tuffs have sapped the original fault scarp so that the receding scarp is now represented only by Windy Point and the basalt ridges farther east. On the west side of the John Day River the fault is obscured by landslide blocks composed of basalt and tuff but it is apparent along Hog Ridge and west of the area where it continues for many miles.

Vertical displacement on the Middle Mountain fault is obscured by landslide and subsequent erosion but it is estimated to be approximately 700 feet and the displacement on the smaller branching fault is estimated to be about the same. Fault breccia zones along Deer Gulch were found to be nearly 30 feet wide and slickensides associated with the breccia indicate that some horizontal displacement accompanied the vertical movements. Figure 12 illustrates the expression of the fault breccia which was generally more resistant than the formations on either side of the fault. The dip of the fault taken from the point illustrated in Figure 12 is 52° due north.

It appears that this fault is post-Mascall in age although proof is lacking. Field evidence indicates only that the fault followed the warping of the Columbia River Basalts and so it could have taken place anytime during the Upper Miocene. The angular unconformity between the Mascall and Rattlesnake suggest that this faulting is partly responsible for the angular unconformity between these two formations in this area.

## Post-Rattlesnake Deformation

A belt of northwest-southeast en echelon gravity faults extend across the southern portion of the area. The average bearing of the strike of these faults is N. 50° W.

and the average dip of the fault plane is 60°, N. 40° E. In the Rock Creek area these en echelon faults show rotational movement as the throw increases to the northwest and in some places completely dies out to the southeast. This rotational movement is well shown on a fault just south of the McDonald Ranch, where the throw on the northwest end of the fault is approximately 200 feet whereas southeast of the McDonald Ranch the fault completely dies out. The illustration in Figure 13 shows this rotational fault as seen southeast of the McDonald Ranch. North of the Mascall Ranch these en echelon faults show little or no hing movement but in some places considerable horizontal movement.

The vertical displacement on these faults ranges from 50 to 500 feet as the rotation of the faults has made their displacement highly variable. Generally these faults have had a profound effect on the present topography. In the Rock Creek area these faults have exposed blocks of Columbia River Basalt which now stand as resistant ridges across the Rock Creek Valley. The extensive Rattlesnake "rimrock" mesas also have been deformed as illustrated in Figure 14. North of the Mascall Ranch these faults have disrupted the original dip slope formed during the warping of the Columbia River lavas. Instead of gentle slopes the surface now is a series of northwest-southeast fault block ridges.

The age of these faults is post-Rattlesnake or Upper

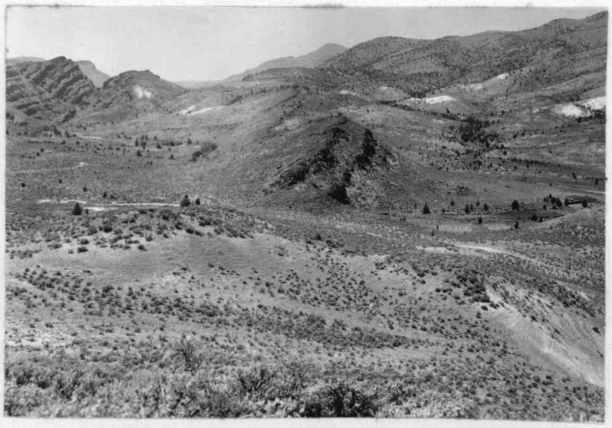


Fig. 13 Post-Rattlesnake fault block ridge south of the McDonald Ranch.

Fig. 14 Deformation of the "rim-rock" by post-Rattlesnake faulting, southeast of the McDonald Ranch.

Pliocene or early Pleistocene. Much of the ignimbrite within the Rattlesnake formation shows deformation due to these faults. Along Birch Creek the Rattlesnake as well as the Mascall and Columbia River Basalts show a repetition of bedding by these post-Rattlesnake faults. Near the "Hole in the Ground" Rattlesnake ignimbrite abuts directly in fault contact against the Columbia River Basalts.

It appears that the regional force responsible for the post-Rattlesnake faulting was a couple. This couple may have been formed by an easterly movement on the north side and a westerly movement on the south or by northerly movement on the east side and southerly movement on the west.

### Pleistocene(?) and Recent Landslides

Important to the interpretation of the present topographic features seen in the Picture Gorge quadrangle is the great amount of landslide area, especially in Butler Basin. Approximately 6 square miles of Butler Basin is composed of landslide.

The sliding in this area probably began after aggradation of the Rattlesnake fanglomerate and during the period of erosion which followed this deposition. It is still in progress in this region. As the present John Day River cuts through the Columbia River Basalts into the John Day tuffs, the tuffs are more rapidly eroded and as a result the sapping of the basalt creates a situation ideal for large scale landslides. The type of landslide that occurs in this region is the slump type as defined by C.F. Sharpe (24, p.65). The slumping in this area apparently has continued over a long period of time although individual movements may have been completed by a single rapid slip.

Removal of the softer tuffs underlying the basalt creates large areas of unstable ground along the river. Undoubtedly enough water is present to form a lubricated slip surface in the clayey John Day tuffs. This water and the weight of the overlying mass of unstable basalt causes the downward slipping of large units of basalt and tuff. Associated with this slumping of large units is the backward rotation of the displaced blocks on a horizontal axis parallel to the cliffs of basalt. This backward rotation of large blocks of basalt is shown in Figure 15. Terraced and hummocky slopes are produced by the backward inclination of these large blocks. The slumping in Butler Basin has extended almost two miles on either side of the river and is generally responsible for the formation of Butler Basin. The basin is surrounded by steep slump escarpments of Columbia River Basalt which may be seen in Figure 16.

Middle Mountain has undergone no major slumping as the synclinal structure of the basalts at this point forms a perfect structural barrier against landslides. Continuing on north of Middle Mountain and beyond the area is another extensive area of slump like that found in Butler Basin.

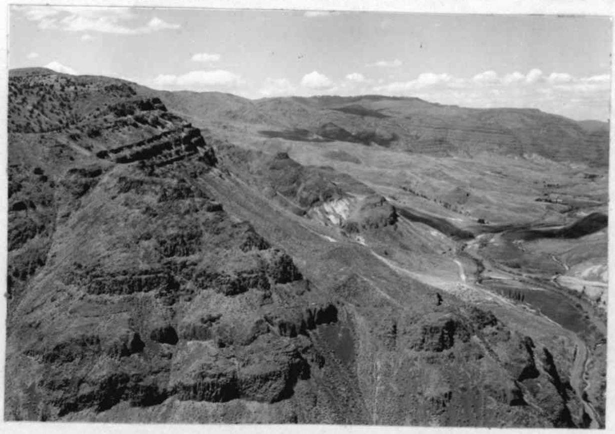


Fig. 15 Slump blocks of Columbia River Basalt and John Day tuff just north of Picture Gorge. Note backward rotation of block in the middle distance.

Fig. 16 Slump area in west Butler Basin. Columbia River Basalt escarpments on the left.

## JOHN DAY FORMATION

### General Statement

The John Day formation consists of three major members and two minor members of distinct petrographic character. The three major members are (1) the lower red tuff beds, (2) the middle green tuff beds, and (3) the upper buff tuff beds. The two minor members are (1) local basalt flows interbedded in the lower red beds and (2) the welded-tuff bed separating the middle and upper tuff beds.

The John Day formation is subdivided and discussed in the text as follows: (1) Lower Member of the John Day formation, includes lower red beds and interbedded basalts; (2) Middle Member of the John Day formation, all of the tuff between the lower red beds and the welded-tuff bed; (3) Ignimbrite of the Middle Member, thick bed of welded-tuff separating the middle and upper members; (4) Upper Member of the John Day formation, all of the tuff between the ignimbrite bed and the overlying Columbia River Basalt.

Merriam (17, p.293) originally divided the John Day formation into three units: Lower John Day (red beds), Middle John Day (green tuff and ignimbrite flow), and Upper John Day (buff tuff beds). This division was done on the basis of color and the paleontological character of the fossil vertebrate faunal zones. Heretofore no mention has been made of the basalts interbedded in the Lower Member of the John Day. The subdivisions used in this text are based on the lithology of the beds without consideration for the various faunal zones described.

### Lower Member of the John Day Formation

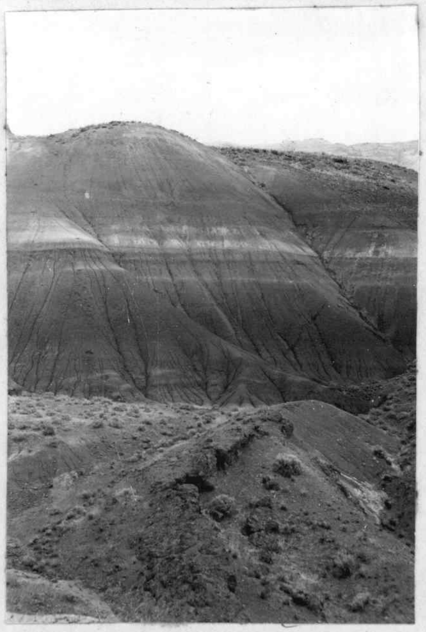
Areal Distribution and Topographic Expression. The Lower John Day, the lowest member of the John Day Formation, occurs in rather limited outcrops in the Picture Gorge quadrangle. The best exposure of this member outcrops near Sheep Rock where it is expressed as low rounded hills in which the typically red beds of tuff are interstratified with several layers of white ash. Other exposures of the Lower John Day are found north of Sheep Rock, but these exposures are limited and show only the lower portion of the member.

The Lower John Day basalts are exposed in small patches in the northern part of the area. Directly east across the John Day River from the Humphrey Ranch is an excellent exposure of the basalts which shows the interbedding of the tuffs and basalts. Just south of Deer Gulch and extending eastward from the John Day River are several small outcroppings of the basalt. Another small exposure of the basalt interbedded in the Lower John Day tuffs is seen 1/4 mile south of the Humphrey Ranch on the west side of the river.

The large scale landslide area surrounding these exposures presented such a problem in taking an uninterrupted profile that an alternative section to be used for detailed study was taken north of Picture Gorge proper (Fig 17) in the S.E. 1/4 N.E. 1/4 of Sec. 20, R. 26 E., T. 11 S. instead. The lithology at this location differs somewhat from the exposures in the Picture Gorge quadrangle in that the intercalated layers of white ash and basalt are not present.

Bedding. The tuff beds show evidence of bedding by an alternation of color and an alternation of the hard and soft layers. If at one time there was better delineated bedding it has been obscured by subsequent weathering of the ashy material. Also contributing to the concealment of the bedding is the action of rain wash on the soft tuff which has covered the surface uniformly with a coat of red mud. Locally abundant in some of the tuff interbedded in the basalts are bedding laminations. This bedding is manifested by thin bands of color and is so regular that it suggested seasonal deposition or varving. The distance between the laminations varies from 1 to 5 mm.

Color. The dominant color of the Lower John Day is a dull brick red, although there are many variations of the hues of red. The lower member exposed near Sheep Rock appears to have a more purple coloration especially near the lower contact, than the beds at the sampling locality. Several beds of white ash are interbedded within the red



Fi g. 17 Lower John Day formation red beds resting unconformably on folded Cretaceous(?) conglomerate, 1 mile north of Picture Gorge quadrangle along Dick Creek.

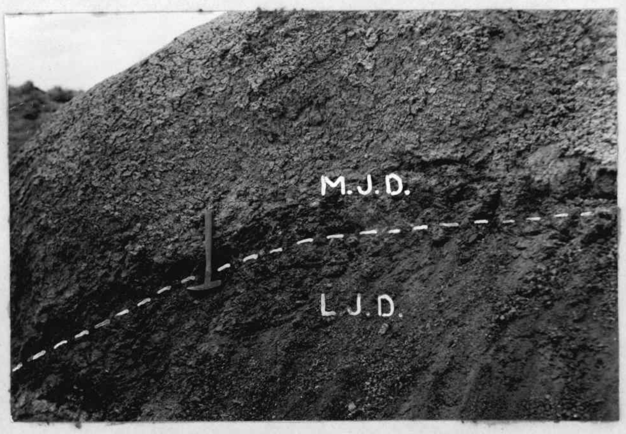



Fig. 18 Contact of the Lower and Middle John Day formation showing a slight erosional unconformity.

tuffs near Sheep Rock and are notably lacking at the sampling locality. The tuff beds interstratified with the basalts generally are light yellow to buff in color. The highly laminated tuff has a light maroon color alternating with light yellow.

The basalt generally is black although in areas of extreme weathering the basalt has a buff-yellow color. Where the basalt has been partially replaced by chlorite the color is light green.

The various hues of red and yellow in the Lower John Day are due to the iron minerals in the tuff which have undergone various degrees of oxidation.

General Petrographic Character. The Lower John Day beds are composed of a well weathered clayey tuff which now is composed mostly of fine-grained clay. On the average 40% of each bed studied is composed of material finer than 200 mesh (0.074 mm.). Much of the finer material is clay which was formed after deposition, although the cognate crystals studied have an average size of 0.4 mm. The tuff is cemented with secondary iron oxides or in some localities with secondary gypsum. Thin sections are difficult to make as the clayey nature of the rock causes slaking in water although several poor sections were produced by using an oil bath. Inspection of the thin sections showed faint outlines of the original vitroclastic texture although the original vesicular and pumiceous material has been altered to kaolin impregnated with iron oxide. The original crystal content exceeds 50% in many of the beds and does not fall below 25% in any of them, while the content of lithic fragments averages 20% for the whole tuff member. The tuff may be then classified as a Fine Essential Crystal-Vitric Tuff (28, p.52) at the time of deposition although at the present time the tuff has lost most of its original characters and is more nearly a clay than a tuff.

Several specimens were analyzed quantitatively for iron oxide and were found to show a relatively high iron content. No distinction was made in the analysis between ferric and ferrous iron as all of the iron present was reduced to the ferrous state during the analysis. The following table gives the results:

Table 3

Iron Oxide Content of the Lower John Day Beds

| Sample Number | Percent Total Fe as FeO |
|---|---|
| L.J.D. # 2-1 | 3.07 |
| L.J.D. # 2-2 | 7.05 |
| L.J.D. # 2-3 | 6.37 |
| L.J.D. # 2-4 | 7.99 |
| L.J.D. # 2-8 | 6.13 |
| L.J.D. # 2-9 | 8.76 |
| Average | 6.56 |

It appears that much of the iron present was oxidized subsequent to the deposition. The duration of this weathering period apparently was short, however, as the larger fragments of feldspar show little or no alteration in contrast to the well altered fine material.

In some outcrops of the lower red beds extreme concentration of iron oxide is noted, especially in the red beds near Sheep Rock. Interspersed in the beds near their contact with the Cretaceous(?) are numerous nodules ranging in size from several inches to a foot or more in diameter. On close inspection with the hand lens the nodules present an oölitic texture. The interstices between the oölites were filled with a white fine ash. In thin section the material composing the oölites is opaque although with the aid of reflected light and of chemical tests the material is found to be composed mainly of limonite and hematite. The interstitial material is white ash typical of the lower red beds.

Microscopic Character. The texture of the tuffs under the microscope is faintly vitroclastic with much of the material altered to kaolin. Figure 19 is a photomicrograph of a typical thin section of the lower red beds. The crystalline material is fairly abundant in most of the beds. Particles larger than 0.1 mm. appear clear and fresh. Sanidine, acid plagioclase, altered pumice, and vesicular glass shards make up the essential constituents of the tuff. Magnetite, brookite, biotite, quartz, zircon, limonite, hematite, rutile, and fragments of micro-trachyte and basalt make up the accessory materials of the tuff. Table 4 is a summary of the size analysis and heavy-mineral

TABLE 4

GRAIN SIZE AND HEAVY-MINERAL CONTENT OF THE LOWER MEMBER OF THE JOHN DAY FORMATION

| Sample Number | Percentage by weight | | | Relative percentage of heavy-minerals (estimated) | | | | |
|---|---|---|---|---|---|---|---|---|
| L.J.D. | less than 200-mesh | more than 200-mesh | heavy-separate | magnetite | brookite | zircon | biotite | secondary hematite and limonite |
| 2-1 | 49 | 51 | 0.18 | 30 | 20 | 20 | ... | 5 |
| 2-2 | 63 | 37 | 0.46 | 40 | 40 | 30 | 1 | 5 |
| 2-3 | 74 | 26 | 0.61 | 40 | 40 | ... | 2 | 10 |
| 2-4 | 51 | 49 | 0.78 | 40 | 30 | 1 | ... | 25 |
| 2-5 | 49 | 51 | 0.92 | 30 | 20 | ... | ... | 50 |
| 2-6 | " | " | " | " | " | ... | ... | " |
| 2-7 | 62 | 38 | 0.69 | 45 | 45 | 1 | ... | 5 |
| 2-8 | 59 | 41 | 1.05 | 50 | 20 | 3 | 3 | 5 |
| 2-9 | 82 | 18 | 0.27 | 40 | 30 | ... | ... | 2 |

studies for each bed in the lower member.

Sanidine occurs as clear euhedral crystals which are tabular parallel to the (010) face. Twinning is common in most crystals, usually following the Carlsbad law. Most of the sanidine crystals are water-clear but contain many inclusions of magnetite and apatite. Weathering of the larger cystals is not apparent while the smaller fragments under 0.05 mm. have been more or less completely altered to kaolin. Iron stain is common along the cleavage cracks of most of the phenocrysts. The bulk of the sanidine crystals range in size from 0.5 to 1.3 mm.

Acid-plagioclase is a common constituent of the lower red beds, but usually it is less abundant than sanidine. The index of refraction and extinction angle indicates that it is oligoclase. The phenocrysts are mostly euhedral with some anhedral fragmental particles. The albite twinning occasionally is combined with percline twinning. The plagioclase spars are fresh and nearly as clear as the sanidine crystals. Inclusions of magnetite and apatite are also common in the plagioclase. Weathering and iron stain has affected the plagioclase in the same manner as in the potash-feldspars. The prevailing size range is from 0.5 to 1 mm.

The only indication that the bulk of the tuff was formerly composed of glass shards and pumice is the relict outlines seen in thin section. The pumice and glass shards

Fig. 19 Photomicrograph of Lower John Day tuff showing large relict pumice fragment, small feldspar phenocrysts, and accidental basalt particles in a fine ashy groundmass. Plain light x 80.

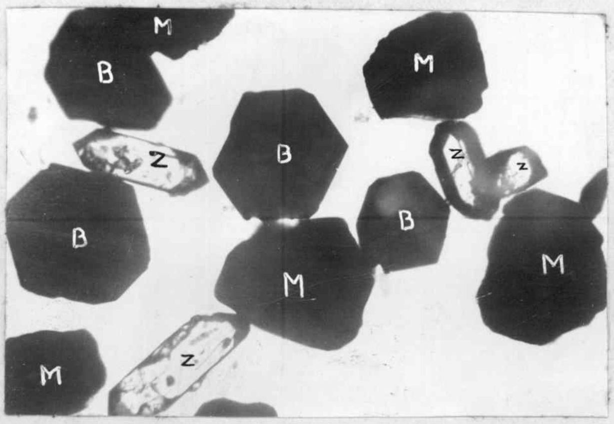



Fig. 20 Photomicrograph of heavy-minerals from Lower John Day tuff. Brookite (B), zircon (Z), and magnetite (M). Plain light x 85.

have been altered completely to kaolin and montmorillonite which have become impregnated with iron oxide stain. This impregnation makes identification of the material composing the groundmass difficult. In plain light the altered material is very cloudy with deep red to brown coloration and under the crossed nicols shows faint aggregate polarization with many areas completely opaque. The plasticity of the tuff when wet and the low birefringence of the altered material indicates that, in part at least, the material has altered to one or more of the clay minerals.

The crystals (Fig. 20) of magnetite are well developed octahedrons with some forms modified by dodecahedrons. Some beds contain massive particles of magnetite some of which were rounded by resorption. The crystals are splendent black and rarely show any alteration to either hematite or limonite. Magnetite was found consistently throughout the lower red beds to make up about 50% of the heavy-minerals in all of the beds studied. This amounts to about 0.3% of the total specimen. The size range is from 0.1 to 0.5 mm.

The occurrence of primary brookite in the lower red beds is considered rare, as the typical occurrence of the mineral is in decomposed granite, gneiss, quartz porphyry, and the sedimentaries. The hydrothermal alteration of igneous rocks produces brookite as a secondary mineral although fresh igneous rocks rarely have it as a primary mineral. Inclusions of brookite are common within the other intratelluric crystals of the lower red beds and indicate its origin within the parent magma. Previous petrographic investigations of the John Day have classified as ilmenite the mineral referred to in this paper as brookite. The form of the mineral is orthorhombic with well developed (010) faces that are sometimes flattened so as to give the mineral a tabular form. The tabular crystals assume a pseudohexagonal form on which the (112) faces and the (110) faces are equally well developed. The normal crystal is short and stubby with the prism, pyramid, and brachypinacoid faces nearly equal. Skeleton crystals showing interrupted crystallization and even some rounding by resorption are prevalent in every sample inspected. The color varies somewhat but commonly is submetallic black. Dark blood-red fragments are found occasionally. Under the microscope (Fig. 20) the black crystals are opaque while the red crystals show slight pleochroism from red to yellow and have a high birefringence. Brookite and magnetite make up about 65% of the heavy-minerals in the lower red beds (Table 4). The magnetite is usually more abundant than the brookite. The size of the brookite crystals varies from 0.2 to 0.6 mm. Except for an occasional patch of leucoxene, the brookite shows little or no alteration.

Biotite appears sporadically throughout the lower red beds but never exceeds more than 5 or 6 fragments in any one sample studied. The crystals are mostly subhedral and are partly altered on the edges to chlorite.

Primary quartz is present in limited quantities in most of the beds studied but does not exceed 1% of the total bulk of the rock. The crystals are anhedral and all of them, in contrast to the clear surfaces of the feldspars, have iron oxide stain on the surface. Secondary quartz is present in small quantities in several of the beds. These grains have iron oxide stain disseminated throughout their mass. The primary quartz grains range in size from 0.3 to 0.8 mm.

Zircon is consistently present in small quantities throughout the lower red beds. The first two beds (L.J.D. # 2-1 and # 2-2) show a high relative content of zircon. The actual amount of zircon in the first two beds is 0.3% of the total sample studied and 20% of the total heavy-minerals. The crystals (Fig. 20) are euhedral in form and elongated parallel to the c-axis. Gas inclusions are present in all of the grains. The average length along the elongated c-axis is 0.2 mm.

Several small grains of rutile were observed in the lower portion of the exposure. The grains are deep sky-blue with distinct dichroism from white to blue and extreme dispersion in the optic figure.

Secondary limonite and hematite are present in fairly large amounts throughout the lower red beds. These minerals were formed by the weathering of the primary iron-bearing minerals within the tuff. The secondary materials are massive in form and are without any particular shape. The limonite and hematite are usually brown-yellow and red respectively. Nodules of limonite and hematite mentioned previously show rudimentary oölitic structure.

Material derived from previously solidified volcanic rocks of consanguineous accessory origin is present in small amounts throughout the lower red beds. The material consists of small irregular fragments which show micro-trachytic texture. Small orthoclase laths make up the largest part of the fragments. Also of importance is accidental material derived from volcanic rocks, non-consanguineous with the magma involved during the eruption, and from other rocks, both sedimentary and igneous, through which the vent was developed. This material is more abundant than the accessory material. Most of the particles are small and consist of basaltic (Fig. 19) fragments. Other material, originally part of a sedimentary series, includes small fragments of sandstone and quartzite. This accessory and accidental material in some beds becomes sufficiently abundant to make the lithic content close to 30% of the total specimen studied. These particles, ranging in size from 0.5 to 1.5 mm., are somewhat larger than the intratelluric crystals. Allogenic sedimentary material is scarce in most of the beds except in the basal bed which carries a large amount of reworked material derived from the underlying Cretaceous(?).

The basalts intercalated in the lower red beds show little of the structures typical of basalts. Columnar jointing is notably lacking in most of the outcrops studied. Instead rough vertical joint patterns and faint pillow structure are noted. The basalts are readily distinguished in the field by the weathered appearence of the basalt and by the abundance of secondary weathering products such as chalcedony, opal, zeolites, and green chloritic stains.

Megascopically the basalt is usually fine-grained, dark, and compact although some specimens are so advanced in the processes of weathering that the rocks resemble buff sandstone. At the top of the flows the original vesicles have been filled with secondary calcite, chlorite, chalcedony, and zeolites. The contact of the basalt and tuff shows no alteration or baking of the underlying tuff bed. Top and bottom breccias were not apparent in any of the outcrops studied.

Microscopically the Lower John Day basalts divide themselves into two distinct textural types. The basal flow generally has ophitic texture (Fig. 22) while the overlying basalts have pilotaxitic texture (Fig. 21). Generally the dominant texture found is pilotaxitic and the ophitic types are found only at the head of Deer Gulch.

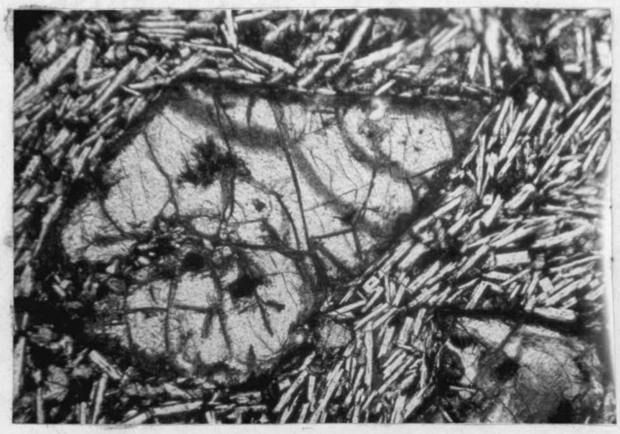


Fig. 21 Photomicrograph of Lower John Day basalt. Large phenocrysts are partially altered olivine in a pilotaxitic groundmass of labradorite laths. Plain light x 80.

Fig. 22 Photomicrograph of Lower John Day basalt. Ophitic texture is expressed by the labradorite laths surrounding darker areas of olivine and augite. Some of the olivine and augite have altered to antigorite, upper left hand corner. Opaque areas are magnetite. Plain light x 80.

The groundmass of the basalts is holocrystalline and occasionally interspersed throughout the mass are microphenocrysts of euhedral olivine. The advanced stage of weathering is clearly seen under the microscope. The olivine crystals have been altered to antigorite and iddingsite, and in some specimens have altered completely to limonite. The magnetite in the basalts has been altered partly to limonite and some of the plagioclase has been replaced by calcite. Some basalt samples examined at the head of Deer Gulch show mild chloritization which gives the rock a green hue.

Classification. The acid character of the plagioclase-feldspars and the large amount of potash-feldspars along with the almost complete lack of ferromagnesian minerals suggests that the parent magma of the lower John Day tuffs was trachytic. A complete chemical analysis of the tuff was not attempted, but silica was determined in a typical sample to be 50.59%. The combination of low silica content and the acid character of the residual feldspars along with the scarcity of ferromagnesian minerals indicates considerable leaching of the original rock. The fairly high water content (8%) and the above average iron oxide content (7%) indicate also that fairly extreme weathering processes acted upon the tuff.

The basalts interbedded in the lower member are classified as typical basalts. Olivine is present in noteworthy quantities in all of the rocks studied and in the ophitic basalts the olivine makes up 30% of the rock. Chemical analysis of the basalts was not attempted as the rock type is evident after thin section study.

Thickness. The thickness of the Lower John Day formation at the point of sampling north of Picture Gorge is 110 feet. This was measured by the plane table and alidade and is thought to be correct within 1 foot. The thickness of the lower member at Sheep Rock is estimated to be 161 feet. The thickness of the individual basalt flows intercalated in the lower red beds varies from 11 to 50 feet. The thickest flows are seen at the head of Deer Gulch but westward from this area near the John Day River they become thinner. The thickness of the tuff interbedded between the basalts varies between 20 and 30 feet.

Stratigraphic Relations. The Lower John Day tuff beds north of Picture Gorge quadrangle are nearly flat lying. The dip is 2°, N. 12° W. At Sheep Rock the beds dip 20°, S. 30° W. Underlying the Lower John Day beds north of the area is the highly indurated Cretaceous(?) conglomerate. The overlying red ash of the lower red beds has stained the conglomerate a light red color to a depth of a hundred or more feet. The Cretaceous(?) conglomerate is separated from the lower red beds by a distinct structural unconformity. The Cretaceous(?) conglomerate is folded into simple isoclinal folds while the red beds have a gentle dip to the north. Overlying the Lower John Day beds at this point is the green tuff of the middle member of the John Day formation. The relation between these two beds (Fig. 18) shows a slight erosional unconformity. This is seen at only a few points whereas other exposures of the contact show the two members to be conformable. The lower red beds at Sheep Rock also are separated from the Cretaceous (?) conglomerate by a distinct structural unconformity. The red beds at this point dip 20° to the southwest and the gently folded conglomerate at this point is nearly flat lying. The upper contact with the green beds is obscured at this point by landslide. The interbedded basalts lie conformably on the lower beds and show no discordance with the overlying tuff beds.

## Middle Member of the John Day Formation

Areal Distribution and Topographic Expression. The tuffs of the Middle John Day member include all of the tuffaceous material which occurs between the contact of the underlying red trachytic tuff of the lower member and the overlying welded-tuff bed.

The outcrops of the middle member are very limited in extent within the Picture Gorge quadrangle. Extensive exposures occur only where there is a protective cap rock of basalt or ignimbrite. The largest exposure of the middle member is located within a large box canyon (Turtle Cove) on the north flank of Middle Mountain in the N.W. 1/4 N.E. 1/4 of Sec. 29, T. 11 S., R. 26 E. The headward erosion of a small intermittent stream has exposed about one square mile of the middle member and formed the box canyon entirely within the tuffs. A less extensive exposure outcrops at the base of Sheep Rock although only part of the middle member is exposed as its lower portion is obscured by landslide. Other small exposures of the middle member outcrop along the base of the landslide scarp which surrounds Butler Basin. In general these outcrops are very small in areal extent, seldom exceeding more than several hundred square feet.

Where the middle member is exposed (Fig. 23) it is characterized by typical badland topography. Differential erosion of the alternating hard and soft beds has produced a series of terraces underlain by fluted earth pillars. Residual outliers from the main exposure form a myriad of different structures, such as hoodoos, miniature tepee buttes, demoiselles, and rounded mud hills.

Bedding. The bedding of the middle member is manifested by transitions in color and relative hardness. From a distance the beds give the appearence of being evenly bedded but on close inspection the bedding is rough and shows no sharp bedding planes or laminations. None of the beds inspected in the field show evidence of being laid down in water as the individual beds are massive in

Fig. 23 Typical exposure of the Middle John Day at Turtle Cove showing erosional forms characteristic of the middle member. Detailed sampling profile was taken at this locality.

Fig. 24 Bedding of the Middle John Day tuff beds. Note local irregularities and calcareous concretions.

appearence and do not have the characteristic fine laminations usually associated with water-laid tuffs.

Color. The middle member is dominantly green although many shades of that color are found in the individual beds. The color ranges from blue-green to light buff. On close inspection the coloring of the beds is seen to be banded. The bottom portion is dark green but grades to a buff in the middle. Whereas the resistant layer at the top is light buff-green. This resistant layer has a high calcium carbonate content. Most of these resistant beds have numerous random calcareous concretions. The repeated combinations of color and hardness apparently were developed at a time when periods of volcanic activity were followed by quiescent periods which allowed the processes of weathering time enough to change the original pyroclastic material then at the surface. The green tuff in the bottom portion of each phase is poorly cemented and easily washed away. The green coloration is due to reducing conditions within the tuffs after deposition. The primary iron minerals which were in a finely disseminated state were partially reduced and hydrated to produce a combination of ferro-ferric compounds, as noted by G.R. MacCarthy (14, p.31). The conditions necessary for this process are: Low oxygen content and sufficient organic material to carry on partial reduction. The middle portion of each series usually shows a lighter green coloration, indicating less reducing conditions nearer the surface. The cap-bed usually is darker buff with only a slight green tinge. The calcareous material of the cap-bed is concentrated in random buff-colored concretions. The concretions are very irregular in form and range in size from several inches to a foot or more in diameter. The presence of these resistant calcareous layers at the top portion of each color series indicates that this bed represents a formerly exposed surface of each of the many ash falls. The climate at the time of deposition apparently was similar to the savannah type found on the borders of the tropical areas of today. The dry periods brought about conditions favorable for the concentration of the calcium carbonate through caliche action. On the other hand the rainy seasons brought about enough growth of organic material to furnish reducing solutions to produce ferro-ferric compounds.

General Petrographic Character. The beds of the middle member are composed exclusively of Fine Essential Vitric Tuff (28, p.52). The beds generally have a massive structure except for a well defined set of joints. These joints have two definite directions both normal to the bedding and forming a rhombic pattern. The joints extend vertically through the middle member without regard to bedding planes or other structures found in the outcrop. The joints invariably are well healed by secondary calcite.

The size of the individual particles within the tuff ranges from 1.5 mm. to colloidal dimensions. The average tuff specimen has more than 75% of its bulk smaller than 200 mesh (0.074 mm.) while the remaining 25% has an average size of 0.6 mm. The original cognate material has been altered partially to a fine clay but the larger crystalline grains and altered glass still retain their original size and it is presumed that the size analysis of the tuff closely approaches the original size distribution of the ash at the time of deposition. Table 5 is a summary of the size analysis and study of the heavy-minerals for the middle member beds. The intratelluric crystal content of the tuff never exceeds 15% of the total sample although some specimens carry nearly 25% lithic material. The tuffs universally exhibit vitroclastic texture. Most of the glassy material still shows the original vesicular and irregular pyroclastic forms (Fig. 25). As a whole the middle member has undergone extensive weathering by devitrification and induration by calcium carbonate and finely disseminated ferro-ferric compounds.

<u>Microscopic Character</u>. The pumice and individual glass shards still show their original form. Crystalline material is generally scarce and is usually in euhedral or subhedral form. The groundmass consists of finely comminuted material generally impregnated with the green ferro-ferric compounds.

Pumice, devitrified glass shards, intermediate

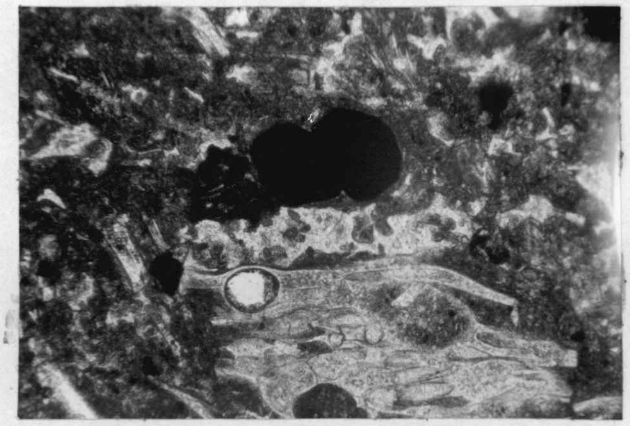


Fig. 25 Photomicrograph of Middle John Day tuff showing typical vitroclastic texture. Note large pumice fragment and opaque magnetite phenocryst. Plain light x 80.

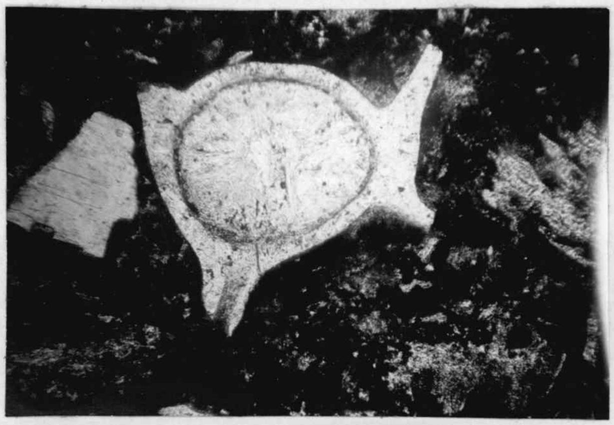


Fig. 26 Photomicrograph of Middle John Day tuff. Large particle in the center of the field is a devitrified glass pellet. Andesine phenocryst to the left of the glass pellet. Groundmass consists of comminuted ash. Plain light x 80

plagioclase, and augite are the essential constituents which make up the tuffs. Accessory material present in the middle member includes quartz (primary and secondary), acid-plagioclase, potash-feldspar, tridymite, magnetite, apatite, hornblende, brookite, biotite, secondary hematite, collophane, blue-rutile, zircon, and rock particles of accessory and accidental origin. Table 5 gives the relative percentage of the common heavy-minerals for each bed in the middle member.

Andesine is the principal plagioclase in the middle member although in the lower portion of the member oligoclase is common. The plagioclase phenocrysts appear as euhedral to subhedral tablets usually flattened parallel to (010) face. The plagioclase tablets show albite twinning and are commonly combined with percline twins. Some zonal growth was noted in thin section but is uncommon in most grains studied. Magnetite inclusions are common and occasionally are accompanied by apatite. The larger crystals of plagioclase were particularly striking in that they have undergone little or no weathering. Plagioclase fragments smaller than 0.05 mm. usually show advanced weathering and decomposition. The average crystal is clear and shows some cloudy patches of kaolin on the surface. The prevailing size range of the plagioclase particles is from 0.2 to 0.7 mm.

Pumice makes up a large part of the tuffs in the

TABLE 5

GRAIN SIZE AND HEAVY-MINERAL CONTENT OF THE MIDDLE MEMBER OF THE JOHN DAY FORMATION

| Sample Number | Percentage by weight | | | Relative percentage of heavy-minerals (estimated) | | | | |
|---|---|---|---|---|---|---|---|---|
| M.J.D. | less than 200-mesh | more than 200-mesh | heavy-separate | augite | magnetite | hornblende | brookite | biotite |
| 1-1 | 72 | 27 | 0.65 | 40 | 55 | 1 | trace | ... |
| 1-2 | 83 | 17 | 0.34 | 60 | 35 | 1 | 2 | ... |
| 1-3 | 64 | 36 | 0.09 | 60 | 35 | trace | 5 | trace |
| 1-4 | 78 | 22 | 0.57 | 60 | 35 | trace | 1 | ... |
| 1-5 | 80 | 20 | 0.36 | 45 | 40 | 5 | 1 | ... |
| 1-6 | 75 | 25 | 0.34 | 60 | 30 | 3 | trace | ... |
| 1-7 | 76 | 24 | 0.28 | 65 | 25 | 2 | ... | ... |
| 1-8 | 70 | 30 | 0.48 | 75 | 20 | 1 | ... | trace |
| 2-1 | 69 | 31 | 0.39 | 75 | 20 | 1 | ... | ... |
| 2-2 | 80 | 20 | 0.49 | 75 | 15 | 5 | ... | ... |
| 2-3 | 84 | 16 | 0.46 | 60 | 20 | 5 | 1 | trace |
| 2-4 | 73 | 27 | 0.21 | 60 | 25 | 2 | 2 | ... |
| 2-5 | 78 | 22 | 0.46 | 50 | 35 | 10 | ... | ... |
| 2-6 | 69 | 31 | 0.53 | 35 | 40 | 1 | 2 | ... |
| 3-1 | 71 | 29 | 0.51 | 40 | 40 | trace | 1 | ... |
| 3-2 | 83 | 17 | 0.29 | 45 | 37 | 5 | 1 | 3 |
| 3-3 | 78 | 22 | 0.38 | 40 | 20 | 15 | ... | ... |
| 3-4 | 57 | 43 | 0.36 | 50 | 20 | trace | ... | ... |
| 3-5 | 78 | 22 | 0.41 | 40 | 30 | 5 | ... | ... |

middle member. All of the pumice particles are devitrified. The particles are vesicular in structure. The gas cavities, separated by thin partitions, are partly oval or nearly circular in outline and partly strongly drawn out in one direction (Fig. 25). The original glassy septa under plain light appear brown to green but under crossed nicols the devitrification becomes apparent. Some septa have been altered to chlorite and other septa show weak aggregate polarization. The fibrous structure and weak birefringence suggest that the material may be one of the zeolites. The gas cavities are usually filled with minute colorless crystals that are thickly implanted on the walls and project inward. The minerals in the cavities are so small that exact determination is not possible. Some of the crystals have orthorhombic form, weak birefringence, and an index of refraction of 1.47 which suggests the mineral may be secondary tridymite. The color of the pumice fragments ranges from pale white to green. The green is probably due to impregnation of ferro-ferric compounds and also alteration to chlorite. The pumice fragments range in size from 0.4 to 0.9 mm.

The individual glass fragments of the middle member show irregular shapes typical of volcanic ejecta. All of the particles are well preserved as delicate cuspate, lunar, and spherical forms. These delicate forms are still sharp and angular and show little change from their original character, except the devitrification that has taken place. The glass during its formation was blown into individual pellets or into groups of three or four pellets. They differ considerably from the larger pumice fragments in that these glass particles are not elongated or pulled out. In corss section (Fig. 26) the glass vesicles are colorless in plain light and under crossed nicols show weak aggregate polarization which shows clearly the crystalline nature of the formerly glassy particles. The walls of the glass vesicles are usually slightly stained a green color. The inside portion consists of minute crystalline plates that are microspherulitic in form. The center of the gas cavity in all of the vesicles studied is invariably completely or partially filled with crystalline material. The material composing the center portion of these glass vesicles and the material composing the walls has an index of refraction from 1.47 to 1.48 and when the crystals are large enough to identify they have parallel extinction and appear to be orthorhombic. Tridymite of secondary origin seems to be the only mineral that fits this description although it may possibly be a zeolite. The range in size of the discrete glass particles is from 0.2 to 0.7 mm.

Augite crystals persist throughout the middle member and form about 50% of the heavy-mineral separate of each of the beds studied, although augite rarely makes up more than 0.2% of the total rock. The mineral occurs in stout euhedral prisms bounded by (100), (110), and (011) faces. The color is pale green and has only slight pleochroism. Inclusions of euhedral magnetite are common in the augite crystals. Twinning on the (100) plane is common in crystals from several of the beds. The augite crystals are generally fresh although some crystals show a little alteration on the surface. The phenocrysts range in size from 0.1 to 0.3 mm.

Quartz of primary origin is lacking in most of the tuff specimens studied although secondary quartz is locally abundant in some of the beds. The secondary quartz usually is found in the cryptocrystalline form of chalcedony. The primary quartz particles occur as anhedral particles and almost invariably are coated on the outside with a thin film of iron oxide.

An occasional euhedral phenocryst of clear sanidine is found in the lower portion of the series. The crystals are flattened and elongated parallel to the (010) face. Carlsbad penetration twins are numerous.

The occurrence of tridymite in the middle member is always secondary. The mineral is found filling the gas cavities of pumice and individual glass fragments. The crystals are thickly implanted on the septa walls and extend inward to the center of the cavity. In plain light the crystals are colorless and under crossed nicols show weak polarization. The crystal form is difficult to determine as the distal end of the crystal is the only portion showing crystal terminations. The mineral is minute in size and few crystals exceed 0.05 mm. in length.

Magnetite occurs persistently throughout the middle member and makes up about 30% of the heavy-minerals studied in each bed (Table 5), but only 0.13% of the total bulk of each bed studied. The magnetite crystals are well formed euhedral octahedrons that occasionally are modified by dodecahedrons. Massive particles of magnetite are not uncommon. The magnetite crystals range in size from 0.1 to 0.2 mm. The bulk of the magnetite is primary. It is abundant as inclusions in most of the intratelluric crystals. Weathering has not affected the material to any great extent, although some of the crystals show patches of leucoxene on the surface indicating that some of the magnetite is titaniferous.

Apatite is present in very small quantities throughout the middle member although very seldom exceeds 5 or 6 particles in any one sample studied. The apatite crystals are clear, euhedral, rod-like and seldom are larger than 0.02 mm. Occasional inclusions of apatite found within the plagioclase feldspars indicate its primary nature and early crystallization.

The hornblende crystals make sporadic appearance throughout the middle member and are most abundant in the middle portion of the beds. Its dark brown color is characteristic of the glassy varieties commonly found in eruptive rocks. The crystals generally are anhedral in form and very few exhibit fully developed crystals. Absorption for the mineral is X (clear yellow), Y (dark brown), and Z (dark brownish green). The particles appear fresh and have sharp angular outlines. The size range for the hornblende is 0.1 to 0.6 mm.

Brookite which is so abundant and persistent in the lower member appears only occasionally in the middle member. The mineral does not exceed 5% of the heavy-minerals or 0.015% of the total specimen. The form and characteristics are quite similar to those of the brookite found in the lower member. The crystals are euhedral and have a black sub-metallic luster. The blood-red fragments common in the lower member are not found in the middle member. The crystals are stubby orthorhombic forms that have well developed pinacoid and prism faces. The particles show an occasional patch of leucoxene on the surface; otherwise they show little or no weathering. The average size of the crystals is 0.2 mm.

Biotite is generally lacking throughout the middle member although in several beds a noticeable amount of biotite is present (Table 5). The biotite is locally abundant when hornblende is also locally abundant. Biotite rarely exceeds 15% of the total heavy-minerals. The biotite fragments are euhedral to subhedral and commonly are found as small pseudo-hexagonal plates. Biotite shows very little alteration although the edges of some of the crystals have been replaced by chlorite. The range in size is from 0.2 to 0.6 mm.

Hematite is common throughout the middle member and generally increases near the top of the member. All of the hematite present is of secondary origin and comes mostly from finely disseminated ferro-ferric iron and partly from the weathering of the finer particles of magnetite. The hematite is generally massive and has a brick red color.

The abundance of vertebrate fossils in the middle member has produced noticeable amounts of collophane. The collophane is yellowish-brown in plain light and shows weak birefringence with crossed nicols. The original microstructure of the bone is apparent under the microscope. The Haversian canals and the lacunae can be seen quite easily.

Small rare fragments of blue-rutile were found in several of the beds. The fragments are anhedral and show pleochroism from white to blue.

The two beds at the top (M.J.D. # 3-4 and # 3-5) of the sampling section have some traces of zircon. The zircon crystals are short and have prismatic form. The crystals do not exceed 0.1 mm. in length.

The entire middle member contains material which has been derived from earlier solidified material from the parent magma of the tuff and also material nonconsanguineous with the parent magma. That none of this material exceeds more than 2 mm. in size indicates the remoteness of the parent volcano. The most abundant lithic materials are small scoriaceous fragments of basalt. In thin section the fragments show relict microlitic feldspars surrounded by a groundmass of opaque material composed mostly of limonite. Accessory material is scarce in the middle member as only an occasional fragment of material from the parent magma is present. In thin section this accessory material appears vitrophyric and an occasional phenocryst of plagioclase or augite is recognized. Other accidental material found in the middle member is small rounded and sub-angular quartzitic fragments. Under the microscope these fragments are colorless and have disseminated areas of limonite which give the fragment a salt and pepper appearance. The colorless material of the quartzitic fragments under crossed nicols shows aggregate polarization and weak birefringence which is similar to a quartzite or a well indurated sandstone. Several beds show many allogenic particles from reworking of the tuffs after deposition although on the whole reworking of the tuffs is very slight.

The middle member is characterized by the green cast of the beds. The origin of this green colorization has long been a problem. Calkins (3, p.147) states that the color is due to finely disseminated chlorite and glauconite. Inspection of the tuff shows very little chlorite and definitely no trace of glauconite. Hodge (11, p.61) favors reduction and carbonation of the iron minerals to produce the green cast. During the wet sieve test of the middle member it was noted that the green coloring matter would separate into a colloidal suspension when the tuff was left in water. Also the green material is characteristically found as a stain within the porous pumice fragments and individual glass shards. Continued roasting of the tuff in an open container will change the green color to a brick red which indicates that the green coloring is tied up in some ferro-ferric compound. Several attempts to isolate the material met with little success as the material is so fine that particle definition is impossible. A sample of the material was sent to Professor J.W. Gruner of the University of Minnesota for X-ray analysis and his report of the material is as follows: "The pattern we get is as you have already pointed out, very poor, which means in other words, that some of the material must be in such fine division that it is practically amorphous. We do have quartz lines present, which I think might represent not more than 10 or 15% of quartz in the sample. Also the pattern of glauconite seems to be present. I say seems to be present because it is nothing to brag about. Besides that, there is a line at about 3.07A which I have not been able to locate in any of our reference films, unless it is talc, which I can't believe is present in this particular material. Another possibility for this line might be amphibole. We are sure there is no chlorite. There may be some montmorillonite, but if there is it does not give its characteristic pattern so that would mean that there could be no more than 15 or 20% of montmorillonite present." This green material probably is a stain which has impregnated all of the finer material of the tuff as the X-ray analysis reveals that the colloidal material is composed of many different minerals instead of one particular mineral. The green color then is probably due to finely disseminated ferro-ferric iron compounds which have impregnated and colored the whole series. The conditions of formation of this ferro-ferric compound are discussed earlier in the text.

Classification. The tuffs of the Middle John Day formation had their origin from a magma of intermediate composition. On the basis of silica content and mineral constituents the tuff appears to be andesitic in character. Exact classification of aeolian tuffs is always difficult as the original material suffers winnowing before deposition, and after deposition the material is easily altered by weathering processes. A complete chemical analysis was not attempted, but silica was determined in a typical sample to be 61.57%. A quantitative test of the water content of the tuff yielded 4.5% which indicates little or no hydration has taken place since deposition. The deficiency of primary quartz and the persistence of intermediate plagioclase (andesine) and augite throughout the middle member indicate the intermediate character of the parent magma,

Thickness. The thickness of the middle member is at least 220 feet as measured by the plane table and alidade. The contact of the middle and lower members is not exposed within Turtle Cove, therefore the maximum thickness of the middle member may be slightly greater than the figure given. The unevenness of the existing topography at the time the middle member was deposited and the ease of eroding the soft tuffs undoubtedly make the thickness variable.

Stratigraphic Relations. The relation of the middle member to the lower member is inferred to be conformable at the point of sampling. North of Turtle Cove a slight erosional unconformity was noted between the two members (Fig. 18). The overlying welded-tuffs and the middle member are conformable on each other. Some alteration of the tuffs by the ignimbrite was noted at some localities although generally the tuff has not been changed by the acid flow. At the point of sampling the tuff beds dip 16°, S. 55° W. and form part of the east limb of the Middle Mountain syncline.

## Middle John Day Ignimbrite

Areal Distribution and Topographic Expression. The ignimbrite of the John Day formation forms a distinct horizon which serves as the dividing line between the middle member and the upper member. The peculiar character of the ignimbrite makes it an excellent field marker for dividing the John Day formation into separate units.

The distribution of the ignimbrite outcrops in the Picture Gorge area is limited. A complete section of the igńimbrite is exposed in the northwest corner of the area at the junction of Squaw Creek and the John Day River. On the west face of Sheep Rock is another excellent exposure of ignimbrite. Other less extensive exposures of the ignimbrite are at Turtle Cove and along the east scarp of Butler Basin.

Where the overlying tuffs of the upper member have been stripped off, the ignimbrite forms small mesas and fantastic hoodoo erosional forms. The ignimbrite at Squaw Creek shows long fluted columns at the top of the section and rough columnar jointing at the base. Differential erosion has produced an extensive bench on the north side of Sheep Rock. The top of the bench is an array of hoodoo forms which present a symmetrical alignment due to the vertical joints in the ignimbrite (Fig. 27). Other exposures of the ignimbrite in the area produce either prominent benches or as in Turtle Cove act as a capping of residual hills.

Bedding and Color. Bedding is conspicuously absent. At Squaw Creek the material grades imperceptibly from one type of material to the next, and the only manifestation of a change is the transition in color and in the degree of welding. The tuff at Sheep Rock is almost homogeneous except for a slight color change. The color transitions are marked but the composition remains the same. The Squaw Creek outcrop has a dark band at the base which grades upward into a light buff color. Overlying the buff section is a thick band of brick red material which in turn grades upward into light grey. The top portion is dominantly green which grades imperceptibly into the green tuff of the upper member of the John Day formation. The welded-tuff at Sheep Rock is dull brown at the base and dark green at the top.

General Petrographic Character. The essential material of the welded-tuff is rhyolitic. Devitrified particles of pumice and glass shards are the most abundant material. Generally the glass and pumice particles have undergone incipient crystallization and much of the crystalline material is tridymite and feldspar. Phenocrysts of sanidine, acid-plagioclase, augite, and quartz are noted in the groundmass of vitroclastic material. The crystalline material of cognate origin composes about 10% of the rock and the vitroclastic material composes the remaining 90% of the

Fig. 27 Erosional forms of porous welded-tuff on the left overlain by Upper John Day tuffs on the right, Sheep Rock.

Fig. 28 Stony welded-tuff near the base of the section, Squaw Creek. Note shatter cracks.

tuff. Accidental rock particles are common in the groundmass.

The texture is extremely variable and marked changes are noted between the top and bottom of the thicker sections. These changes are gradational in nature and the sequence in textural change is always the same. Near the bottom of the section the welded-tuff is extremely coherent and stony, and resembles a normal rhyolite (Fig. 28) in outward appearance. Under the microscope the vitroclastic texture of the rock becomes apparent (Fig. 29) as the groundmass is composed of completely welded and somewhat flattened tuff. Directly under the stony welded-tuff is a glassy tuff. The texture of this rock shows less compaction and accommodation of the vitroclastic material (Fig. 30) although the outward appearance of the rock is similar to that of the stony tuff except that it has a glassy surface. The material from the middle of the section is more punky and less compact than the bottom phase. Particles of pumice can be seen with the aid of the hand lens. Under the microscope the vitroclastic material still exhibits warping and some flattening (Fig. 31) parallel to the horizontal plane. The tuff at the top of the section shows unoriented pumice fragments and a more porous groundmass. In thin section the vitroclastic material shows little or no warping or accommodation (Fig. 32).

Generally then the tuff at the bottom of the section

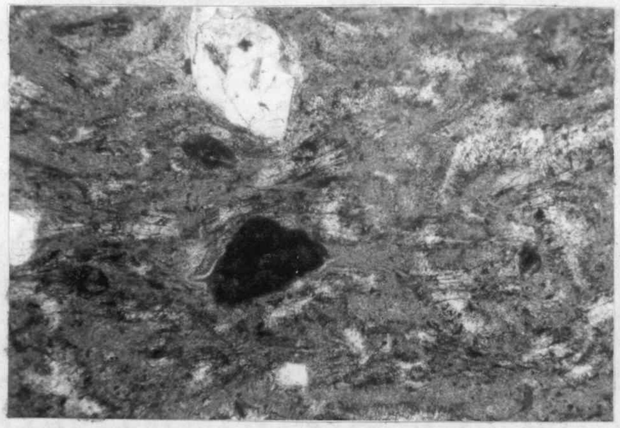


Fig. 29 Photomicrograph of stony welded-tuff showing completely welded and much flattened tuff. Note welded material squeezed between the two particles. Plain light x 80.

Fig. 30 Photomicrograph of glassy tuff that shows accomodation and warping of the vitroclastic material. Large phenocryst of sanidine in upper left hand corner. Plain light x 80.

Fig. 31 Photomicrograph of welded-tuff in the middle of the section showing marked warping of the vitroclastic material and some flattening in the horizontal plane. The large particle at the bottom of the field is accidental rock. Plain light x 80.

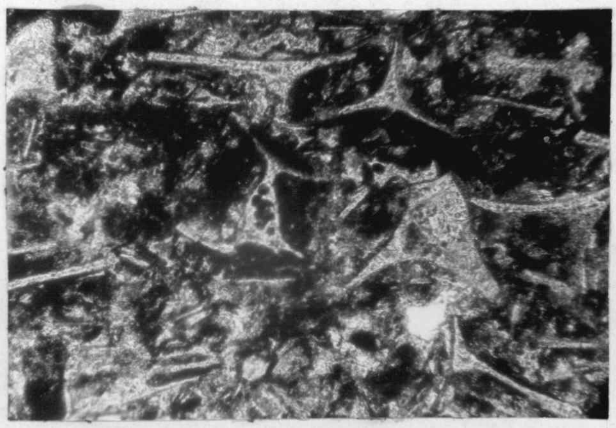


Fig. 32 Photomicrograph of welded-tuff near the top of the section. This tuff has typical vitroclastic texture without noticeable warping or squeezing. Plain light x 80.

is extremely welded, hard, dense, and stony or crystalline; and in the upper portions the tuff is soft and extremely tenaceous. The rock may be pierced with a pick without fracturing although it may be broken easily by a blow of a hammer. The hardness and degree of welding appear to be related to the amount of overlying material.

The constituents of the ignimbrite are generally the same throughout the thickness of the section. Alteration and devitrification have given the porous material near the top slightly different composition than the stony-tuff.

Generally the glass has undergone incipient crystallization and is now composed of an aggregate of potash-feldspar and tridymite. The glass in the lower glassy tuff has not undergone devitrification and has an index of refraction between 1.48 and 1.50. Some of the pumice fragments from the welded-tuff at Sheep Rock show replacement by chlorite which gives the rock a green cast.

The feldspars present are sanidine and oligoclase. The crystals of sanidine and oligoclase are generally well formed but in the lower portion of the section show some resorption. Occasional inclusions of zircon and apatite are noted in the sanidine crystals. The average size of the feldspar crystals is 0.6 mm.

Augite, though present in all thin sections studied, is abundant in none. The crystals are generally euhedral and show very little resorption. An occasional augite crystal is found as an inclusion in the feldspars. Most of the augite crystals are pale green although some are colorless. The size of the augite is slightly less than that of the feldspars and averages 0.3 mm.

Quartz is present in fairly large amounts in all of the thin sections studied although well developed phenocrysts are not abundant. The quartz is usually found finely disseminated in the groundmass as interstitial material. The larger crystals of quartz show some resorption and fracturing. The average size of the quartz phenocrysts is 0.5 mm.

Minute crystals of magnetite are scattered sparsely throughout the groundmass. Secondary hematite is present in large amounts in the middle of the section and has impregnated the rock completely, so as to give the rock a brick red color. Secondary calcite is noticeable in the more porous phase of the ignimbrite, occasionally forming small concretions within the rock. The calcite has replaced some of the vitroclastic material and acid-plagioclase. Chlorite is also a common secondary mineral in the porous ignimbrite and ordinarily is found replacing pumice or is present as small plates in the interior of the individual vesicles of glass.

Accidental fragments of rock are commonly found throughout the section. They range in size from angular pebbles to grains as small as 0.7 mm. In thin section the rock particles appear to be andesitic or basaltic as they are composed of microlitic feldspars in a groundmass of opaque limonite or are completely composed of feldspar microlites.

Thickness and Stratigraphic Sequences. The character and thickness of the ignimbrite is illustrated by the following section:

Section of Ignimbrite in N.W. 1/4 Sec. 30,
R. 26 E., T. 11 S., on Squaw Creek

| | Thickness feet |
|---|---|
| Coarse, buff welded-tuff grading to green at the top .................... | 40 |
| Coarse, red welded-tuff showing some compaction parallel to horizontal plane ......................... | 17 |
| Stony, buff welded-tuff ................... | 40 |
| Glassy, dark welded-tuff ................... | 0.5 |
| Total | 97.5 |

The glassy tuff is separated sharply from the stony tuff by several inches of light colored friable ash which indicates a slight time interval between the two flows. The felsitic stony tuff shows rough columnar jointing and many shatter cracks (Fig. 28) throughout the mass. The buff stony tuff grades imperceptibly into the overlying red tuff. The red tuff is much more porous than the underlying material and being softer forms irregular erosional hoodoos. Grading upward from the red zone the tuff changes to buff and is slightly more porous and soft although it still retains its tenacity. The top portion of the welded-tuff at Squaw Creek is light green and grades into the overlying green tuff of the upper member of the John Day formation.

The ignimbrite at Sheep Rock is slightly different from that in the Squaw Creek section in that the stony and glassy phases are missing. The following section illustrates the thickness and sequence:

Section of Ignimbrite in N.E. 1/4 Sec. 8, R. 26 E., T. 12 S., Sheep Rock.

| | Thickness feet |
|---|---|
| Coarse, green welded-tuff with large flattened pumice lapilli ............. | 34 |
| Coarse, buff welded-tuff .................... | 74 |
| Total | 108 |

The welded-tuff of this outcrop is similar to that of Squaw Creek section with the exception of the stony and glassy phase. Pumice particles show some flattening and accommodation and are generally unsorted. Parts of this section are striking in that there appears to be a great amount of replacement of the pumice by chlorite. Inspection of thin sections shows the glassy material completely replaced by secondary chlorite and tridymite. The tuff is generally porous and tenaceous throughout the section.

Origin of the Ignimbrite. The pyroclastic nature of the welded-tuff cannot be doubted. The origin of the basal portion of the glassy and stony tuff might be open to some question were it not for the complete lack of top and bottom breccias usually associated with acid flows and for the complete gradation from the obviously pyroclastic surface to the lowermost parts. In addition, microscopic examination shows the base to be pyroclastic, as the pumice and glass shards are plainly visible although intensely flattened and bent.

At the time of emplacement the material apparently was hot and still in a viscous state. The distortion of the pumice and the collapse of the glass vesicles was accomplished without fracture of these particles. The material evidently was not rigid but viscous instead. Much of the crystallization took place after emplacement as the smaller crystals show little or no fracturing. The accompanying columnar jointing of the rock also indicates contraction of the tuff by cooling from high temperatures.

This type of volcanic deposit has been described by several authors and it is generally recognized to be the result of dry avalanche or "nuée ardente" of pyroclastic material. The term "ignimbrite" was first suggested by P. Marshall (16, p.198) for this type volcanic deposit. C.A. Cotton (8, p.204) discusses ignimbrite as follows:

"In a thick sandflow or "nuée ardente" deposit some or all of the material may become agglutinated, though probably in most cases portions of it remain incoherent volcanic sand or tuff. The term "ignimbrite" is applicable to all rocks formed by such agglutination. These grade from indurated but open-textured and porous tuff to firmly compacted rocks which have been mistaken for flow rhyolites. This is the condition assumed by deeply buried material which has been compressed under the weight of the upper layers of the deposit. For this process the expression "welding" is perhaps admissible; but the welded product no longer presents any resemblence to a "tuff". It rings under the hammer, and may closely resemble a flow rhyolite, or even obsidian, though generally distinguishable under the microscope from rocks of lava-flow origin."

The Middle John Day welded-tuff undoubtedly is of the type described by C.A. Cotton and therefore is a true ignimbrite. This type of material has its source in a fissure or small vent, but as yet no such source has been discovered for the John Day ignimbrite.

Stratigraphic Relations. The lower portion of the ignimbrite rests conformably upon the middle member of the John Day formation and is overlain by the upper member in a conformable relationship. The top contact of the ignimbrite with the overlying tuff is almost imperceptible as the two rocks have about the same coloration and texture.

## Upper Member of the John Day Formation

Areal Distribution and Topographic Expression. Sheep Rock shows the only complete section of the upper member in the Picture Gorge area. Other small exposures of the upper member are seen along the eastern landslide scarp of Butler Basin which extends north from Sheep Rock to Windy Point. East from Windy Point the upper member is present but for the most part is covered by a thin soil layer. Middle Mountain exposures of the John Day formation include only the middle member as the Columbia River Basalts there rest directly upon the middle member.

The upper member is similar to the middle member in topographic expression. Differential erosion of the hard and soft layers has produced a series of terraces which are underlain by fluted columns of the softer material, as illustrated in Figure 34. Near the top portion of the middle member the beds are less resistant and form smooth mud covered slopes. The expression of the beds at the point of sampling is shown in Figure 33.

Bedding. The bedding of the upper member is shown by the relative hardness of the beds and the perceptible changes of color. The bedding of the lower portion (Fig. 34) of the beds is similar to that of the middle member, as the hard resistant layers are highly indurated by calcite which is concentrated into irregular concretions. These layers, as in the middle member, also represent the

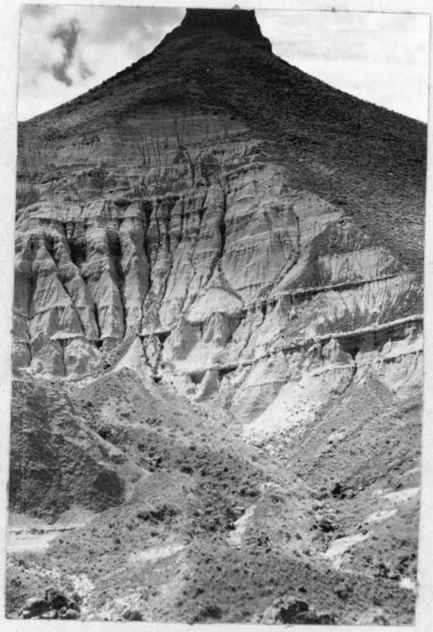


Fig. 33 Sampling locality for the Upper John Day showing typical erosional forms and bedding, on north face of Sheep Rock.

Fig. 34 Terraces and fluted pillars produced by differential erosion of the Upper John Day tuff, at Sheep Rock.

land surface between ash falls and have undergone a concentration of calcium carbonate through caliche action. The bedding above the lower portion is not as clearly defined as the beds are generally much thicker and more massive and show little transition in color or hardness. The individual beds are uniform and show no internal laminations or bedding characteristic of waterlaid deposits.

Color. The dominant color of the upper member is buff although green is not uncommon. The coloring of the John Day formation has often been used erroneously as a basis for the division of the formation. Actually the buff which is found to be dominant in the upper member is common in the middle member, and the green which is dominant in the middle member is not uncommon in the upper member. The color of the upper member is transitional in all of the outcrops studied as there is no sharp boundary between one shade and the next. The green color in the lower portion of the upper member is present in approximately the first 100 feet and is the result of impregnation by ferro-ferric compounds previously described. Near the top of the sampling section are several thin beds which have a green color. The buff color found in most of the beds is the result of slight oxidation of the original iron-bearing minerals. In some beds oxidation is so slight that the beds are almost white. This indicates that the climate during the deposition of the upper member changed to a slightly more arid type as the constituents appear less altered and generally are nearly in the same condition as at the time of deposition except for devitrification of the glassy material. Or the rate of deposition increased and the ash was not exposed to weathering processes long enough to undergo the more intense alteration noted in the middle and lower members.

General Petrographic Character. The beds of the upper member are composed exclusively of Fine Essential Vitric Tuff (28, p.52). The vitric particles since deposition have been completely or partially devitrified. The particles that make up the tuff range in size from 1.2 mm. down to colloidal material. On the average, 79% of the material in the upper member is smaller than 200 mesh (0.074 mm.) and the remaining 21% has an average size of 0.5 mm. The weathering of the upper member is so slight that it is assumed that the grain size is approximately the same now as at the time the ash was deposited. Table 6 gives the percent of material larger and smaller than 200 mesh for each bed. The intratelluric crystal content never exceeds 15% of the total sample, although the lithic content exceeds 30% in some of the beds in the upper portion of the upper member. In thin section the tuff usually shows typical vitroclastic texture which is exhibited by the delicately preserved particles of devitrified pumice and glass shards (Fig. 35). As a rule, the upper member shows less

TABLE 6

GRAIN SIZE AND HEAVY-MINERAL CONTENT OF THE UPPER MEMBER OF THE JOHN DAY FORMATION

| Sample Number | Percentage by weight | | | Relative percentage of heavy-minerals (estimated) | | | | |
|---|---|---|---|---|---|---|---|---|
| U.J.D. | less than 200-mesh | more than 200-mesh | heavy-separate | augite | magnetite | hornblende | brookite | biotite |
| 2-2 | 86 | 14 | 0.65 | 70 | 15 | 2 | trace | ... |
| 2-3 | 78 | 22 | 0.45 | 60 | 32 | trace | 3 | ... |
| 2-4 | 64 | 36 | 0.20 | 45 | 25 | " | 1 | ... |
| 2-5 | 67 | 31 | 0.19 | 55 | 20 | 2 | 1 | ... |
| 3-1 | 82 | 18 | 0.32 | 55 | 28 | 1 | 1 | ... |
| 3-2 | 86 | 14 | 0.40 | 45 | 25 | trace | trace | ... |
| 3-3 | 56 | 44 | 0.42 | 50 | 30 | trace | 2 | ... |
| 3-4 | 76 | 24 | 0.37 | 40 | 20 | trace | trace | ... |
| 3-5 | 66 | 34 | 0.25 | 30 | 20 | trace | 1 | 2 |
| 3-6 | 88 | 12 | 0.40 | 35 | 22 | 15 | trace | ... |
| 3-7 | 87 | 13 | 0.31 | 45 | 25 | 0.5 | trace | 22 |
| 3-8 | 85 | 15 | 0.33 | 40 | 30 | trace | trace | trace |
| 3-9 | 83 | 17 | 0.54 | 35 | 20 | 15 | trace | ... |

alteration than do the lower and middle members. The induration by calcium carbonate and ferro-ferric compounds is present only in the first 100 feet of the member. The rest of the tuff is in much the same form as it had during deposition. Only slight oxidation of the finer iron minerals is noted.

Microscopic Character. The groundmass usually is made up of comminuted ash particles and disseminated iron compounds. Phenocrysts of subhedral andesine are common and are accompanied by some augite, larger pieces of pumice and glass, magnetite, and accidental rock particles. Typical texture and general appearance of the tuff are shown in Figure 35.

Devitrified pumice and glass shards, andesine, augite, and hornblende are the essential constituents of the upper member. Accessory minerals present in the upper member include quartz, magnetite, apatite, brookite, biotite, zircon, and rutile. Secondary minerals present are calcite, collophane, hematite, and tridymite. Also present in noticeable amounts are accidental and accessory rock particles. Table 6 gives the relative amounts of heavy-minerals in percentages based on the total heavy-separate. The heavy accidental and accessory rock percentages are not included. Figure 36 shows a typical heavy-separate of the tuff from the upper member.

Andesine is the only feldspar identified in the upper

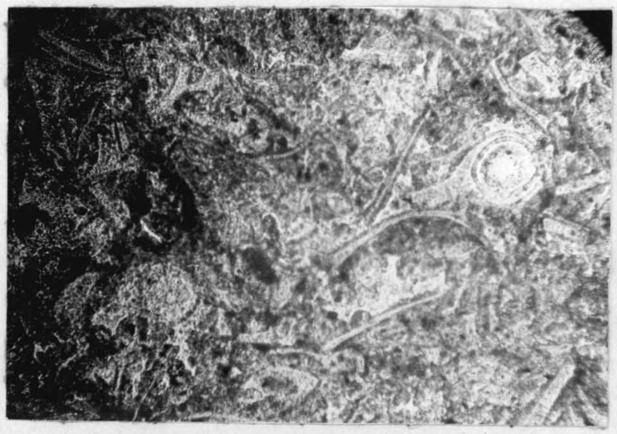


Fig. 35 Photomicrograph of Upper John Day tuff showing typical vitroclastic texture. Note the cuspate, lunar, and oval shapes of the devitrified glass shards. Plain light x 80.

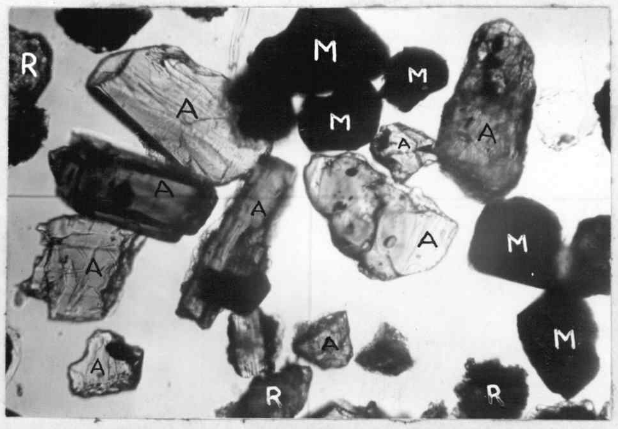



Fig. 36 Photomicrograph of heavy-minerals from Upper John Day tuff. Augite (A) with magnetite inclusions, magnetite (M) and accidental rock particles (R). Plain light x 85.

member although there may be some oligoclase. The andesine phenocrysts are both euhedral and anhedral. The crystals are flattened parallel to the (010) face and generally show albite twinning accompanied by occasional percline combination. Inclusions are very common and invariably are present in every particle studied. Apatite is the most common inclusion, followed by magnetite and gas bubbles. The andesine crystals in this member are particularly clear and show little or no weathering as only occasional cloudy surfaces are noted. The size range for the andesine is from 0.1 to 0.9 mm.

Pumice particles make up a large part of the tuffs in the upper series. The particles are generally white or grey except for the pumice in the lower portions which is stained green by the ferro-ferric compounds. Most of the pumice particles have undergone incipient crystallization. The particles are highly vesicular in structure and usually the gas cavities are strongly drawn out and form oval outlines. The pumice particles are the largest fragments found in the tuff. Their size ranges from 0.2 to 1.2 mm.

The glass shards also contribute a large part to total bulk of the tuff but are less abundant than the pumice particles. The glass shards are cuspate, rudely triangular, or lunar in shape, or in some instances they form pellets or tear drops quite similar to Pele's tears. Most of the glass shards are delicately preserved and show no signs of abrasion. The glass particles are completely devitrified. In thin section and under crossed nicols the devitrification becomes apparent as the particles show aggregate polarization which is microsperulitic in the larger fragments. Not only are the walls of the gas vesicles crystalline but the center cavities also have been filled with crystalline material. The individual crystals therein are so small that they defy identification, although the index of refraction is 1.475. They may be tridymite. The glass particles are white except in the lower beds where they are stained green. The size of the glass shards ranges from 0.2 to 0.6 mm.

Augite is persistent in small amounts throughout the upper member and averages about 47% of the total heavy-separate, as shown in Table 6. The particles (Fig. 36) are pale green or olive green, stubby, euhedral and anhedral crystals. The orthopinacoid, clinopinacoid, clinodome, and prism faces are equally well developed. Inclusions of magnetite are common and occasionally the augite itself is present as inclusions in the plagioclase crystals. The individual crystals are clear and only slightly altered on the surface. The size range of the augite is from 0.1 to 0.6 mm.

Quartz of primary origin is scarce in the upper member and exceeds 3 or 4 particles in very few of the 20-gram samples studied. The particles are anhedral and ordinarily have a slight film of iron oxide on the surface. The average size of the particles is 0.4 mm.

The secondary crystalline material composing the devitrified pumice and glass shards is presumably tridymite. The low index of refraction, weak polarization, and minute orthorhombic forms are the only evidence.

Magnetite is persistently present throughout the upper member. Table 6 shows the relative amounts of magnetite in each bed. The magnetite (Fig. 36) crystals are euhedral octahedrons although massive forms also are common. The magnetite is of primary origin and is abundant as inclusions in other intratelluric crystals. Weathering of the crystals is not apparent as most of the crystals present clear, splendent, black surfaces. The size range of the magnetite is from 0.05 to 0.3 mm.

Apatite is present as inclusions in the plagioclase although several individual crystals are noted in most of the heavy-separates studied. These crystals are clear, euhedral, rod-like particles. The crystals are very minute, few exceeding 0.02 mm.

Hornblende is consistently present in the upper member although the amounts present are very sporadic from bed to bed, as shown in Table 6. The color is dark brown and the thicker crystals appear almost black. The crystals are generally subhedral in long bladed particles. Absorption for the mineral is distinct as follows: X (clear yellow), Y (dark brown), and Z (dark brownish green). The particles are fresh and have sharp angular outlines. The average size is 0.6 mm., although in one bed (U.J.D. # 3-6) several particles are nearly 1 mm. long.

Brookite again is noted in limited amounts throughout the upper member. The crystals are well developed orthorhombic prisms and pyramids. The color is typical of the brookite described in the other members, sub-metallic black. The surface of the brookite shows occasional patches of leucoxene although the mineral is comparatively fresh. The average size of the crystals is 0.2 mm.

Biotite is not present in all of the beds of the upper series and makes its appearance only in the upper portion of the member. The only bed to produce large quantities of biotite was U.J.D. # 3-6 where the mineral composes 22% of the total heavy-separate. The mineral forms euhedral pseudohexagonal plates although anhedral flakes also are common. The biotite in the upper member shows no alteration and is splendent dark brown. The size range of the biotite flakes is from 0.3 to 0.7 mm.

Secondary hematite is a common constituent of the upper beds. It is present both as red massive particles and less abundantly as large black massive fragments. All of the hematite is of secondary origin and probably was formed from the decomposition of the finer iron-bearing minerals in the tuff.

The presence of collophane also is noted in the upper series and in the same form as in the middle member. Peculiar soft, honey-yellow particles resemble very minute bone fragments. Under the microscope the bone structure is easily discerned.

Small pink zircon crystals are present in several of the beds. These crystals are euhedral and form needle-like prisms that carry numerous gas inclusions. The average size is 0,05 mm.

Much of the material composing the upper member is accidental rock derived from material non-consanguineous with the parent magma and also accessory rock consanguineous with the parent magma. None of this material exceeds 1 mm. in size. The small size indicates that the rock must have been ejected along with the other material and not incorporated into the ash after deposition. The accidental particles are basaltic in appearance as in thin section the fragments show relict microlitic feldspars surrounded by an opaque groundmass of limonite. Other particles appear to be of quartzite as the thin section reveals irregular patches of low birefringent material similar to quartz. The accessory rock particles which possibly may be referred to the parent magma are small sub-rounded fragments that appear to have a glassy groundmass. The groundmass has undergone incipient crystallization and now shows aggregate polarization. Magnetite is finely disseminated throughout the groundmass. Originally the rock was probably a magnetite vitrophyre. Allogenic rock particles are not present in any part of the upper member. The lack of allogenic particles indicates that little or no reworking of the tuffs has taken place since deposition.

Petrographic Classification. The constituents of the upper member are strikingly similar to those of the middle member and it is assumed that the two members were derived from an andesitic magma. Silica content of the upper member is 56.65%, slightly lower than the middle member. The persistence of andesine and augite and a deficiency of quartz indicate a magma of intermediate composition. The loss on ignition is 4.13%. This indicates that some hydration has taken place since deposition but not enough to alter the composition of the tuff.

Thickness. The upper member of the John Day formation as measured by the plane table and alidade is 400 feet thick. This figure may be slightly erroneous as the basalt-tuff contact is hidden by talus. The measurement is thought to be correct within 10 feet. Merriam (17, p.295) reports gravels and crossbedded sands in the top portion of the upper member and the absence of such gravels at Sheep Rock suggests that the full thickness of the upper member of the John Day formation is not represented there.

Stratigraphic Relations. The upper member rests conformably on the underlying ignimbrite. The contact is not sharp as the two members grade one from the other. This gradational contact indicates that possibly the regional ash falls continued while the ignimbrite was implaced. The Columbia River Basalts are separated from the upper member of the John Day formation by a distinct erosional and very slight structural unconformity as the dip of the John Day is slightly greater than the dip of the overlying basalts. Interbedded tuff is found between the first and second flows of basalt and also between the second and third flows of basalt. Inspection of the tuff reveals that it has the same composition as the underlying John Day tuffs. The similar compositions of the tuff suggests that the period of volcanic activity which produced the John Day tuff was still in progress during the extravasation of the first flows of Columbia River Basalt.

### Origin and Mode of Deposition

The volcanic ejecta contained in the John Day tuffs were all derived from a common source, as shown by their identity in mineralogical composition and by the unusual occurrence of brookite, a rare mineral in eruptive rocks, in all of the tuff members. The possibility of local vents producing the tuffs is dismissed on the basis of the size-analysis of the material making up the tuff. Almost 70% of the tuff is smaller than 0.074 mm. and nowhere in the immediate area of Picture Gorge does any of the material composing the tuff range larger than 1.5 mm. Possibly more than half of the fine material (less than 0.074 mm.) is the result of weathering after deposition but those cognate crystals which have not been altered by weathering average only 0.4 mm. Furthermore, ash deposits around local vents ordinarily carry pieces of lapilli and occasionally larger blocks of ejecta. None of this coarse material is present in the Picture Gorge area or in the immediate vicinity.

Recent studies of the Crater Lake pumice falls by Howel Williams (29, p.68-98) give some insight on the relative size distribution of ejecta at different distances from the parent vent. Williams noted that the pumice generally becomes finer with increasing distance from the source. Williams (29, p.73) summarizes the size distribution as follows: "The largest pumice lumps are to be found on Timber Crater (8 miles N.E. of Crater Lake), where many exceed 6 inches in maximum dimension, and a few reach a length of 8 inches. Lumps up to 4½ inches across may be collected as far as 30 miles from the source, on Skookum Butte and Walker Rim. Even 40 miles to the northeast there are occasional lumps 3 inches across. Seventy miles distant in the same direction, pieces between 1/2 and 1 inch in size are not uncommon."

It would seem then that the John Day ash traveled considerable distance through the air before deposition. The predominance of the light pyroclastic material over the heavier crystalline material is pronounced and the relatively smaller size of the heavier material is noticeable. Undoubtedly during the transportation of the pyroclastic material from the parent vent or vents to the point of deposition in this area some winnowing and sorting took place. This size sorting and winnowing persists throughout the John Day tuff formation. The nearly uniform size of the individual particles that make up the tuff suggests that the source of the tuff was situated in approximately the same geographic position during the several periodic eruptions.

The ignimbrite of the John Day formation is undoubtedly of local origin but represents only a small time span in the accumulation of the John Day formation. This type of "nuée ardente" eruption takes place in a very short time. Possibly only several days elapsed between the initial eruption and the final deposition of the ignimbrite. Also of local origin is the interbedded basalt in the lower member. The actual areal extent of the flow is not more than 2 or 3 square miles. As yet this basalt has not been found at any of the other exposures of the lower member in central Oregon.

The problem of determining the precise location of the source of the John Day tuffs is a regional one and does not come under the scope of this detailed study of one small area of the John Day formation. It is here suggested that the vents responsible for the expulsion of this tremendous amount of tuff are located in the Cascade Mountains and are buried under more recent volcanic material. A superficial inspection of the John Day tuffs exposed on the eastern slope of the Cascade Mountains near the Mutton Mountains shows that the individual particles composing the John Day tuffs there are considerably larger. Some of the pumice fragments are nearly 10 mm. long while the average size of the particles that can be seen with the unaided eye is 5 mm. The larger individual particles that compose the John Day tuff in the Mutton Mountain region came a much shorter distance than did the material studied in the Picture Gorge area 100 miles to the east as it would hardly be possible to transport fragments up to 10 mm. farther than 60 or 70 miles. The John Day tuffs in the Mutton Mountain region appear to be aeolian, but there is a possibility that they may be waterlaid. If so, the above comparison becomes less convincing.

The John Day beds generally were considered entirely lacustrine in mode of deposition by the early geologists who worked in this region. Merriam (17, p.302) was the first to suggest that the beds were partially aeolian deposits. Today the mode of deposition of the John Day tuffs is generally accepted as aeolian although some geologists prefer the lacustrine hypothesis. The investigation of the John Day tuffs of the Picture Gorge reveals some convincing evidence in favor of aeolian deposition.

The stratification which is so even in the John Day tuffs is the strongest argument in favor of the lacustrine hypothesis. It was noted during the course of the investigation however that this even stratification on close inspection does not appear even but is generally related to the amount of induration of the particular bed and that small scale undulations separate the individual beds. The investigation also revealed that these so-called evenly stratified beds which are manifested only by the indurated layers, represent land surfaces between each successive ash fall. The apparent stratification then as we see it today is due to the weathering of the tuff under terrestrial conditions. There may be some question as to how it is possible to have such comparatively even beds deposited on a land surface without causing noticeable unevenness of bedding by rapid erosion of the soft ash. Undoubtedly during the early stages of deposition rapid erosion of the ash took place as evidenced in the lower member where small pockets of finely stratified waterlaid tuff grade into massive poorly stratified aeolian tuff. The rapid erosion of the tuffs was overcome as the ash falls continued. The thick blanket of ash as it accumulated smoothed out the topography and reduced the relief of the area so as to produce an almost featureless plain. Another effect that possibly checked the erosion of the tuffs is that the permeable ash deposits caused the disappearance of surface streams and produced an extensive development of dry valleys. Such dry valleys would introduce delay into the process of dissection ordinarily active on soft material such as ash.

A complete lack of banding and of very thin bedding typical of lacustrine deposits was also noted in the John Day tuff beds. Only in the lower portion of the red beds are typical lake sediments observed. Heavy-minerals such as augite and magnetite are present in enough quantity to have formed streamers or bands if they had been deposited in a quiet lake but no evidence of this type of bedding is seen in any of the outcrops in the Picture Gorge area.

The paucity of allogenic rock particles such as gravels and sands also demonstrates that the John Day tuffs are not waterlaid. Merriam (17, p.300) discusses the impossibility of lacustrine emplacement of the random vertebrate bones scattered throughout the formation without being accompanied by larger detritus such as sands and gravels.

It is suggested that the lower portion of the John Day formation was deposited partially in small lakes and partially on the surrounding terrain. The upper and middle members are for the most part aeolian deposits although shallow lakes may have existed on the surface from time to time. The time interval between ash falls was sufficient to produce enough vegetation to support the animal types found as fossils in the tuffs although these time intervals between the ash falls were not extensive enough or other conditions favorable enough to produce marked unconformities between each successive ash fall.

### Fossils and Correlation

Lower John Day Formation Flora and Fauna. The lower member of the John Day formation has produced very little fossil vertebrate material although near the base of the lower member the waterlaid tuffs have produced an abundant flora which is referred to by Chaney (4, p.65) as the Bridge Creek Flora.

During the investigation of the Picture Gorge area vertebrate material was removed from a tuff bed between the basalts of the lower member near the Humphrey Ranch. The material consists of several vertebrae, ribs and a mandibular ramus. The material was identified as belonging to the *Entelodontidae* family. The species is undeterminable from the material at hand, although the generic position of the vertebrate is fairly certain to be *Archaeotherium*. A complete description of the material is given in an appendix. Merriam (18, p.188) also found some sparse vertebrate material in the lower member but gives little information as to species. He records finding a large species of *Elotherium* (*Archaeotherium*) and an unidentified rhinoceros.

The Bridge Creek Flora has been described by Chaney (4, p.65). Part of this flora is found in the Picture Gorge area, designated as Cant's Ranch locality by Chaney, in the NW 1/4, NW 1/4 Sec. 31, T. 11 S., R. 26 E. It occurs in the "paper" shales interbedded in the lower member basalts. The list of species is as follows:

Pteris silvicola C.C. Hall n. sp.
Pinus knowltoni Chaney
Abies Link sp.
Sequoia langsdorfii (Brnt.) Heer
Taxus Linne sp.
Typha lesquereuxi Cockerell
Salix californica Lesquereux
Myrica difrome Chaney
Juglans oregoniana
Corylus macquarrii Heer
Carpinus grandis Unger
Ostrya oregoniana Chaney
Alnus carpinoides Lesquereux
Fagus pacifica Chaney
Castanea orientalis Chaney
Quercus clarnensis Trelease
Quercus consimilis Newberry
Quercus cf. ramaleyi Cockerell
Ulmus brownellii Lesquereux
Ulmus speciosa Newberry
Celtis obliquifolia Chaney
Asarum circularis Chaney
Odostemon simplex Cockerell
Umbellularia oregonensis Chaney
Philadelphus bendirei Kn., new combination
Platanus aspera Newberry
Platanus condoni Knowlton
Amelanchier grayi Chaney
Crataegus newberryi Cockerell
Rosa hilliae Lesquereux
Prunus coveus Chaney
Cercis Linne n. sp.
Rhus praeovata Chaney
Acer osmonti Knowlton
Ceanothus blakei Chaney
Tilia Linne sp.
Nyssa crenata Chaney
Cornus ovalis Lesquereux

Arbutus matthesii Chaney
Fraxinus denticulata Heer

Chaney (4, p.99) indicates that the Bridge Creek Flora resembles the Redwood Belt of California today and that the climate at this stage of John Day time was mild and equable. The list above is the complete flora from all the different Bridge Creek Flora localities in the John Day Basin. The dominant species found in all of these localities are: Quercus clarensis, Alnus carpinoides, Typha lesquereux, and Sequoia langsdorfii.

Middle and Upper John Day Formation Fauna. The vertebrate and invertebrate fossils of these two divisions have long been confused and will therefore be considered together. The mammalian fauna is well known and has long been a source of great interest to the paleontologists the world over. As yet there has not been a systematic stratigraphic classification of the fossils from the middle and upper members and as a result the exact stage of each member has not been clearly defined. Merriam (18, p.183) proposed that the middle member be called Diceratherium beds and the upper member be called the Promerycochoerus beds as these types appeared to be dominant in each of the members. It has since been noted by C.B. Schultz and C.H. Falkenberg (22, p.91) that Promerycochoerus is present in the middle member in enough quantity to disqualify Merriam's names. The faunal similarity of the middle and upper members of the John Day formation indicates that they should be referred to a single time unit (Lower Miocene). The similarity of the upper and middle members is also borne out by the petrographic analysis of the tuff as the material from both members is quite similar.

The fossil mammal assemblage of the middle and upper members of the John Day formation consists of 100 different species. The most common mammals living during John Day time were oredonts, rodents, hypertragulus (small deer-like animal), rhinoceroses, and small pigs. In addition to these common mammals there were many other diversified types of cursorial and grazing animals. A complete list of the fauna from the middle and upper members of the John Day formation is given in the appendix.

Accompanying this extensive mammalian fauna in the John Day beds numerous fossil land and fresh water mollusks have been collected and described incidentally to the collection of the vertebrate material. Again the stratigraphic sequence of the material is indefinite as no record is available on exact localities. The following list is taken from G.D. Hanna (10, p.6-8) who worked on the invertebrate collection in the Condon Museum of the University of Oregon.

Ammonitella lunata (Conrad)
Epiphragmophora antecedens Stearns
Epiphragmophora dubiosa Stearns
Epiphragmophora marginicola (Conrad)
Gastrodonta imperforata Hanna

Helicina oregona Hanna n. sp.
Lymnaea stearnsi Hannibal
Oreohelix lecontei Stearns
Polygyra dalli (Stearns.)
Polygyra expansa Hanna
Polygyra martini Hanna
Polygyrella polygyrella (Bland and Cooper)
Pyramidula mascallensis Hanna
Pyramidula simillima Stearns
Rhiostoma americana Hanna n. sp.
Unio condoni White

Most of these forms are terrestrial types of mollusks and the only fresh water type represented in this list is Unio condoni. The predominance of land shells over fresh water shells again demonstrates that the environment of the John Day deposition was largely aeolian.

Correlation. Much has been said on the age and correlation of the John Day formation and it seems advisable to limit this discussion to the recent papers on the subject.

It generally has been accepted that the upper and middle members of the John Day formation are Miocene in age and that the age of the lower member is uncertain on account of the scarcity of fossils. C. Stock (25, p.328) has correlated the John Day with the Vaqueros formation of California and the upper part of the Sespe formation which he considers Lower Miocene or Arikareean age. Placing the middle and upper members of the John Day formation in the Arikareean age would also make the Harrison formation of Nebraska and Wyoming its equivalent. In addition Stock suggests that only the upper and middle members of the John

Day are in the Lower Miocene and that possibly the lower member of the John Day extends into the Upper Oligocene. C.B. Schultz and C.H. Falkenberg (22, p.83) agree with Stock on the relative age and correlation of the John Day formation. Schultz and Falkenberg place the Upper and Middle John Day in the Lower Miocene on the basis of their study of the _Promerycochoerus_ genus found in the John Day. Schultz and Falkenberg also have made the upper and middle members of the John Day formation the equivalent of the Harrison and Lower Rosebud formations of the Great Plains region. This correlation also places the middle and upper members of the John Day in the Arikareean age.

It is here suggested that the Lower John Day formation be considered equivalent to the White River stage of the Great Plains region, on the basis of the genus of the entelodont found in the lower member of the John Day. The fossil is referred to the genus _Archaeotherium_ and its affinities appear close to the White River stage of _Entelodonts_, as the mandible seems more primitive in many respects than that of _Daeodon shoshonensis_, Daeodon calkinsi, and _Choerodon_ (_Daeodon_) _caninus_, the other John Day _Entelodonts_ described. Until additional vertebrate fossils are discovered in the lower member of the John Day formation the age and correlation of this member will remain somewhat questionable.

## GEOLOGIC HISTORY

The events that occurred during the early geologic history of the Picture Gorge area are obscure, owing largely to the apparent absence in the district of most of the Paleozoic and Mesozoic deposits. The oldest sedimentary rocks of the area originally were mostly fine silts and limestone but are now greatly altered, and any fossil remains that they may have contained have been completely destroyed by metamorphic processes. Tentatively these rocks are referred to as "Pre-Cretaceous". Apparently before Cretaceous time there was a marine inundation to deposit these rocks, possibly in Paleozoic time. Since their deposition one or more major orogenic revolutions must have taken place as shown by the extreme metamorphism of the rock and the profound angular unconformity below the Cretaceous(?) conglomerates.

Supposedly in the late Mesozoic the land again subsided and another marine inundation covered this part of central Oregon. The material that collected in the Picture Gorge area was a massive deposit of unsorted pebbles, cobbles, and boulders accompanied by an occasional sand lense. This type of deposit although not typical of the other Cretaceous deposits in the John Day Basin is probably a shoreline development by an extensive Cretaceous seaway. The absence of fossil marine invertebrates in this formation leaves some doubt as to its age as the other

Cretaceous deposits in central Oregon have produced abundant fossil marine invertebrates. However these fossiliferous deposits are generally composed of more favorable sandstone, siltstone, and shales instead of conglomerates.

Following the deposition of the Cretaceous(?) there was an uplift of the land surface and a recession of the seaway which marks the last inundation by marine waters in the central Oregon region. This uplift was accompanied by gentle folding of the Cretaceous(?) conglomerates. Following this uplift and folding a long period of erosion followed, during which a low rolling erosional surface was developed on the Cretaceous(?) conglomerates. The surface is one of late maturity as differences of relief on this surface are slight.

The violent volcanic activity which marks the beginning of the Tertiary elsewhere in this region is entirely lacking in the Picture Gorge area. Evidence of this volcanic activity is present within several miles of the area where volcanic agglomerates, tuffs, and lava flows outcrop. This Eocene material is usually referred to the Clarno formation which is present over much of central Oregon. Presumably the Picture Gorge area was a highland during Clarno time and so was not covered by the Clarno lavas and agglomerates or possibly the Clarno material was eroded away soon after emplacement.

Not until late Oligocene time does the record of the geologic events in this area again become evident. The violent volcanic activity which characterized most of the Eocene time began again in John Day time. Periodic ash falls that probably originated in the ancestral Cascades blanketed much of the central Oregon landscape. During the initial stages much of the ash was deposited in small lakes as indicated by the abundance of shales near the base of the John Day formation. Accompanying the accumulation of the ash in the initial stages were several small local basaltic lava flows, now seen interbedded in the Lower John Day tuffs and shales.

Fossil leaves found in the Lower John Day indicate humid and temperate conditions. From his study of the Bridge Creek Flora in the Lower John Day, Chaney (5, p.17) states the climatic and topographic implications of the flora as follows: "..., it seems clear that its topographic and climatic setting must have been essentially like that of the modern coast range redwood forest which it so closely resembles. This conclusion is based not only on the presence of fossil redwood in the Bridge Creek Flora, but also the association with it of a large percentage of the forms now making up the redwood forest, which have similar topographic and climatic requirements."

The red beds of the lower member also suggest a warm temperate alternately wet and dry climate. The finer material of the tuff was partially decomposed to clay and the finely disseminated iron compounds were oxidized so as to give the tuff its characteristic red color. This type of weathering as stated by Twenhofel (27, p.776) is usually due to a humid or warm climate and not to arid conditions as suggested by Calkins (3, p.171).

Sometime between the Oligocene and Miocene epochs the character of the John Day tuffs changed from trachytic to andesitic composition.

A slight erosional unconformity was formed between the Lower John Day and the Middle John Day and indicates a slight hiatus in the volcanic activity that marks most of John Day time. It is suggested that this slight unconformity be used as the Oligocene-Miocene boundary in the area.

As the ash of the John Day time continued to fall in the Lower Miocene the climate appears to have become less moist. The abundance of cursorial and grazing animals indicates a terrain similar to the Central Plains region of today or the savannahs found on the borders of tropical regions. A seasonally wet and dry climate is also suggested by the sediments themselves. The presence of calcareous layers throughout the Middle and Upper John Day beds indicates that each of these beds represents the exposed surface of the land during the hiatus between ash falls. Dry periods like those usually associated with the Great Plains or savannah regions brought about conditions favorable for the concentration of calcareous material at the surface through caliche action. The rainy seasons brought about enough growth of vegetation to support the animal life and also to furnish reducing solutions to produce ferro-ferric compounds which give the tuffs their characteristic green hue.

Near the Middle Miocene the terrain of the John Day Basin undoubtedly presented an almost featureless plain, broken only by the higher Clarno hills, as the accumulations of ash in some places exceeded several hundreds of feet. This large accumulation of ash represents many hundreds of separate ash falls as it hardly seems possible that a single ash fall could account for such a large thickness of material. Furthermore the presence of a large fauna indicates favorable life conditions that would require a considerable time interval between each series of eruptions. The marked evolution of some of the fossil mammals also suggests that a long period of time elapsed between the initial and final phases of deposition of the ash.

The only local volcanic activity certainly recorded during John Day times in the Picture Gorge area is the violent emplacement of the "nuée ardente" deposit found between the middle and upper members of the John Day formation. This local activity was of very short duration as only one bed of this material is found in the area and it is generally recognized that this type of volcanic flow lasts only a matter of days or weeks at the most.

Following the deposition of the John Day formation slight warping of the John Day beds and a short period of erosion took place. In some places adjacent to the Picture Gorge district the John Day tuffs were completely removed so that the next younger Columbia River lavas rest directly on older rocks.

The base of the Columbia River lavas marks the beginning of one of the largest and most extensive accumulations of basic lavas in the world. In places the Columbia River Basalt is composed of as many as thirty flows. The prevailing thickness of the flows ranges from 30 to 100 feet. In this area the Columbia River Basalt attained a thickness of 800 to 1200 feet and as many as 23 separate flows were superposed.

The basalts came to the surface in a highly liquid state and flowed for many miles. To have fed so many flows required many vents or fissures. These feeder dikes or vents are relatively scarce in this area; only two small feeder dikes are known. These dikes cut the "Pre-Cretaceous" metamorphics in the northeast corner of the area.

At the close of this tremendous outpouring of lava much of Oregon, Washington, and Idaho presented a featureless plateau as this basalt now deformed and eroded is found on the highest mountain ranges of the region as well as in the lower basins of the region.

The extravasation of the basalt during the Middle Miocene was followed by settling and warping of the Columbia River Basalt. This is shown by the Middle Mountain syncline in the north portion of the area and the John Day syncline to the south. This warping was accompanied by faulting on a small scale in the John Day tuff beds.

The collection of tuffaceous sediments in the John Day syncline marks the beginning of Mascall time. These sediments are mostly waterlaid. The deposition of the finer tuffaceous material was accompanied by coarser crossbedded gravels and sands. The source of the Mascall tuffs as yet is undetermined although they may possibly be the result of a continuation of activity in the Cascade Mountains or the result of pyroclastic ejecta from local vents. The Mascall sediments are preserved entirely within the limits of the John Day syncline and are not found overlying the Columbia River Basalts at elevations higher than 3600 feet in the Picture Gorge area. Possibly the Mascall sediments may have extended farther from the present basin. If so, they have since been eroded from the basalt surface and are now restricted to a strip about 5 miles wide.

The Mascall formation has furnished many fossil remains including those of mammals, fish, and plants. The climatic conditions indicated by the Mascall flora are stated by Chaney (6, p.18) as follows: "The dominance of the late Miocene Mascall flora from the John Day Basin of

Oregon, of <u>Alnus</u>, <u>Arbutus</u>, <u>Pinus</u>, <u>Platanus</u>, <u>Populus</u>, <u>Pseudotsuga</u>, and <u>Quercus</u>, indicated that the typical redwood assemblage of the earlier Miocene had been largely displaced by a forest better suited to a cooler and drier environment. Such a border forest may be supposed to have occupied the ridges and other exposed situations during the time that the redwood forest was widely developed, at the beginning of the period (Bridge Creek Flora Lower John Day formation)."

The close of the Miocene was marked by regional faulting in the area. This faulting brought about the tilting of the Mascall and the deposition of the coarse gravels of the Rattlesnake formation. Middle Mountain fault in the Picture Gorge area probably is related to this post-Mascall faulting and in part responsible for the disconformable relation between the Mascall and Rattlesnake formations. The highlands produced by the post-Mascall faulting furnished much of the gravels and silts found in the Rattlesnake formation. The preservation of the gravels again was controlled by the original John Day syncline and by the post-Mascall faults which run parallel to the axis of the syncline.

During the deposition of the Rattlesnake formation in the Pliocene epoch a short episode of volcanic activity took place. This activity deposited the ignimbrite found now as "rim-rock" capping the gravels or interbedded within the gravels. This welded-tuff was formed under conditions similar to the emplacement of the welded-tuff of the John Day formation. A huge stream of semi-molten, highly gaseous rhyolitic material, commonly called "nuee ardente", poured into the John Day Valley and completely blanketed the valley floor. This activity probably represents only several days in the Pliocene.

The deposition of the Rattlesnake gravels continued uninterruptedly after the extrusion of the ignimbrite. These gravels accumulated to thicknesses of several hundred feet over the underlying ignimbrite. The gravels or fanglomerates formed large coalescing fans at the base of the highlands surrounding the John Day Valley and extended into the valley itself. Since the deposition of these fans they have been truncated and deeply eroded by the John Day River and its tributaries.

The silts and gravels of the Rattlesnake formation have yielded numerous fossil mammalian bones. From these fossils the following types of animals have been identified: wolves, bears, weasels, ground sloths, elephants, horses, camels, bison, etc. This fauna is distinctly different from the fauna of the underlying Mascall formation and is generally considered to be Middle Pliocene in age. This assemblage of animals seems to indicate a rather mild climate not much different from the climate during the Upper Miocene.

The close of Rattlesnake time was marked by two events, post-Rattlesnake faulting and the active erosion of the aggraded John Day Valley plain. The post-Rattlesnake deformation probably preceded the erosional period, and in part may have been the initial cause of the degradation. Most of the present streams are superimposed on the post-Rattlesnake structures which indicated that alluvial deposition continued after faulting and on into the Pleistocene epoch, long enough to allow the streams to aggrade over the structures and thus be in the superimposed position before the Pleistocene erosional stage began.

This erosion, initiating the Pleistocene, has continued to the present time and is still active in the Picture Gorge area. The present course of the John Day River reveals part of the erosional history of the Pleistocene epoch. The warping of the Columbia River Basalts controlled the preservation of the Mascall and Rattlesnake and also later determined the course of the John Day River. The geological map (Plate V) shows how the John Day River swings sharply north at Picture Gorge and flows northward directly along the axis of the Middle Mountain syncline. This syncline contemporaneous with the John Day syncline affords an excellent reason for the abrupt swing of the river to the north at Picture Gorge. The John Day River flowing over the aggraded Rattlesnake surface during Pleistocene time cut down through the Rattlesnake and Mascall formations and became superimposed upon the Columbia River Basalts at Picture Gorge.

The John Day River was superimposed on the Cretaceous(?) monocline in Butler Basin also, but as yet has not cut through the complete thickness of Columbia River Basalts at Middle Mountain.

A late event in the geologic history of this area was accumulation of a very thin ash fall on or near the present erosional surface. The ash is found only in small pockets along streams or interbedded in larger terraces along Rock Creek and the John Day River. The ash thickens to the north of the Picture Gorge area towards the Columbia River and is thin and almost nonexistent 50 miles to the south of the area, this thinning to the south indicates that the source was possibly to the north of the area. The age of the ash fall is uncertain although probably not more than several thousand years.

Since the deposition of the ash fall erosion of the highlands has continued and small deposits of alluvium have accumulated along the larger stream beds. Slumping of the tuffs and basalts during the Pleistocene has continued up to the present time. After periods of intense rainfall slumping is common in the Butler Basin and Big Basin areas.

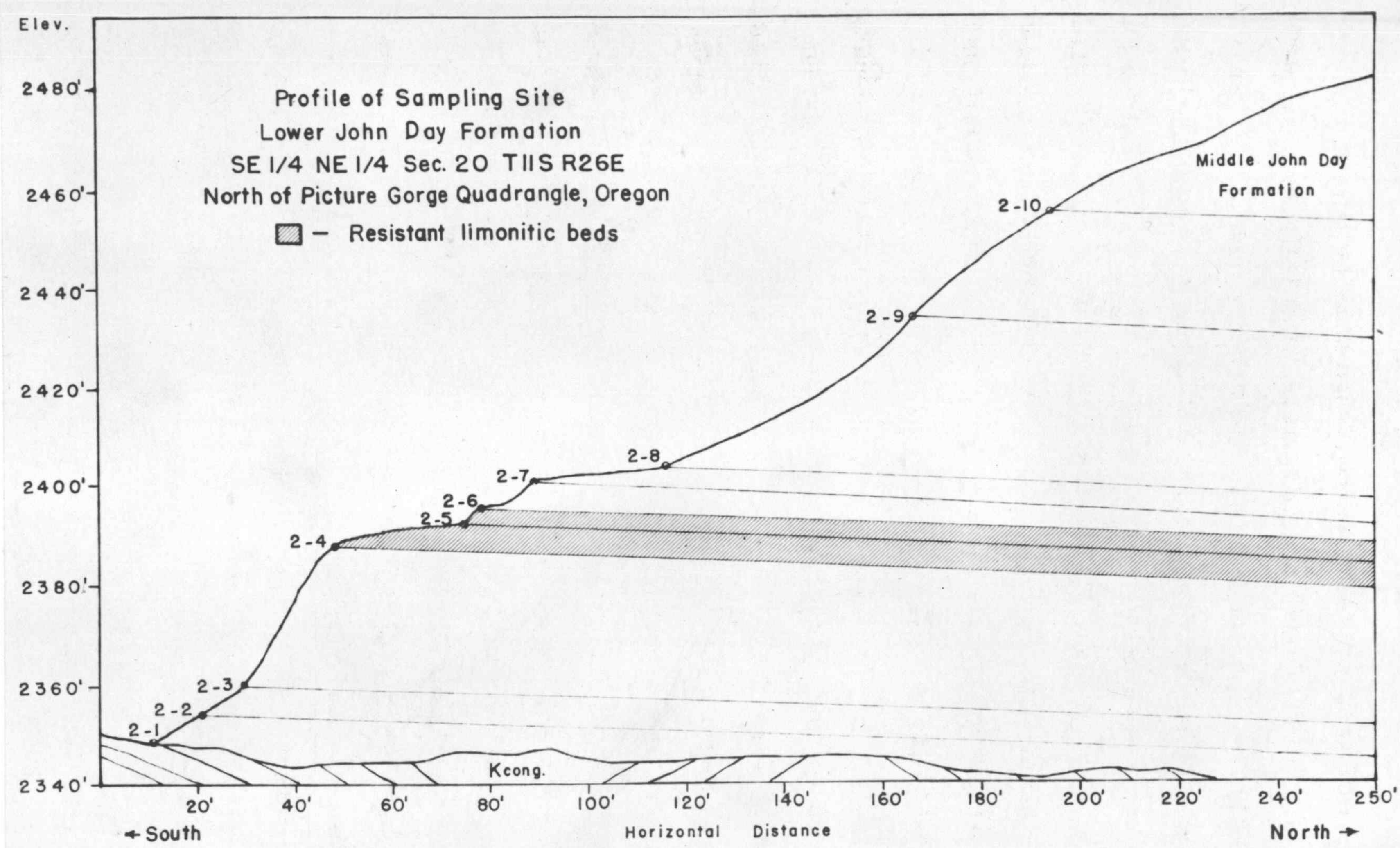
# APPENDIX I

## Description of Specimens

General Statement. The following are general petrographic and lithological descriptions of each bed sampled in the lower, middle and upper members of the John Day formation. The exact location and stratigraphic position of each bed is shown on Plate II (Lower John Day), Plate III (Middle John Day) and Plate IV (Upper John Day). The station numbers indicate the top of each bed sampled.

Each sample was analyzed mechanically for material smaller than 200 mesh (0.074 mm.) and then heavy-mineral separations were carried out on the material larger than 200 mesh. The heavy-minerals and light-minerals were then studied under binoculars and microscope.

The relative percentages of the heavy-minerals were estimated by eye and are presented in Table 4 (Lower John Day), Table 5 (Middle John Day), and Table 6 (Upper John Day). The light-separate, those under 2.86 specific gravity, were not studied in such detail. The type of feldspar and condition of the vitroclastic material was recorded. The size of the individual crystals was determined under the microscope with the aid of a scaled ocular. The material under 200 mesh was not studied petrographically. Colors of the individual specimens are given under the Ridgeway system according to the color chart prepared by



Elev.
2480'
2460'
2440'
2420'
2400'
2380'
2360'
2340'
Profile of Sampling Site
Lower John Day Formation
SE 1/4 NE 1/4 Sec. 20 T11S R26E
North of Picture Gorge Quadrangle, Oregon
– Resistant limonitic beds
Middle John Day
Formation
2-1
2-2
2-3
2-4
2-5
2-6
2-7
2-8
2-9
2-10
Kcong.
20'
40'
60'
80'
100'
120'
140'
160'
180'
200'
220'
240'
250'
← South
Horizontal Distance
North →


PLATE II

Marcus I. Goldman and H.E. Merwin under the auspices of the Division of Geology and Geography, National Research Council, Washington, D.C.

Lower John Day Specimens North of Picture Gorge Quadrangle. The lower member sampling profile was taken north of Picture Gorge quadrangle in the S.E. 1/4 N.E. 1/4 Sec. 20, T. 11 S., R. 26 E. The profile is illustrated on Plate II.

L.J.D. # 2-1 Red tuff from the contact bed. In the hand specimen this is a friable clay when dry and a plastic clay when wet. The color is light red (Ridgeway 3 1 0). Under the binoculars the material is very fine-grained weathered ash. The original pyroclastic forms of the formerly glassy material are not present as this material has been completely altered to clay. The feldspars present are sanidine and plagioclase with sanidine dominant. The plagioclase-feldspar has low extinction angles on the albite twins and an index of refraction of 1.53 which indicates its acid character, probably oligoclase. The average size of the light-separate is 0.7 mm. The heavy-separate consists of magnetite, brookite, and zircon with small amounts of secondary hematite and calcite. Zircon in this bed amounts to 20% of the heavy-separate but only 0.18% of the rock. Several small fragments of blue-rutile were noted; these fragments are dichroic from blue to white with extreme birefringence and dispersion. The heavy-separate ranges in size from 0.05 to 0.5 mm.

L.J.D. # 2-2 Red tuff 7 feet above L.J.D. # 2-1. Megascopically, this is a fine grained, compact, clayey, material which shows on the surface of some of the specimens a slick polish produced by slippage during surficial deformation. The color is light red (Ridgeway 3 1 0). Microscopically the specimen differs little from L.J.D. # 2-1. The bulk of the rock is a well weathered ash showing little of its original vitroclastic structure. The quartz in this specimen shows the typical iron stain surface. This contrasts with the apparently fresh and clear sanidine and oligoclase. The light-separate ranges in size from 0.2 to 0.7 mm. Small fragments of allogenic origin are present and appear to have come from the underlying Cretaceous(?) beds. Magnetite and brookite make up the bulk of the heavy-separate with smaller amounts of zircon, hematite, and accidental fragments of basalt. The average size of the heavy-separate is 0.3 mm.

L.J.D. # 2-3 Red tuff 5 feet above L.J.D. # 2-2. This bed is composed of fine-grained, compact ash. The color is light red (Ridgeway 3 1 0) with small flecks of white ash interspersed throughout the rock. Under the microscope and binoculars the material shows an increase in crystalline fragments as compared to the underlying beds. The ash shows none of its original vitroclastic structure as all of the glass has been altered to clay. Sanidine and oligoclase are present and show little alteration in the larger grains. Magnetite inclusions are common in both feldspars. The few quartz fragments present have the typical iron oxide film on the surface. The light-separate ranges in size from 0.2 to 1.2 mm. The heavy-separate is the same as in the preceding sample except for a slight increase in brookite. Also the appearance of several flakes of fresh biotite was noted. The magnetite particles in this specimen are massive, for the most part, and exhibit very few euhedral crystals. Other grains found in the heavy-separate include secondary hematite, a trace of blue-rutile, and several accidental particles of basalt. The average size of the heavy-separate is 0.3 mm.

L.J.D. # 2-4 Red tuff 30 feet above L.J.D. # 2-3. This bed forms a thick steep-faced outcrop of dull, earthy, fine-grained, clayey tuff. On inspection with the hand lens some of the clear feldspars can be seen in the earthy matrix. The color is light red (Ridgeway 3 1 0). Under the microscope this material is consistent with the underlying beds in that it shows none of its original vitroclastic structure as most of the fine material is highly weathered. The quartz fragments are limited in number and show the typical film of iron oxide. Sanidine is present as well-formed clear crystals except where the iron oxide stain has penetrated the cleavage cracks. Oligoclase is also present in well-formed fresh crystals which have been penetrated slightly by iron oxide stain. The average size of the light-separate is 0.7 mm. Heavy-minerals present include magnetite, brookite, biotite, and zircon. Among them brookite and magnetite are dominant, both in euhedral forms. Biotite is scarce and shows little alteration except on the edges where it has altered to chlorite. Zircon is also very limited in occurrence as only two or three euhedral crystals are present. Massive secondary hematite is more evident than in the preceding samples. Several accessory particles of micro-trachyte are present along with the usual accidental basalt fragments. The average size of the heavy-separate is 0.3 mm. although the basaltic fragments exceeded this by several tenths.

L.J.D. # 2-5 Resistant limonitic layer of red tuff 4 feet above # 2-4. This specimen was taken from the lower portion of a resistant layer which forms a distinct terrace in the lower red beds. On close inspection of a hand specimen rudimentary limonitic pisolites are seen throughout the groundmass. The structure is quite similar to that seen in the "shot soils" of western Oregon. The bed is traversed by a set of vertical joints which form an irregular pattern. In the thin section the material is seen to be well impregnated with iron oxide which is the main cementing material. Original vitroclastic structures are dimly visible but most of the fragments have been altered to a very fine clay. Sanidine and oligoclase are present, both showing more iron oxide impregnation and decomposition than the feldspars of the underlying beds. Small amounts of quartz in the sample show the typical coating of iron oxide. The size of the light-minerals ranges from 0.5 to 0.8 mm. More than 50% of the heavy-separate consists of reddish brown, massive fragments of secondary limonite. The large relative increase of this material indicates more intense weathering of this bed. The rest of the heavy-separate consisted of magnetite, brookite, and small particles of manganese oxide. The secondary manganese oxide can be observed in the hand specimen both as stain and partial filling of the pisolites. Both magnetite and brookite are less abundant in this specimen as a further result of extreme weathering at this horizon. The average size of the heavy-separate is 0.3 mm.

L.J.D. # 2-6 Top of resistant limonitic bed 3 feet above L.J.D. # 2-5. Material same as described in the underlying bed.

L.J.D. # 2-7 Light red tuff 6 feet above L.J.D. # 2-6. On the surface this material is white or slightly red while the material under the weathered layer has a deeper red color (Ridgeway 3 l i). The ash weathers out into small spheroidal particles which disintegrate into hemispherical particles, similar to exfoliation on a larger scale. The low iron oxide content (Table 3) of this bed accounts for the lighter color of the exposure. Microscopically the ash shows little of its original structure as the finer material and glass have weathered to a fine clay. Sanidine exhibits well developed euhedral crystals with some inclusions of apatite and magnetite. Oligoclase is more abundant in this sample and exhibits typical iron stain along the cleavage cracks. In contrast to the other beds, the quartz shows little or no iron oxide stain on the surface. The average size of the light-minerals is 0.8 mm. The magnetite occurs as well-formed octahedrons and is common as inclusions in the feldspars. Brookite crystals present show both euhedral and skeletal forms. Penetration twins were common to the brookite in this specimen although no apparent reason is evidenced. A few subhedral crystals of zircon were noted. The size of the heavy-minerals ranges from 0.2 to 0.3 mm.

L.J.D. # 2-8 Brownish red tuff 2 feet above L.J.D. # 2-7. Examination of the hand specimen of this bed reveals a large amount of secondary gypsum which has the form of roots of plants. The gypsum has surrounded the roots and left the center of the root filled with the original plant material. This original material has subsequently been altered to carbonaceous matter. The presence of plant material at this horizon indicates that the profuse fossil flora found at the base of the lower member may have survived further into John Day time. Further searching of the bed yielded no fossil leaf prints. The tuff is fine-grained, crumbly, and brownish-red (Ridgeway 3 1 j) which is mottled by particles of white gypsum. Under the microscope the colored ash appears to have undergone complete weathering which has obscured the original vitroclastic structures. The feldspars present are sanidine and oligoclase both in euhedral form and fresh in appearance. Secondary quartz also was observed as well as several accidental particles of basalt. Clear angular fragments of quartz are more abundant in this bed. The size of the light-minerals ranges from 0.3 to 1 mm. Heavy-minerals include magnetite, brookite, biotite, zircon, and secondary hematite. The magnetite forms euhedral octahedrons as well as massive particles. The brookite crystals are of smaller size in this specimen and less numerous than in the preceding samples. The few fragments of biotite present show some alteration to chlorite. Small euhedral crystals of zircon are present and have typical inclusions. The average size of the heavy-minerals is 0.3 mm.

L.J.D. # 2-9 Red tuff 30 feet above L.J.D. # 2-8. In the hand specimen this is a fine-grained, flaky, red-buff (Ridgeway 3 1 i) rock. With the aid of the hand lens many feldspar fragments can be picked out. Under the microscope the ash appears in the same weathered condition noted previously. The feldspar and quartz fragments are several millimeters larger in this rock than in any of the preceding rocks. The sanidine crystals are well developed euhedral forms and occasionally show Carlsbad penetration twinning. Iron stain is commonly found on the angular fragments of quartz. The average size of the light-minerals is 1.5 mm. Magnetite and brookite make up the bulk of the heavy-minerals, accompanied by minor amounts of massive hematite and accidental fragments of basalt. The magnetite crystals are both euhedral and massive. Brookite crystals present exhibit the same characteristics found in other beds. Several fragments of euhedral apatite were noted in this specimen. The average size of the heavy-minerals is 0.3 mm.

L.J.D. # 2-10 Light buff-red tuff 22 feet above L.J.D. # 2-9. This bed represents the top-most part of the Lower John Day member at the sampling locality. The material composing this bed grades almost imperceptibly into the green tuffs of the Middle John Day. At the contact the two members are separated by a slight erosional unconformity. Under the microscope this specimen shows less complete alteration of the vitroclastic constituents. In contrast to all of the underlying beds, the vitroclastic material in this bed exhibits all of its original forms. This material consists mostly of pumice fragments which have been completely devitrified to secondary quartz and chlorite. The groundmass still consists of fine material altered to clay that is highly impregnated with iron oxide. The plagioclase-feldspar, oligoclase, is the dominant crystalline component accompanied by minor amounts of sanidine and quartz. The size of these particles ranges from 0.2 to 0.4 mm. A large amount of accessory and accidental igneous rock fragments is present. The accessory material is micro-trachyte and the accidental fragments are basalt. The heavy-minerals in this bed were not separated, but both magnetite and brookite were noted in thin section. The average size of this material is 0.3 mm. The presence of several small particles of augite and an increase in plagioclase indicate that the parent magma at this stage of eruptive history was changing from an acid type to a magma of more intermediate composition.

Lower John Day Specimens from Sheep Rock. The following descriptions of the rocks from Sheep Rock includes only the three intercalated beds of light colored tuff. These specimens were studied only with the aid of thin sections.

L.J.D. # C-2A White clayey ash 10 feet above the Cretaceous(?) contact. In the hand specimen this is a white, fine-grained, clayey rock with some iron stain along the joints. The clayey rock has undergone little or no impregnation with iron oxide. Under the microscope the groundmass shows aggregate polarization although there are very few intratelluric crystals present. The primary crystals present are potash feldspars, plagioclase, and possibly a little quartz. No ferromagnesian minerals or secondary limonite and hematite are present. The bulk of the rock is made up of kaolin and montmorillonite. These two clay minerals are generally pseudomorphic after the original vitroclastic material. The rock is bentonitic in character as it absorbs large quantities of water and swells slightly in the process.

L.J.D. # E-1 Basal bed of the buff tuff in the top portion of the lower member. This rock is a medium-grained, light buff (Ridgeway 21 2 f) tuff. Under the microscope the groundmass is composed of vitroclastic material. The bulk of this material is devitrified glass in lunar, cuspate, and vesicular fragments. The crystalline material replacing the walls and filling the cavities of these vesicular fragments is secondary tridymite, quartz, and possibly some zeolites. The size of the vitroclastic material ranges from 0.3 to 1.25 mm. Secondary calcite is abundant throughout the rock and replaces much of the devitrified glass. Intratelluric crystals are scarce in this tuff as only intermediate plagioclase and possibly some potash-feldspar crystals were found. These feldspars show little alteration and range in size from 0.1 to 0.4 mm. Magnetite is present as an accessory mineral and generally shows some alteration to limonite. This tuff is strikingly different from the rest of the lower member both in color and in its well defined vitroclastic texture.

L.J.D. # E-2 Cap bed of buff tuff in the upper portion of the lower member. In the hand specimen this rock is a medium-grained tuff with visible fragments of light colored (Ridgeway 18 3 A) pumice scattered throughout the groundmass. In the thin section this rock differs little from the underlying tuff bed except that the groundmass is dominantly pumice fragments instead of the individual glass shards. The pumice has been completely devitrified and is now made up of secondary quartz and shreds of material similar to chlorite. The individual glass shards present also have been subsequently devitrified and are now composed dominantly of secondary quartz, feldspar, and tridymite. Intratelluric crystals are also scarce in this tuff as only several particles of intermediate plagioclase, potash-feldspar, and quartz were found. The average grain size of this material is 0.3 mm. Accidental particles of basalt, ranging in size from 0.3 to 0.4 mm., are fairly common. Throughout its mass the tuff is impregnated very lightly with limonite, whence the light brown coloration. The groundmass under crossed nicols shows aggregate polarization indicating that all of the original glassy material has undergone complete devitrification. The parent magma of the tuff was possibly andesitic as the dominant feldspar is intermediate plagioclase and quartz is subordinate.

Lower John Day Interbedded Basalt Specimens. The following descriptions treat the general petrography and lithology of the basalts interbedded in the lower red beds. The basalts were studied under the microscope and with the use of the hand lens. The basalts were divided into two general types on the basis of texture and occurrence. There are two distinct flows, each having a characteristic texture. The basal flow generally is black with ophitic texture and the overlying basalt flow, separated from the first by tuff beds, generally has pilotaxitic texture and a red-grey color.

The basal flow generally shows irregular vertical joints although some exposures exhibited columnar jointing. In the hand specimen the rock is fine-grained and black. Occasionally with the aid of the hand lens plagioclase crystals can be identified and the altered olivine crystals are apparent by limonite rims. Under the microscope the texture of the basalt is ophitic to sub-ophitic. Small anhedral and euhedral plates of feldspar surround anhedral patches of olivine, and occasionally some augite. The constituents present are primary plagioclase, olivine, magnetite, and some augite, and secondary antigorite, iddingsite, calcite, and limonite. The plagioclase is euhedral to anhedral in lath-like crystals. The terminations of the plagioclase spars are generally ragged. The extinction angles of the plagioclase twins indicates it to be labradorite. Olivine is found interstitially between the feldspar laths and has no euhedral forms. Generally the olivine is completely or partially altered to antigorite or iddingsite. The magnetite present is generally in irregular forms, both as interstitial material and also as inclusions in the other crystalline material. The olivine and augite apparently crystallized after the feldspars so as to suggest that this flow is close to the source. Ophitic texture generally is associated with intrusives or exceptionally thick flows. Inspection of thin section from the basal flow ½ mile from the head of Deer Gulch shows a marked decrease in the ophitic texture. This decrease suggests that the basalt at the head of Deer Gulch may be close to the dike that fed the flows.

The basalt examined in the top flow has undergone more extensive weathering than has the basal flow. Usually the basalt on close examination shows the extreme amount of weathering as it has a reddish tinge from secondary limonite. Some outcrops are so highly weathered that it is hard to distinguish them from sandstone. The top flow exposed near the head of Deer Gulch exhibits rough pillow structure while the other exposures in the area are generally massive. The top flow carries more vesicles near the top than the basal flow. These vesicles are filled with secondary material such as chalcedony, opal, calcite, chlorite, and zeolites. Under the microscope the groundmass is holocrystalline and is made up of small laths of plagioclase and particles of magnetite. The texture is pilotaxitic and shows little or no alignment of the feldspar laths. Some thin sections of the top flow show phenocrysts of euhedral olivine in the groundmass. The main constituents of the basalt are labradorite, olivine, magnetite, and some augite. Secondary minerals almost equal the original crystals in quantity. Antigorite, iddingsite, chlorite, calcite, limonite, and chalcedony are present as the secondary minerals. The plagioclase laths are generally sub-hedral and have ragged terminations. Both albite and Carlsbad twins are present on the feldspar laths. The olivine crystals are euhedral although most of the crystals have been replaced by either limonite, iddingsite, or antigorite. The replacements of the olivine by secondary minerals is universal in all of the Lower John Day basalts. Magnetite fragments are abundant and usually have anhedral forms. Limonite has replaced much of the primary magnetite. Amygdaloidal fillings are represented by several different types of minerals although calcite is the most common. Secondary silica, calcite, and chlorite commonly occupy the same amygdule. Other minerals found in the amygdules include opal, zeolites, and limonite.

Middle John Day Specimens from Turtle Cove. The middle member sampling profile was taken at Turtle Cove in the N.W. 1/4 N.E. 1/4 Sec. 29, T. 11 S., R. 26 E. The profile is illustrated on Plate III.

M.J.D. # 1-1 Basal bed exposed in Turtle Cove. In the hand specimen this rock is a medium fine-grained light buff-green tuff (Ridgeway 30 4 d). The tuff has a massive

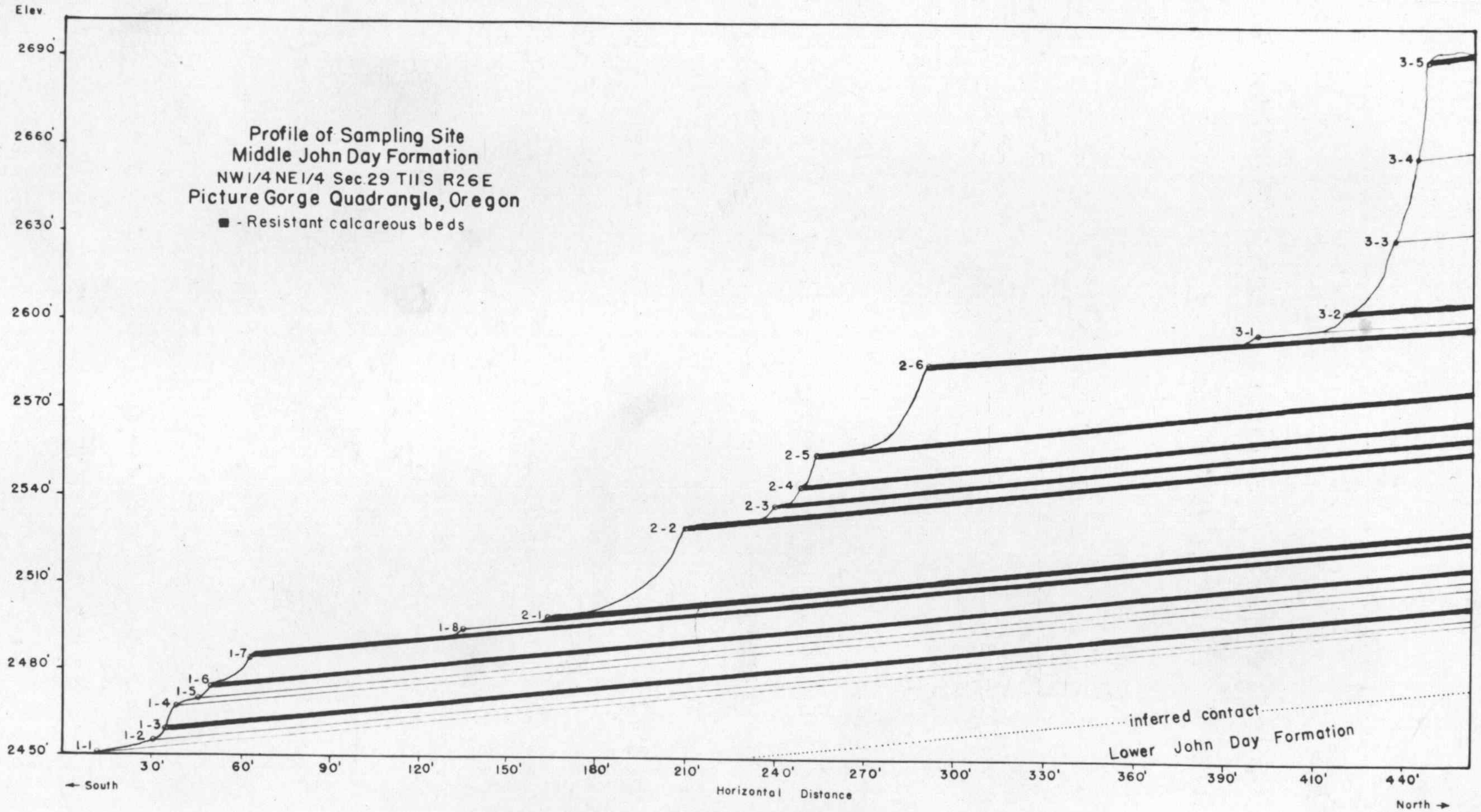

Profile of Sampling Site
Middle John Day Formation
NW1/4 NE1/4 Sec. 29 T11S R26E
Picture Gorge Quadrangle, Oregon
■ - Resistant calcareous beds
Elev.
2690'
2660'
2630'
2600'
2570'
2540'
2510'
2480'
2450'
1-1
1-2
1-3
1-4
1-5
1-6
1-7
1-8
2-1
2-2
2-3
2-4
2-5
2-6
3-1
3-2
3-3
3-4
3-5
inferred contact
Lower John Day Formation
30'
60'
90'
120'
150'
180'
210'
240'
270'
300'
330'
360'
390'
410'
440'
← South
Horizontal Distance
North →

PLATE III

structure in the outcrop and on inspection with the hand lens a few small phenocrysts of feldspar and kaolinized pumice fragments are distinguishable. Microscopic inspection of the fragments shows the bulk of the tuff to be made up of clay-sized particles. The heavy-minerals present are magnetite, augite, apatite, hornblende, and secondary hematite. The magnetite and augite crystals are the most abundant. The magnetite forms euhedral octahedrons and the augite crystals, light-green, euhedral particles. The light-separate consists of plagioclase, devitrified glass shards and pumice, secondary quartz, and accidental rock particles. The plagioclase is mostly andesine and partly oligoclase. The delicate glass shards and pumice fragments are both well preserved and present typical pyroclastic structures. The average size of the heavy-minerals is 0.2 mm. and the size of the light-minerals 0.7 mm.

M.J.D. # 1-2 Buff tuff 8 feet above M.J.D. # 1-1. This is a fine-grained light buff (Ridgeway 25 4 d), massive tuff. The color transition from the underlying bed is gradual. With the hand lens several accidental rock fragments are distinguishable. The heavy-minerals consist of augite, magnetite, brookite, hornblende, and secondary hematite. The augite and magnetite are the most abundant heavy-minerals. The brookite particles are splendent, black, euhedral crystals. The light-minerals consist of andesine, sanidine, quartz, and pyroclastic fragments of devitrified glass shards and pumice. The andesine crystals are fresh and clear although the smaller particles show considerable alteration to kaolin. The glass and pumice show considerable surface wear but still retain their original pyroclastic forms. Scoriaceous basaltic fragments of accidental origin are numerous. These accidental particles are accompanied by quartzitic fragments that are rounded and impregnated by iron oxide. The average size of the heavy-minerals is 0.2 mm. and the size of the light fragments is 0.7 mm.

M.J.D. # 1-3 Light buff tuff 4 feet above M.J.D. # 1-2. This is a calcareous tuff that forms a small terrace about 2 feet thick. The tuff is well indurated and has a light buff color (Ridgeway 25 $^4$ d). The large amount of secondary calcite present gives the rock a much lighter color than the underlying and overlying beds. Inspection of the tuff under the microscope shows complete impregnation by secondary calcite. The typical green stain found on the particles elsewhere is completely missing in this bed. The heavy-fraction of minerals consists mostly of augite and magnetite accompanied by minor amounts of apatite, brookite, hematite, hornblende, and several particles of biotite. The euhedral octahedrons of magnetite are occasionally modified by dodecahedrons. Magnetite is found also as in other intratelluric crystals. Apatite crystals are clear, elongated, and bear minute gaseous inclusions. The lighter fraction of minerals consists of andesine, glass shards, cemented fine-ash, and pumice particles. The andesine crystals show slight frosting on the surface which is probably due to weathering action. The individual glass particles exhibit cuspate and spheroidal forms. Some show extreme elongation. The average size of the heavy-minerals is about 0.2 mm. and the average size of the light-minerals is 0.6 mm.

M.J.D. # 1-4 Light grey-green tuff 7 feet above M.J.D. # 1-3. In the outcrop this tuff forms a soft bed that is covered on the surface by several inches of rain-washed material. The tuff weathers into small spheroidal particles very similar to spheroidal weathering of igneous rocks. The hand specimen reveals a fine-grained, massive, light grey-green (Ridgeway 30 4 d) tuff. This bed produced numerous fragmentary fossils of rodents and Hypertragula. Under the microscope the tuff appears poorly cemented as no aggultinated aggregates were noted. The heavy-minerals consist of augite, magnetite, hornblende, apatite, hematite, and brookite. Again augite and magnetite make up the bulk of the heavy-minerals. The augite shows considerable incrustation of fine ash on the surface. The other heavy-minerals are similar to those described in the preceding beds. The heavy-minerals range in size from 0.1 to 0.3 mm. The light-separate consists mostly of fine white ash accompanied by smaller amounts of devitrified pumice and glass shards, andesine, and allogenic rock particles. Zoning in the andesine is prominent in most of the fragments studied. The devitrified glass and pumice particles show little change in their original forms. The size range for the light-separate is from 0.3 to 0.8 mm.

M.J.D. # 1-5 Light buff tuff 3 feet above M.J.D. # 1-4. This is a massive, fine-grained, light buff (Ridgeway 25 $^4$ d) tuff. This tuff is soft and similar to the underlying bed in that the surface is also covered by several inches of rain-washed material. Under the microscope the aggregate appears poorly cemented and shows no trace of green coloring material. The heavy-minerals consist mostly of augite and magnetite accompanied by minor amounts of hornblende, apatite, brookite, and secondary hematite. This group of minerals is similar in most respects to the preceding samples except for a slight increase in the amount of hornblende. The heavy-mineral particles range in size from 0.1 to 0.3 mm. The lighter fraction consists mostly of fine white ash, devitrified glass shards, and pumice, and plagioclase feldspars. The devitrified glass shards show unusually good preservation as the delicate spheroidal gas bubbles still retain their original shape. The plagioclase feldspar is andesine although some oligoclase crystals are present. Some of the particles of feldspar show advanced stages of kaolinization. Pumice fragments show excellent preservation and generally are considerably larger than the crystals. The size range of the light particles is from 0.3 to 0.8 mm.

M.J.D. # 1-6 Light cream-buff tuff 6 feet above M.J.D. # 1-5. In the hand specimen this rock is a massive, fine-grained, light cream-buff (Ridgeway 22 $^{2}$ f) tuff. This bed is well indurated with calcite and forms a slight terrace. Under the microscope the matrix appears well impregnated with secondary calcite and quartz. The individual particles are very slightly impregnated with the green iron compounds. The heavy-mineral fraction includes augite, magnetite, hornblende, apatite, hematite, and brookite. Augite is the most abundant heavy-mineral and magnetite is next. The other heavy-minerals account for only a minor percentage. The size range of the heavy-minerals is from 0.1 to 0.3 mm. The bulk of the light-minerals consists of fine ash, devitrified glass shards and pumice. Smaller amounts of andesine, quartz, and sanidine are also present. The devitrification of the glass particles becomes apparent under the crossed nicols as all of the mass shows aggregate polarization. The feldspars show mild alteration to kaolin. Several large pieces of accidental blue-grey quartzite are also present. The average size of the light-separate is 0.6 mm.

M.J.D. # 1-7 Light green tuff 7 feet above M.J.D. # 1-6. In situ this bed is a massive, compact, fine-grained, light green (Ridgeway 30 $^{4}$ d) tuff capped by a light buff tuff bed 2 feet thick. This cap bed forms a small but persistent terrace. The underlying light green tuff grades imperceptibly into the buff cap bed. Under the microscope the green tuff is seen to be poorly cemented and highly impregnated by the green iron compounds while the cap bed is highly impregnated with calcite and shows a slight impregnation of green material. Magnetite and augite make up the bulk of the heavy-minerals accompanied by minor amounts of hornblende and massive hematite. The heavy-minerals range in size from 0.1 to 0.2 mm. The light-separate consists mostly of devitrified glass shards and pumice, fine ash, and some accidental particles of basalt. Crystalline material is scarce in this bed and consists mostly of andesine. These andesine particles are either clear or coated with a thin film of kaolin. The glass shards are well preserved and show delicate cuspate and spherical forms. These light-minerals range in size from 0.1 to 0.6 mm.

M.J.D. # 1-8 Green tuff 5 feet above M.J.D. # 1-7. In the outcrop this bed forms an extensive terrace which contains random concretions that are light brown and highly calcareous. The rest of this bed is composed of fine-grained, massive, green (Ridgeway 30 $^{4}$ d) tuff. Under the microscope the tuff appears well indurated by calcite and impregnated by green iron compounds. The heavy-minerals consist of magnetite, augite, hornblende, biotite, hematite, and collophane. Augite and magnetite make up the bulk of the heavy-minerals. Biotite and hornblende are present only in minor amounts. The phosphate, collophane, makes up about 3% of the heavy residue. The collophane is massive, honey-yellow and shows relict bone structures under the high-power objective. The light-fraction consists of devitrified pumice and glass shards, andesine, and some secondary quartz. The average size of the heavy-minerals is 0.2 mm. and of the light-minerals 0.5 mm.

M.J.D. # 2-1 Light green to buff-green tuff 3 feet above M.J.D. # 1-8. In the outcrop this bed forms a small extensive terrace. The base of the bed is a light green which grades to a buff-green at the top (Ridgeway 33 $_4$ f to 34 $_5$ d). The tuff is fine-grained, massive rock which is cut by a well defined set of rhombic joints that are normal to the plane of bedding. Under the microscope the matrix shows fairly high induration by calcite and the green iron-bearing compounds. The heavy-fraction consists of augite, magnetite, hornblende, and hematite. Augite and magnetite make up 90% of the heavies and augite is in excess of the magnetite. The average size of the heavy-minerals is 0.1 mm. The light-fraction consists of devitrified glass shards and pumice, andesine, accidental particles of basalt and quartzite. The devitrified glass shards accompanied by lesser amounts of pumice and crystalline material are the most abundant particles in the tuff. The glass shards have an index of refraction close to 1.48 and show aggregate polarization. This secondary crystalline material has been determined to be tridymite. The andesine grains are both euhedral and sub-hedral and generally show alteration to kaolin. The size range of the light-separate is from 0.5 to 0.7 mm.

M.J.D. # 2-2 Light buff-green tuff 27 feet above M.J.D. # 2-1. This bed is 27 feet thick, one of the thickest beds in the middle member. The color is dark green at the base but grades into a light buff-green near the top. The top of the bed is capped by a 2 foot resistant calcareous layer. In the hand specimen the tuff from this bed is uniformly fine-grained, massive rock. The color transition is slight and the average Ridgeway color is ($41\ ^3$ d). Interspersed in the cap bed are random calcareous concretions that form miniature hoodoos when the softer surrounding tuff is eroded away. The cap bed when inspected under the microscope shows extensive induration by calcite while the underlying material is poorly cemented and slakes easily in water. The heavy-separate consists of augite, magnetite, hornblende, apatite, hematite, collophane (trace), and accidental particles of basalt. Again magnetite and augite are the dominant heavy-minerals while the other minerals are present in minor amounts. The size range of the heavy-separate is from 0.1 to 0.3 mm. The light-separate consists of andesine, sanidine, devitrified glass shards and pumice, and accidental particles of scoriaceous basalt and quartzite. The andesine crystals carry numerous magnetite inclusions and generally appear fresh and clear. Sanidine is present in very minor amounts. The devitrified pumice and glass shards compose the bulk of the light material. The shards are delicately preserved as discrete spheroidal particles. The pumice fragments are highly impregnated by the green iron-bearing compounds which give them the appearance of chlorite fragments. The size range of the light-separate is from 0.3 to 1 mm.

M.J.D. # 2-3 Light green tuff 6 feet above M.J.D. # 2-2. This is a fine-grained, massive tuff which grades from green at the base to light green near the top. The top is again capped by a resistant calcareous layer that forms an extensive terrace. The transitions in color are so slight that the over-all color is light green (Ridgeway 30 $^{4}$ d). Microscopically the cap layer again shows a high concentration of secondary calcite while the underlying material is poorly cemented. The heavy-separate consists of augite, magnetite, hornblende, apatite, brookite, hematite, biotite, and accidental particles of basalt. Augite and magnetite are dominant. The augite in the lower portion of the bed shows well formed fresh crystals while in the cap bed the augite shows considerable decomposition. Brookite crystals are scarce but show fresh, euhedral forms. The size range of the heavy-minerals is from 0.1 to

0.5 mm. The augite and hornblende generally are the larger particles. The light-separate consists of andesine, devitrified glass shards and pumice, quartz, and accidental particles of basalt and quartzite. The shards are delicately preserved and show lunar, cuspate, and spherical forms. The pumice from the lower portion of the bed is slightly stained by the green iron-bearing compounds and practically white in the upper part of the bed. The andesine crystals are clear and unweathered and occasionally show numerous magnetite inclusions. The size range of the light-separate is from 0.3 to 0.6 mm. Generally the shards and pumice are larger than the crystalline fragments.

M.J.D. # 2-4 Light buff-green tuff 7 feet above M.J.D. # 2-3. The outcrop of this bed also has several gradual color transitions. The base is a light buff-green that grades into a light blue-green near the top and is capped by a light green calcareous layer. The cap bed also has random calcareous concretions. The tuff bed taken as a whole is a fine-grained, massive, light green (Ridgeway 30 $^4$ d) rock. Microscopically the cap layer shows the groundmass to be well cemented by calcium carbonate and the underlying material poorly cemented. Augite and magnetite make up 90% of the heavy-separate, accompanied by minor amounts of apatite, hornblende, brookite, hematite, and accidental rock particles. The advanced weathering of the augite is noted throughout the whole thickness of the bed.

Hornblende is noticeably more abundant than in any of the previous beds. The size range of the heavy-separate is from 0.1 to 0.5 mm. The light-separate consists of andesine, devitrified glass shards and pumice, quartz, and accidental particles of basalt. Well preserved shards are abundant in the cap layer whereas the shards in the lower portion of the bed have undergone considerable alteration. Pumice particles are scarce in all parts of the bed. The size range of the light-separate is from 0.3 to 0.6 mm.

M.J.D. # 2-5 Light blue-green tuff 10 feet above M.J.D. # 2-4. The outcrop of this bed presents a uniform coloration except for the calcareous cap layer which is slightly lighter in color. The rock is a fine-grained, massive, light blue-green (Ridgeway 41 3 d) tuff. Random concretions are also found in the cap layer. Again under the microscope the cap layer appears well indurated with calcite while the underlying tuff is poorly cemented. The heavy-separate consists of magnetite, augite, hornblende, hematite, and accidental particles of basalt. Augite and magnetite are dominant although there is a slight increase in hornblende. The augite crystals show little weathering except for an occasional cloudy surface. The size range for the heavy-separate is from 0.2 to 0.6 mm. The light-separate consists of andesine, devitrified glass shards and pumice, quartz, and accidental particles of quartzite. The shards and pumice make up the bulk of the light material.

The shards are well preserved and still retain their original pyroclastic forms. The size range of the light-separate is from 0.2 to 0.6 mm.

M.J.D. # 2-6 Light buff-green tuff 24 feet above M.J.D. # 2-5. The outcrop of this bed forms a very prominent terrace that can be traced for some distance in the area. The bed is capped by a resistant calcareous layer that carries random concretions. The rock is a fine-grained, massive, light buff-green (Ridgeway 30 4 d) tuff. Again microscopic examination of the cap layer and underlying material shows a highly indurated calcareous tuff in the cap layer and a poorly cemented tuff underlying it. The heavy-separate consists of augite, magnetite, apatite, hornblende, brookite, collophane, and ferruginous accidental particles. Augite and magnetite are dominant although 20% of the heavy-separate consists of accidental particles. The bulk of the augite crystals are fresh and clear although some crystals show weathering and pitting on the surface. Hornblende is almost completely lacking as it makes up only 0.5% of the heavy-separate. The size range of the accidental particles is from 0.3 to 0.6 mm. and for the other heavies from 0.1 to 0.5 mm.

The light-separate consists of devitrified glass shards and pumice, andesine, quartz, and accidental particles. The accidental particles and the vitroclastic material make up the bulk of the light-separate. The feldspars show little or no weathering and generally carry numerous inclusions of apatite and magnetite. Well preserved glass shards and pumice are generally absent from this bed as they appear to have been worn down or broken into small fragments. The size range of the light-separate is from 0.1 to 0.6 mm.

M.J.D. # 3-1 Light buff-green tuff 3 feet above M.J.D. # 2-6. This bed forms a small terrace which persists for only a few hundred feet from the point of sampling. The rock is a fine-grained, massive, light buff-green (Ridgeway 33 $^{4}$ f) tuff. Several random calcareous concretions are present in the middle portion of the bed. Microscopic examination of the tuff reveals a poorly cemented aggregate impregnated by the green iron-bearing compounds. The heavy-mineral fraction consists of magnetite, augite, hornblende, hematite, brookite, apatite, and accidental particles of basalt. The magnetite and augite make up 80% of the heavy-separate. Accidental basalt particles are next in abundance. The size range for the heavy-separate is from 0.05 to 0.6 mm. The light-fraction, for the most part, consists of devitrified glass shards and pumice accompanied by minor amounts of andesine, accidental rock particles, and secondary quartz. The andesine crystals show little or no weathering. The secondary green iron compounds completely impregnate the pumice fragments. The glass shards are highly fragmented in this bed and exhibit none of the delicate forms common in the underlying beds. Both basalt and quartzite accidental rock particles are present. The size of the light-fraction ranges from 0.3 to 0.7 mm.

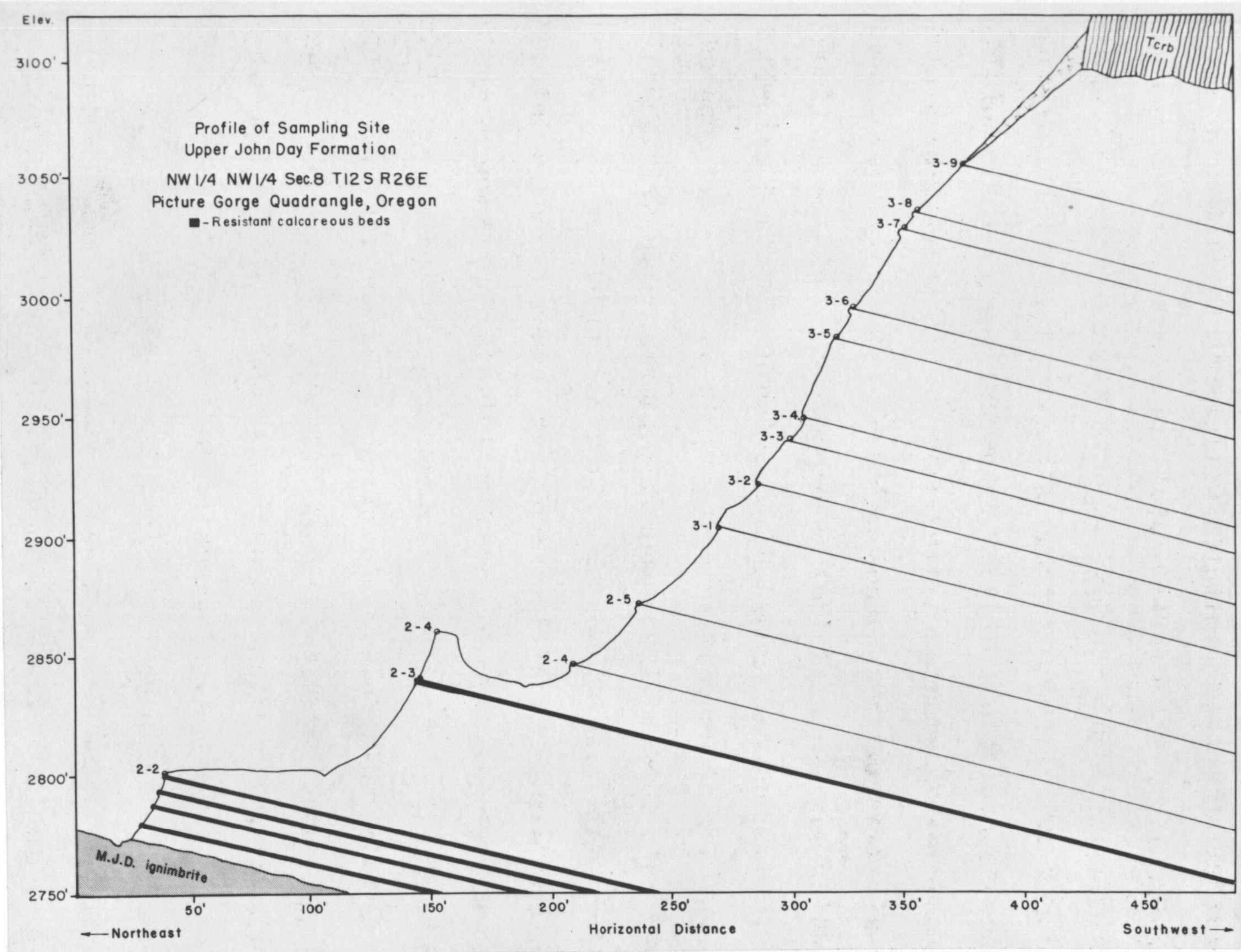
M.J.D. # 3-2 Light buff and green tuff 6 feet above M.J.D. # 3-1. This bed forms a slight terrace which is very persistent in the outcrops of Turtle Cove. The bottom portion of the bed is buff tuff that grades into green tuff in the middle portion which in turn grades upward into buff, concretionary band at the top. The bed as a whole is a fine-grained, massive tuff that has a light buff to light green coloration (Ridgeway 25 $^{4}$ d and 25 $^{3}$ i). Microscopic inspection reveals a poorly cemented tuff in the middle and lower portions and a highly indurated layer at the top. The heavy-separate consists of magnetite, augite, biotite, brookite, hornblende, hematite, collophane, and accidental particles of basalt. Augite and magnetite are dominant. Biotite amounts to 15% of the heavy-separate of this bed. The biotite shows no weathering or alteration and usually occurs as well developed euhedral pseudohexagonal plates. The size range of the heavy-separate is from 0.1 to 0.7 mm. The light-separate consists of andesine, sanidine, quartz, devitrified glass shards and pumice, and accidental particles of scoriaceous basalt and quartzite. The devitrified pumice and glass shards make up the bulk of the light-separate. The pumice from the top and lowest portions of the bed is white and unstained while the pumice from the middle portion is well impregnated by green iron-bearing compounds. The accidental particles are particularly abundant in this bed and consist, for the most part, of vesicular red basalt particles. The size range of the light-separate is from 0.3 to 1.2 mm.

M.J.D. # 3-3 Light green tuff 24 feet above M.J.D. # 3-2. This bed forms a thick section of tuff in the middle member but it is not characteristic in that it is not capped by a resistant calcareous layer. The rock is a massive, fine-grained, light green (Ridgeway 30 $^4$ d) tuff. Microscopic examination of the tuff shows a poorly cemented aggregate and a noticeable increase in the size of the individual particles. The heavy-separate consists of magnetite, augite, hornblende, hematite, apatite, rutile, and accidental rock particles. Augite and magnetite again are dominant with a slight increase in secondary hematite. Rutile is present as small blue, anhedral fragments which show distinct dichroism from blue to white. The accidental particles are basalt and a massive ferruginous rock. The range in size of the heavy-separate is from 0.1 to 0.7 mm. The light-separate consists of andesine, quartz, devitrified glass shards and pumice, and accidental particles of basalt and quartzite. The average size of the pumice particles is from 0.5 to 1.5 mm, a definite increase over any of the previous samples. The glass shards are distinctive in that most of the particles still retain their original discrete spherical shapes and attain sizes ranging from 0.6 to 0.7 mm. The size range of the light-separate is 0.3 to 1.5 mm.

M.J.D. # 3-4 Green tuff 27 feet above M.J.D. # 3-3. In the hand specimen this is a fine-grained, massive, green (Ridgeway 30 $^3$ d) tuff. The bed has several random calcareous concretions throughout its thickness but lacks a calcareous cap layer. Microscopic examination of the tuff indicates that the green iron-bearing compounds have affected a well indurated tuff. The heavy-separate consists of magnetite, augite, hornblende, apatite, zircon, hematite, and accidental rock particles. Augite and magnetite again are dominant. The crystals of zircon are the first recorded in this study of the middle member. The other heavy-minerals are present in their usual form. The size range of the heavy-separate is from 0.1 to 0.3 mm. The light-separate consists of andesine, devitrified pumice and glass shards, secondary hematite, and accidental particles of basalt and quartzite. Crystalline material in the light-separate is scarce in this bed. The pumice fragments are well impregnated by the green iron compounds and the glass shards show extreme fragmentation. The light-separate ranges in size from 0.1 to 0.6 mm.

M.J.D. # 3-5 Light buff-green tuff 33 feet above M.J.D. # 3-4. This bed is the cap bed of the Middle John

Day exposure at Turtle Cove. The bed at the point of sampling is not overlain by any other material, but 200 yards to the west the bed is overlain conformably by the welded-tuff flow of the middle member. The bed is a fine-grained, massive, light buff-green (Ridgeway 29 $^4$ d) tuff. The top portion of the bed is capped by a thin resistant calcareous layer which contains numerous random calcareous concretions. The microscopic examination of the tuff reveals a poorly cemented aggregate except for the cap layer which is impregnated with both calcite and green iron compounds. The heavy-separate consists of magnetite, augite, hornblende, zircon, hematite, and accidental particles of basalt. The augite and magnetite are dominant. Some augite particles show advanced weathering while the hornblende and other crystalline material appears comparatively fresh and unaltered. The heavy-separate particles range in size from 0.1 to 0.3 mm. and some accidental particles of basalt range up to 0.5 mm. The light-separate consists of andesine, devitrified pumice and glass shards, quartz, and accidental particles of basalt and quartzite. The anhedral quartz fragments have a thin film of iron oxide stain on the surface. The andesine crystals appear to have undergone very little weathering or alteration. The well preserved pumice fragments are generally well impregnated by the green iron-bearing compounds. The light-fraction ranges in size from 0.2 to 0.7 mm.



Elev.
3100'
3050'
3000'
2950'
2900'
2850'
2800'
2750'
Profile of Sampling Site
Upper John Day Formation
NW 1/4 NW 1/4 Sec. 8 T12S R26E
Picture Gorge Quadrangle, Oregon
■ - Resistant calcareous beds
Tcrb
3-9
3-8
3-7
3-6
3-5
3-4
3-3
3-2
3-1
2-5
2-4
2-4
2-3
2-2
M.J.D. ignimbrite
50'
100'
150'
200'
250'
300'
350'
400'
450'
← Northeast
Horizontal Distance
Southwest →


PLATE IV

<u>Upper John Day Specimens from Sheep Rock</u>. The upper member sampling profile was taken on the north face of Sheep Rock in the N.W. 1/4 N.W. 1/4 Sec. 8, T. 12 S., R. 26 E. The exact location and stratigraphic position of each sample is shown on Plate IV. The sampling does not continue to the Columbia River Basalt-John Day tuff contact because of the overlying talus slope. Sampling was continued on the south face of Sheep Rock and is also described.

U.J.D. # 2-2 Basal bed of the Upper John Day tuffs. This bed rests conformably upon the ignimbrite and at the base of the bed there is a large amount of reworked coarse ignimbrite material. The rock is a medium-grained, massive, buff-green (Ridgeway 25 $^{4}$ b) tuff. Intercalated within the tuff are several calcareous beds which have concretions similar to the concretions of the Middle John Day tuffs. Under the microscope most of the tuff appears poorly cemented but that from the calcareous beds is highly impregnated by secondary calcite. The heavy-separate consists of augite, magnetite, hornblende, hematite, brookite, and accidental rock particles. Small amounts of zircon, apatite, and rutile are present in the bottom portion of the bed. The magnetite and augite are dominant. Generally the crystalline material is fresh and clear and shows little or no weathering. The size range of the heavy particles is from 0.1 to 0.5 mm. The light-separate consists mostly of devitrified pumice and comminuted ash accompanied by minor amounts of andesine, quartz, and accidental rock particles. The andesine is clear and sub-hedral and carries abundant magnetite and apatite inclusions. Quartz is present in very minor amounts as only a few grains were identified. The accidental rock particles consist of red, scoriaceous basalt and bluish quartzitic material. The size range of the light particles is from 0.2 to 1 mm.

U.J.D. # 2-3 Green tuff 64 feet above U.J.D. # 2-2. This bed is one of the thickest units in the upper member. The outcrop of the bed presents a massive, mud-washed slope of very uniform tuff capped by a resistant calcareous bed. The rock is a fine-grained, green (Ridgeway 30 $^4$ d) tuff. Inspection under the microscope reveals the tuff to be highly impregnated with green iron-bearing compounds and very little calcite except in the cap layer. The heavy-separate consists of augite, magnetite, hornblende, brookite, hematite, and a few accidental rock particles. The augite and magnetite are dominant and the other minerals are present in minor amounts. Brookite is more abundant in this bed than in the preceding bed. The accidental rock particles appear to be basalt and limonitic quartzite. The size range of the heavy particles is from 0.05 to 0.5 mm. The light-separate consists of andesine, quartz, and devitrified pumice. Pumice and finer ash compose the bulk of the light-separate and also the bulk of the entire tuff. Generally this bed is highly impregnated by the green iron-bearing compounds as is especially noticeable in the pumice fragments. The small amount of quartz present is stained on the surface by a thin film of red iron oxide. The andesine crystals are clear and show little or no weathering. Red scoriaceous basalt and limonitic quartzite are present as accidental rock particles. The size range of the light-separate is from 0.3 to 0.8 mm.

U.J.D. # 2-4 Light buff tuff 21 feet above U.J.D. # 2-3. This bed represents the dividing line in the John Day formation where the dominant green color typical of the middle member changes to light buff which is typical of the upper member. This bed forms a prominent terrace as can be seen on the profile in Plate IV. The terrace is due to a highly indurated layer capping this bed although the cementing material here appears to be finely disseminated secondary silica instead of calcite. The rock is a fine-grained, massive, light buff (Ridgeway 21 $^{3}$ d) tuff. In the thin section this tuff shows aggregate polarization of the groundmass which indicates that all of the glassy material is devitrified. The heavy-separate consists of augite, magnetite, hornblende, apatite, rutile, brookite, collophane, hematite, and accidental particles of rock. All of the crystals are fresh and show no evidence of weathering. Rutile is present as anhedral, blue fragments and amounts to about 1% of the heavy-separate which is about 0.001% of the total sample. The size range of the heavy-separate is from 0.05 to 0.4 mm. The light-separate consists of andesine, devitrified pumice, and accidental particles of basalt and quartzite. Noticeable in this bed is the scarcity of original crystalline material as compared to crystalline material present in previous samples studied. The devitrified pumice and fine ash make up the bulk of the rock. The size range of the light-separate is from 0.05 to 0.7 mm.

U.J.D. # 2-5 Light buff tuff 21 feet above U.J.D. # 2-4. This bed is composed of fairly soft material although its limits are apparent as it has a characteristic resistant cap bed. The rock is a medium-grained, massive, light buff (Ridgeway 21 $^{3}$ e) tuff. The heavy-separate consists of augite, magnetite, hornblende, brookite, apatite, zircon, hematite, and accidental rock particles. Magnetite and augite are the most abundant heavy-minerals. Zircon is common in the lower portion of the bed while in the upper portion it is not present. The zircon crystals are pink, euhedral particles about 0.05 mm. long. The size range of the particles in the heavy-separate is from 0.1 to 0.4 mm. The light-separate of this bed consists of andesine, devitrified pumice and glass pellets, quartz, and accidental rock particles. The devitrified vitroclastic material in this bed has two distinct forms, (1) pumice which is generally white and considerable larger than the crystalline material; (2) and spherical shaped, white pellets which usually are almost round or similar to tear drops. These pellets represent original gas bubbles surrounded by glass which were thrown from the parent volcano. Since deposition they have been devitrified possibly to tridymite. The accidental rock particles are more abundant in the middle of the bed and appear to represent three distinct rock types: basalt, quartzite, and a vitrophyre which may be from the parent magma and hence possibly accessory. The size range of the light-separate is extreme. The devitrified pumice and pellets are the largest, ranging from 1.5 to 0.5 mm., while the other material ranges from 0.2 to 0.6 mm.

U.J.D. # 3-1 Buff tuff 40 feet above U.J.D. # 2-5. This bed is a soft, massive material that forms mud covered slopes. The rock is fine-grained, soft, buff (Ridgeway 19 $^3$ c) tuff. The heavy-separate consists of augite, magnetite, brookite, hornblende, apatite, hematite, and accidental particles of basalt. The dominant heavy-minerals are augite and magnetite. Generally the crystalline material is fresh and shows little alteration by weathering. The rock particles in this particular bed appear highly fused and carry inclusions of the intratelluric crystals, and indicate the possibility that the particles may belong to the parent magma. The size range of the heavy-separate is from 0.1 to 0.5 mm. The light-separate consists of andesine, devitrified pumice and glass shards, and accidental rock particles. The pumice is generally scarce and the glass shards make up the bulk of the light-separate. The form of the shards is cuspate or lunar as compared to the unbroken pellets in the previous sample. Numerous masses of agglutinated fine ash also were noted in this bed. The accidental rock particles are red scoriaceous basalt and quartzite. The andesine is fresh and clear and carries inclusions of apatite and magnetite. The size range of the light-separate is from 0.2 to 0.8 mm.

U.J.D. # 3-2 Grey-buff tuff 21 feet above U.J.D. # 3-1. This bed is a massive tuff which shows induration near the bottom and grades upward into soft material near the top. The lower indurated part of the layer forms a slight terrace. The rock is a fine-grained, compact, grey-buff (Ridgeway 21 $^{3}$ c) tuff. The heavy-separate consists mostly of augite and magnetite associated with minor amounts of apatite, hornblende, hematite, and accidental rock particles. The augite and hornblende are fresh and show no indication of weathering. The rock particles are more abundant in this bed than in the preceding beds and represent several types including red scoriaceous basalt, a glassy material similar to a vitrophyre, and limonitic quartzite. The size range of the particles in the heavy-separate is from 0.2 to 0.5 mm. The light-separate is composed almost entirely of devitrified ash, pumice, and glass shards. The crystalline material present is almost exclusively andesine except for several fragments of quartz. The andesine is water-clear and bears numerous inclusions of apatite and magnetite, while the quartz is generally iron stained. Accidental particles of basalt and quartzite are also present in the light-separate. The basalt in the light-separate is usually more scoriaceous than the basalt in the heavy-fraction and the quartzite has less disseminated limonite than the quartzite in the heavy-fraction. The size range of the light particles is 0.2 to 0.9 mm.

U.J.D. # 3-3 Buff tuff 21 feet above U.J.D. # 3-2. This bed forms a rather thick terrace as the whole thickness of the bed is fairly well indurated. The rock is a fine-grained, compact, buff (Ridgeway 21 $^3$ e) tuff. Inspection with the hand lens reveals small irregular patches of secondary black hematite which in part is responsible for the hardness of the bed. Under the microscope the tuff shows no evidence of induration by calcite or other material although the groundmass shows weak aggregate polarization which suggests secondary silica as the cement. The heavy-separate consists of magnetite, augite, brookite, hornblende, collophane, secondary hematite, and accidental particles of basalt. The augite in this bed shows some alteration to chlorite on the surface of the fragments although most of the fragments are fresh and clear. The magnetite is unweathered and indicates that the large amount of secondary hematite is not due to the alteration of the magnetite but to the alteration of the finer iron-bearing minerals. The size range of the heavy particles is from 0.1 to 0.4 mm. The light-separate is peculiar in that devitrified pumice and glass shard fragments are almost non-existent in this bed. Instead the mass of the rock is composed of fine ash which is highly agglutinated. The minor parts of the light-separate consist of clear, euhedral andesine crystals and accidental particles of scoriaceous basalt. The size of the light particles ranges from 0.2 to 0.6 mm.

U.J.D. # 3-4 Light buff tuff 12 feet above U.J.D. # 3-3. This is a relatively thin bed of fine-grained, soft, light buff (Ridgeway 21 $^2$ f) tuff. The heavy-separate consists of augite, magnetite, biotite, brookite, hornblende, secondary hematite, and accidental rock particles. The augite and magnetite are again dominant although the accidental rock particles account for almost 30% of the total heavy-separate. The rock particles are scoriaceous basalt and a glassy rock highly impregnated with finely disseminated magnetite. The appearance of the biotite in this bed is the first noted in the upper member. The biotite particles are both euhedral and anhedral, usually as thin pseudohexagonal plates. The augite crystals in this bed are particularly well formed as many of the crystals show perfect form and present all the common faces.

The size range of the heavy particles is from 0.1 to 1 mm. This is exceptionally high as compared to the size range of heavy particles in other beds described. The light-separate again shows a dearth of devitrified pumice and glass shards but instead is composed of finely comminuted and agglutinated ash particles. Andesine is present in minor amounts and shows in some crystals relatively advanced kaolinization as compared to that of the andesine from the other beds. The accidental rock particles present are the same as in the heavy-separate although the basalt is generally more scoriaceous than the basalt in the heavy-fraction. The size range of the light-separate is from 0.2 to 1 mm.

U.J.D. # 3-5 Light buff tuff 35 feet above U.J.D. # 3-4. The outcrop of this bed forms a thick resistant terrace and is uniformly indurated throughout the thickness of the bed. The rock is a fine-grained, massive, hard, light buff (Ridgeway 21 $^{3}$ e) tuff. Inspection of the heavy-separate shows that more than half of the material is lithic. These rock particles are light grey, irregular and have a large amount of finely disseminated magnetite in a groundmass of devitrified glass. Numerous particles of scoriaceous basalt are also present. The other heavy-minerals include augite, magnetite, brookite, hornblende, and a trace of apatite. These minerals appear in the same form and condition as described previously. The light-separate consists of andesine, devitrified pumice, and accidental particles of rock. The andesine is characteristically clear and carries abundant inclusions. The pumice fragments are generally white and have undergone complete devitrification. The accidental lithic material is basalt and the same magnetite bearing rock found in the heavy-separate. The size range of the heavy particles is from 0.05 to 0.2 mm. and for the light particles 0.3 to 0.5 mm.

U.J.D. # 3-6 Light green and white tuff 13 feet above U.J.D. # 3-5. This is a distinctive bed in the upper member in that the bottom portion is light green and grades up to a white indurated cap bed. The bottom and middle portion is composed of fine-grained, soft, light green (Ridgeway 30 $^{4}$ d) tuff and the cap bed is a fine-grained, highly indurated, white (Ridgeway 21 $^{2}$ f) tuff. The white cap bed is highly indurated by calcium carbonate although calcareous concretions are not present. The heavy-separate varies from top to the bottom of this bed. The dominant minerals in the lower portion are magnetite and augite while the dominant minerals in the cap bed are biotite and hornblende. The accompanying minor minerals of the whole bed are similar and include apatite, brookite, and hematite. Accidental rock particles are particularly lacking in most of the bed although scoriaceous basalt particles were noted. The size range of the heavy particles is extreme as the biotite and hornblende found in the cap bed range from 0.5 to 1.5 mm. while the other material in the bed ranges from 0.1 to 0.4 mm. The light-separate includes andesine, devitrified pumice and glass shards, and accidental rock particles. Generally the andesine is clear and unweathered although in the middle of the bed cloudy kaolinized surfaces are noted on the andesine. The pumice in the lower portion of the bed is highly impregnated with green iron-bearing compounds while the pumice from the cap bed is white. The accidental rock fragments include basalt and quartzite. The size range of the light particles is from 0.1 to 0.9 mm.

U.J.D. # 3-7 Light buff and green tuff 39 feet above U.J.D. # 3-6. The outcrop of this bed is variegated in tones of buff and green. The middle portion of this bed is green (Ridgeway 30 $^4$ d) while the top and bottom is light buff (Ridgeway 21 $^3$ c). The top of the bed is capped by a thin calcareous layer. The rock as a whole is a fine-grained, compact, variegated tuff. In thin section the tuff shows a groundmass composed of comminuted ashy material with larger grains of pumice and feldspar. The finely disseminated limonite gives part of the bed a brownish cast while ferro-ferric compounds give the middle portion a greenish cast. The heavy-separate consists of augite, magnetite, hornblende, biotite, brookite, and accidental particles of rock. The augite and magnetite are the dominant heavy-minerals although the accidental rock particles compose 30% of the heavy-separate. The accidental rock particles are composed of magnetite bearing devitrified vitrophyre and scoriaceous basalt. The size range of the heavy particles is from 0.05 to 0.4 mm. The light-separate consists of andesine, devitrified pumice and glass shards, and accidental rock particles. The pumice and glass shards in the lower and upper portions of the bed are white while in the middle portion this material is deeply stained by the green ferro-ferric compounds. The andesine crystals are generally water-clear although some fragments show a cloudy surface of kaolin. The rock particles are the same type of rock as found in the heavy-separate except that the basalt is more scoriaceous. The size range of the light particles is from 0.2 to 0.7 mm.

U.J.D. # 3-8 Buff tuff 8 feet above U.J.D. # 3-7. This bed is a thin layer of soft tuff capped by a resistant bed which forms a slight terrace. The rock is a fine-grained, compact, buff (Ridgeway 25 4 e) tuff. In the thin section typical vitroclastic forms can be seen and noticeable is the incomplete devitrification of some of the glassy shards. The groundmass is composed again of comminuted ash which is slightly stained by disseminated limonite. The heavy-separate consists of augite, magnetite, brookite, hornblende, secondary hematite, collophane, and accidental rock particles. The heavy-minerals again are dominated by augite and magnetite. Minute bone particles composed of collophane are present and indicate by their shape that there may be small fossil mammals yet unidentified in the John Day formation. The accidental lithic particles are composed of the previously mentioned magnetite bearing devitrified vitrophyre and basalt. The light-separate consists mostly of small particles of partially devitrified pumice and glass shards accompanied by minor amounts of clear, sub-hedral crystals of andesine. The lithic particles are the same as the above mentioned accidental rock in the heavy-separate. The size range of the heavy particles is from 0.1 to 0.3 mm. and for the light particles is from 0.1 to 0.6 mm.

U.J.D. # 3-9 Buff tuff 24 feet above U.J.D. # 3-8. This bed is the last bed sampled on the continuous profile at Sheep Rock as talus accumulations prohibited any further sampling at higher levels. The top bed is seen on the south side of Sheep Rock. The outcrop of this bed (# 3-9) forms mud covered slopes and is capped by a thin indurated layer. This rock is a fine-grained, soft, buff (Ridgeway 21 $^{3}$ c) tuff. The heavy-separate of this bed is peculiar in that the material near the top produces nearly 30% hornblende. The other heavy material in this bed consists of augite, magnetite, apatite, brookite, biotite, secondary hematite, and accidental lithic particles. These minerals are present in their normal forms as compared to the heavy-minerals of the other beds except that the accidental rock particles are still abundant and include magnetite-bearing devitrified vitrophyre and xcoriaceous basalt. The size range of the heavy particles is from 0.1 to 0.6 mm. The light-separate includes andesine, devitrified pumice and glass shards, quartz, and accidental lithic fragments. The andesine is generally clear and unaltered while some of the pumice and glass fragments show alteration to clay minerals. The quartz is present in very limited amounts. The rock particles include scoriaceous basalt and some vitrophyre mentioned in the heavy-separate. The size range of the light particles is from 0.1 to 0.7 mm.

U.J.D. # 3-10 Top bed of the upper member, sampled on the south side of Sheep Rock. The talus slopes on the north side of Sheep Rock necessitated the termination of sampling on that face. Hence the rock samples taken for the last bed on the south side of Sheep Rock are not shown on the profile in Plate IV. This bed is approximately 55 feet thick and generally has a uniform appearance throughout its thickness. Above this bed the Columbia River Basalts rest unconformably on the tuff and have baked the tuffs a peculiar dark purple. The altered zone of the tuff extends about 6 inches to a foot below the contact. Elsewhere in the area at the contact of the basalts and tuffs the contact zone is baked a brick red. Close inspection of the tuff reveals that there is some manganese oxide present. The presence of carbonized wood and other organic material at the contact on Sheep Rock indicates that at the time the first flow of basalt poured out over this area there may have been a local accumulation of damp humus from plants or possibly a small swampy area. This environment may have produced enough manganese compounds to give the tuff its peculiar purple coloration at the contact zone. The hot lavas emplaced on this area possibly oxidized the manganese compounds present in the tuff and gave the tuff its peculiar purple cast. The absence of pillow structure in the basalt indicates that this area was not highly saturated with water.

The rock of the top bed is a medium-grained, compact, buff (Ridgeway 21 $^3$ c) tuff. A thin section shows the rock to be composed of comminuted ash and larger particles of pumice and glass shards. The pumice and glass shards below the top contact zone show complete devitrification while the glassy material in the contact zone has reverted to its original glassy state through the baking action of the Columbia River Basalts. Noticeable throughout the groundmass are numerous phenocrysts of andesine, augite, magnetite, and hornblende. The andesine is fresh and shows little decomposition as do the other mentioned minerals. The pumice particles are considerably larger than those found in the other beds composing the upper member. They range in size from 0.5 to 1 mm. The size range of the other minerals in the bed is from 0.2 to 0.6 mm.

# APPENDIX II

## Description of the Lower John Day Vertebrate Material

During the investigation of the Picture Gorge quadrangle additional fossil vertebrate material was found in the Lower John Day formation. The fossil beds are located in the S.E. 1/4 S.W. 1/4 of Sec. 30, R. 26 E., T. 11 S., 700 feet southeast of the junction of Deer Gulch and the John Day River on the south bank of Deer Gulch. Directly west from the fossil beds across the John Day River is the Humphrey Ranch. The Lower John Day beds at this point dip to the southwest and form a small cuesta which is faulted on the south and northeast sides. The stratigraphic position of the beds is obscured at this exposure but similar beds outcropping across the John Day River in the N.W. 1/4 N.W. 1/4 of Sec. 31, R. 26 E., T. 11 S., are underlain by the typical red beds of the Lower John Day formation. This stratigraphic relationship indicates that the fossil material belongs within the Lower John Day member.

The fossil material occurs in a yellow-buff tuff that is overlain by a thin flow of olivine-basalt that is succeeded by another bed of tuff and another thin flow of olivine-basalt. The fossil mammalian material consists of several vertebrae, ribs, and a right mandibular ramus. Associated with the vertebrate material are fossil plant remains which have been referred to the Bridge Creek Flora.

The following description and discussion pertains to the ramus as it is the only bone identified.

Class *Mammalia*
Order *Artiodactyla*
Suborder *Suina*
Family *Entelodontidae*
Genus *Archaeotherium* sp. undt. Leidy

Type - Right mandibular ramus terminated at $M_{\overline{3}}$ including $C_{\overline{1}}$ and $P_{\overline{3}}$.

Horizon - Lower John Day formation.

Locality - Humphrey Ranch, Picture Gorge quadrangle, Oreg.

The incisors are completely missing. The canine tooth is long and recurved with a rather sharp termination which shows little wear (Fig. 38). The alveolus of $P_{\overline{1}}$ indicates a fused double root process at the gum line, although the roots may diverge below the gum line. $C_{\overline{1}}$ and $P_{\overline{1}}$ are separated by a diastema which measures 13 mm. The diastema separating $P_{\overline{1}}$ and $P_{\overline{2}}$ measures 12 mm. The alveolus of $P_{\overline{2}}$ shows a double root process at the gum line. $P_{\overline{2}}$ is separated from $P_{\overline{3}}$ by a diastema which measures 19 mm. $P_{\overline{3}}$ is the only tooth remaining in the molar and premolar series (Fig. 38). The state of preservation is rather poor in $P_{\overline{3}}$ ; although some details can be worked out. The general form of $P_{\overline{3}}$ is a compressed and thick crown, terminated by a rather sharp cone which shows no wear. The basal extremity exhibits a double root process. The base of the tooth is surrounded by a slight cingulum and is without accessory cusps of any kind. $P_{\overline{4}}$ is closely spaced to $P_{\overline{3}}$ and is represented only by its alveolus border which presents a double root process as do the other three premolars. The three molars are indicated only by their alveoli borders; each molar having two thick root processes (Fig. 37). The complete dental formula for the inferior dentition is $I_{\overline{?}}\ C_{\overline{1}}\ P_{\overline{4}}\ M_{\overline{3}}$.

The mandible is quite elongate with the ratio of length to width 4 to 1. A rather large ridge or shelf is developed along the inner side of the mandible about 16 mm. above the inferior margin. The shelf runs from $P_{\overline{3}}$ to $M_{\overline{1}}$ where it extends upward and forms a rugose knob at this position. The shelf extends posteriorly from $M_{\overline{1}}$, but continues at a higher level and disappears at $M_{\overline{3}}$. A mental tubercle is given off beneath $P_{\overline{3}}$ along the ventral border. On this specimen the tubercle was broken off, but by reconstruction it appears to be rather large and to extend straight down from the ventral margin (Fig. 38). The mandible is straight except for this mental tubercle on the inferior margin.

The symphysis is quite long and very thick and massive, extending below the inferior margin of the mandible about 9 mm. The anterior-posterior length of the symphysis extends back as far as $P_{\overline{2}}$. The chin is truncated abruptly and appears flattened below, rising very steeply to the presumed margin of the incisors. A second mental tubercle, similar to but much heavier and more prominent than the posterior process already described, is found below the canine alveolus. This tubercle was also broken off quite close to the mandible, but by reconstruction some notion was obtained as to its form. Unlike the posterior process, which points downward, this process appears to point outward and downward and is much more rugose.

Measurements of the right mandibular ramus:

| | |
|---|---|
| Mandible, length........................... | 330 mm. |
| Length of P and M series................... | 320 mm. |
| Length of M series......................... | 272 mm. |
| Anterior-posterior diameter $C_{\overline{1}}$ ........... | 39 mm. |
| Transverse diameter $C_{\overline{1}}$ ................... | 29 mm. |
| Anterior-posterior diameter $P_{\overline{3}}$ ........... | 42 mm. |
| Transverse diameter $P_{\overline{3}}$ ................... | 23 mm. |
| Height $P_{\overline{3}}$ ................................ | 48 mm. |
| Depth of mandible at $M_{\overline{1}}$ .................. | 70 mm. |
| Depth of mandible at $P_{\overline{2}}$ .................. | 70 mm. |
| Greatest anterior-posterior length of symphysis................... | 107 mm. |

<u>Generic Position</u>. The exact determination of this specimen is restricted because of the lack of available material although a distinct generic identification is made possible by a comparison of the mental tubercles and teeth of the ramus. This specimen has all the more important

characteristics of the <u>Archaeotherium</u> genus.

In reviewing the Entelodonts which have been collected from the John Day formation, this specimen does not fit any of the described species. Altogether five species have been described from the John Day formation:

Boöchoerus humerosus Cope
Daeodon shoshonensis Cope
Daeodon calkinsi Sinclair
Choerodon (Daeodon) caninus Troxell
Elotherium imperator Leidy

Of these species <u>Boöcherus humerosus</u>, <u>Daeodon shoshonensis</u>, <u>Daeodon calkinsi</u>, and <u>Choerodon caninus</u> readily may be eliminated as they are dissimilar to this specimen. <u>Boöcherus humerosus</u> is twice as large as the specimen under consideration, the measurements of the mandible being almost twice as large as the Humphrey Ranch specimen. <u>Daeodon shoshonensis</u> and <u>Daeodon calkinsi</u> are peculiar in that they both lack anterior mental tubercles, whereas the Humphrey Ranch specimen has well developed anterior mental tubercles. <u>Choerodon caninus</u> is similar in many respects to this specimen but is widely different in the placement of the mental tubercles. Also the inferior premolars of <u>Choerodon caninus</u> have little or no diastema separating them as compared to the Humphrey Ranch specimen. <u>Elotherium imperator</u> is considered an inadequate type by Peterson (20, p.41-156) because of the lack of adequate material.

Troxell (26, p.361) states that the genus Archaeotherium is characterized usually by double rooted premolars, longer diastemae separating the premolars, and by its over-all smaller size as compared with the other Entelodonts. The Humphrey Ranch specimen shows distinct double roots for premolars 2, 3, and 4. $P_{\overline{1}}$ possibly has a double root process but the roots are fused together at the gum line. This specimen also has very distinct diastemae separating the premolar teeth. The distinct diastemae distinguishes Archaeotherium from Entelodont (Amyard).

Scott (23, p.276) gives further proof of the generic position of this specimen in his general description of Elotherium (Archaeotherium). His description of the premolar series fits very closely the premolar positions of the Humphrey Ranch specimen. Scott's description, in part, is as follows: "$P_{\overline{3}}$ and $P_{\overline{4}}$ stand quite close together, and $P_{\overline{1}}$ is separated by a short space from the canine, while $P_{\overline{2}}$ is isolated by a considerable diastema both in front and behind it." Also $P_{\overline{3}}$ in the Archaeotherium genus is much the highest of the series, almost reaching the height of the canine. In the Humphrey Ranch specimen, $P_{\overline{3}}$ is the only tooth left in the molar and premolar series, but its height is considerable and extends almost up to the height of the canine.

The mental tubercles of this specimen were broken close to the inferior border of the ramus, but by reconstruction they occur in the same relative position as those of _Elotherium_ (_Archaeotherium_) _ingens_ described by Scott. The apparent variation of these processes in specimens within the same species indicate that they are of rather doubtful value for placing a specimen in some special generic group on the basis of the mental tubercles alone. Their size and form are features which are of doubtful value as some authors think the variation is due to sex differences. The relative position of the mental tubercles on the mandible with reference to the teeth is an important generic factor and the presence or absence of the mental tubercles is also important.

The measurements of the mandible and the teeth given by Scott (23, p.287) for several individual specimens of _Elotherium_ (_Archaeotherium_) _ingens_ check within a reasonable percentage with the same measurements of the Humphrey Ranch specimen. Several morphological differences between _E. ingens_ and the Humphrey Ranch specimen prohibit putting it in this species, although the new material conforms to all of the generic characters of the _Archaeotherium_ genus.

Fig. 37 Archaeotherium sp. Lower dentition, crown view. x 0.33.

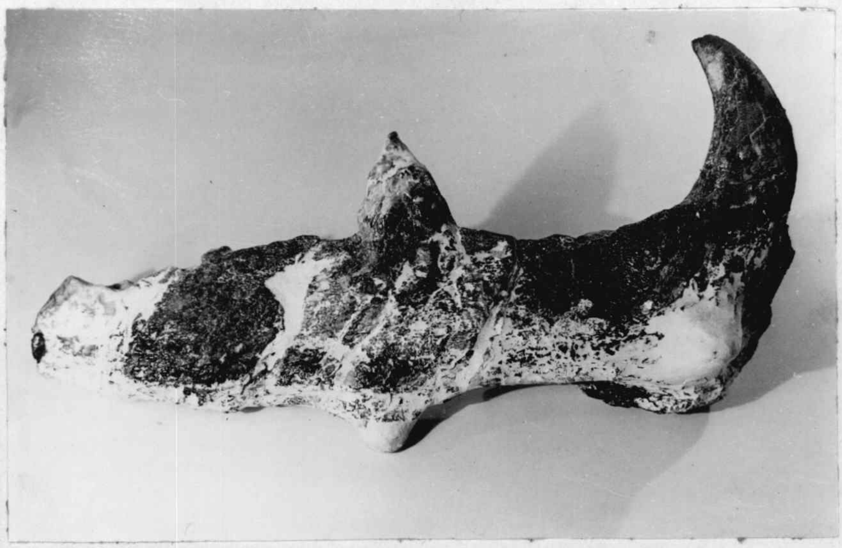


Fig. 38 Archaeotherium sp. Mandible, right side. x 0.33.

# APPENDIX III

## Middle and Upper John Day Faunal List

The following list is of the fossil vertebrate material collected from both the middle and upper members. The list is the same as presented by Merriam (18, p.184) with slight revision.

### CARNIVORA

#### Canidae

Paradaphaenus cusigerus (Cope)
Paradaphaenus, sp. indesc.
Nothocyon geismarianus (Cope)
Nothocyon geismarianus mollis Merriam
Nothocyon lemur (Cope)
Nothocyon latiders (Cope)
Temnocyon altigens Cope
Temnocyon wallovianus Cope
Temnocyon ferox Eyerman
Mesocyon coryhaeus (Cope)
Mesocyon josephi (Cope)
Mesocyon brachyops Merriam
Hyaenocyon basitatus Cope
Hyaenocyon sectorius Cope
Oligobunis crassivultus Cope
Enhydracyon stenocephalus Cope
Philotrox condoni Merriam
Cynodictis (?) oregonensis Merriam

#### Mustelidae

Parictis primaevus Scott

#### Felidae

Dinictis cyclops Cope
Archaelurus debilis Cope
Archaelurus debilis major Merriam
Nimravus gomphodus Cope
Nimravus confertus Cope
Pogonodon davisi Merriam

Pogonodon brachyops Cope
Pogonodon platycopis Cope
Holophoneus cerebralis Cope
Holophoneus strigidens Cope

## RODENTIA

### Sciuridae

Sciurus wortmani Cope
Sciurus ballovianus Cope

### Haplodontidae

Allomys (Meniscomys) hippodus Cope
Allomys (Meniscomys) liolophus Cope
Allomys (Meniscomys) Cavatus Cope
Allomys (Meniscomys) nitens Marsh
Mylagaulodon angulatus Cope

### Castoridae

Steneofiber gradatus Cope
Steneofiber peninsulatus Cope

### Geomyidae

Pleurolicus sulcifrons Cope
Pleurolicus leptophrys Cope
Pleurolicus diplophysus Cope
Entoptychus planifrons Cope
Entoptychus cavifrons Cope
Entoptychus minor Cope
Entoptychus lambdoideus Cope
Entoptychus crassiramis Cope
Entoptychus rostratus Sinclair
Entoptychus sperryi Sinclair

### Muridae

Peromyscus nematodon (Cope)
Peromyscus pravus Sinclair
Paciculus lockingtonianus Cope
Paciculus insolitus Cope

Leporidae

Lepus ennisianus Cope

PERISSODACTYLA

Equidae

Mesohippus praestans (Cope)
Mesohippus equiceps (Cope)
Mesohippus brachylophus (Cope)
Mesohippus longicristis (Cope)
Mesohippus condoni Leidy
Mesohippus anceps (Marsh)
Mesohippus annectens (Marsh)
Mesohippus acutidens Sinclair

Rhinocerotidae

Aceratherium pacificum Leidy
Aceratherium hesperium Leidy
Aceratherium truquianum Cope
Aceratherium tubifer Cope
Aceratherium annectens Marsh
Diceratherium armatum Marsh
Diceratherium nanum Marsh

Chalicotheridae

Moropus disrans Marsh
Moropus senex Marsh

ARTIODACTYLA

Entelodontidae

Daeodon shoshonensis Cope
Daeodon calkinsi Sinclair
Choerodon (Daeodon) caninus Troxell
Elotherium imperator Leidy

Suidae

Thinohyus (Bothrolabis) pristinus Leidy

Thinohyus (Bothrolabis) trichaenus Cope
Thinohyus (Bothrolabis) rostratus Cope
Thinohyus (Bothrolabis) subaequans Cope
Thinohyus (Bothrolabis) decedens Cope
Thinohyus (Bothrolabis) lentus Marsh
Thinohyus (Bothrolabis) socialis Marsh
Thinohyus (Bothrolabis) somonti Sinclair

Merycoidodonts

Agricochoerus trifrons Cope
Agricochoerus gugotianus Cope
Agricochoerus ryderanus Cope
Agricochoerus ferox (Cope)
Eporeodon occidentalis Marsh
Eporeodon occidentalis leptacanthus (Cope)
Eporeodon occidentalis pacificus (Cope)
Eporeodon trigonocephalus (Cope)
Eporeodon major longifrons (Cope)
Eporeodon socialis Marsh
Promerycochoerus superbus (Leidy)
Promerycochoerus macrostegus (Cope)
Promerycochoerus leidyi (Bettany)

Camelidae

Miolabis (Paratylopus) sternbergi (Cope)
Miolabis (Paratylopus) cameloides (Wortman)

Hypertragulidae

Hypertragulus calcartus (?) Cope
Allomeryx planiceps Sinclair

TESTUDINATA

Testudinidae

Stylemys oregonensis Leidy

SQUAMATA

Boidae

Ogmophis oregonensis Cope

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DEPARTMENT OF THE INTERIOR
U. S. GEOLOGICAL SURVEY

67-N-III AND S-I-PARTS OF

*Advance sheet*
*Subject to correction*

OREGON
PICTURE GORGE QUADRANGLE


(Dayville) 1:125000

Topography by W. B. Upton, Jr.,
Surveyed in 1925

TRUE NORTH
MAGNETIC NORTH
21°
APPROXIMATE MEAN DECLINATION, 1925

Scale $\frac{1}{48,000}$

1 ½ 0 1 2 3 4 Miles

5,000 0 5,000 10,000 15,000 Feet

1 ½ 0 1 2 3 4 Kilometers

Contour interval 50 feet
Datum is approximate mean sea level
based on Oregon State Highway elevations

Polyconic projection. North American datum
5000 yard grid based upon U. S. zone system, G

(Dayville) 1:125000

| | | | | |
|---|---|---|---|---|
| | 120° 45° | 66 | 119° 45° | |
| | I | N | II | |
| 52 | III | 67 | IV | 82 |
| | I | S | II | |
| | III | | IV | |
| | 120° 44° | 68 | 119° 44° | |

**PLATE VI**

PICTURE GORGE, OREGON

# GEOLOGICAL RECOINAISSANCE MAP

O

# PICTURE GORGE QUADRANGLE, OREGON

by

ROBERT G. OLEMAN

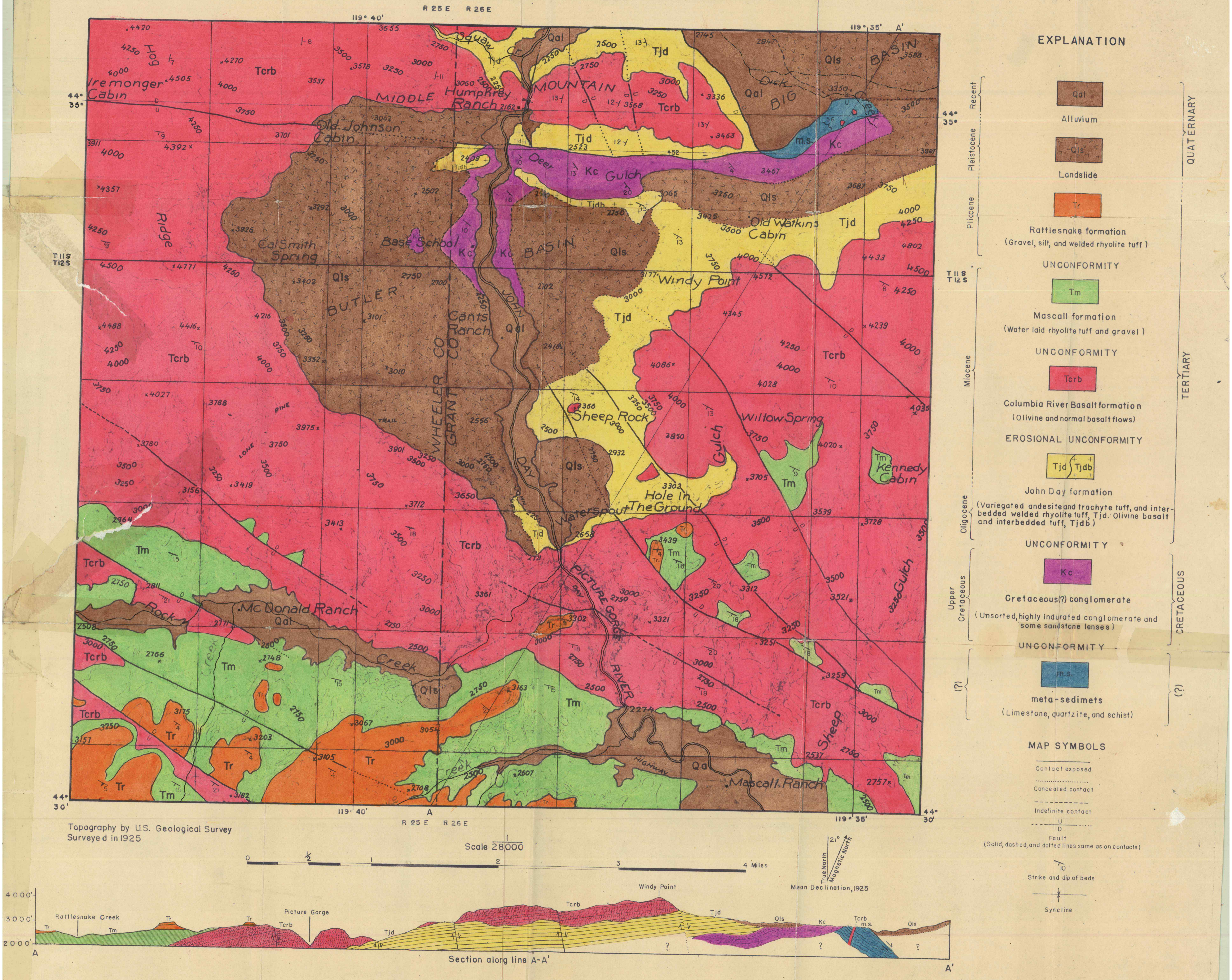


PLATE V