GEOLOGY OF THE SUPLEE AREA
DAYVILLE QUADRANGLE, OREGON

by

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A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1952

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Date thesis is presented June 8, 1951

Typed by Evelyn Davis

ACKNOWLEDGEMENTS

The writer is indebted to Dr. W. D. Wilkinson who suggested this work and whose subsequent field and laboratory assistance helped to make this geological problem a reality.

Sincere appreciation is tendered to Dr. I. S. Allison whose constructive criticism of the manuscript was of great aid. An expression of gratitude is directed to Dr. E. L. Packard whose experience in the area under consideration, as well as his paleontological interest, proved most helpful. A note of thanks to Mr. Harold Boyd for his timely and helpful efforts in reading of the manuscript.

I was most fortunate in having the company of Robert Nesbit while in the Suplee area and with whom discussions of the various problems assisted a successful and enjoyable completion of the field work.

I also wish to thank my father whose interest in the geology of the central Oregon country and editing of the manuscript proved very beneficial.

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GEOLOGY OF THE SUPLEE AREA, DAYVILLE QUADRANGLE, OREGON

INTRODUCTION

Location and Size

The area under consideration in this geological report lies south of the Blue Mountains on the headwaters of the South Fork of Crooked River, 75 miles east of Prineville, Oregon. It is entirely within Crook County between latitudes 44° 00' 00'' and 44° 10' 47'' North and between longitudes 119° 40' 20'' and 119° 50' 10'' West. The Crook-Grant County boundary parallels the eastern border and lies one mile to the east of the area. Wade Butte, Mud Spring Butte, Powell Mountain and Shaw Table are a few of the important geographic points. Streams traversing the area are South Fork Beaver Creek, Camp Creek and Trout Creek, which eventually find their way westward to Crooked River.

Several gravel secondary roads serve means of access, of which the Prineville-Canyon City road is most important. The distance from Prineville is 75 miles, and an eastern approach from Canyon City requires a trip of 60 miles over rough road. An alternate route from Burns, 60 miles to the southeast, over a Forest Service road, is available. A note of caution is advanced concerning travel during the wet season: these roads practically become impassable without use of chains or vehicles with four-wheel drive.

Approximately 100 square miles in areal extent, this area contains mappable units of upper Paleozoic, Mesozoic and Tertiary

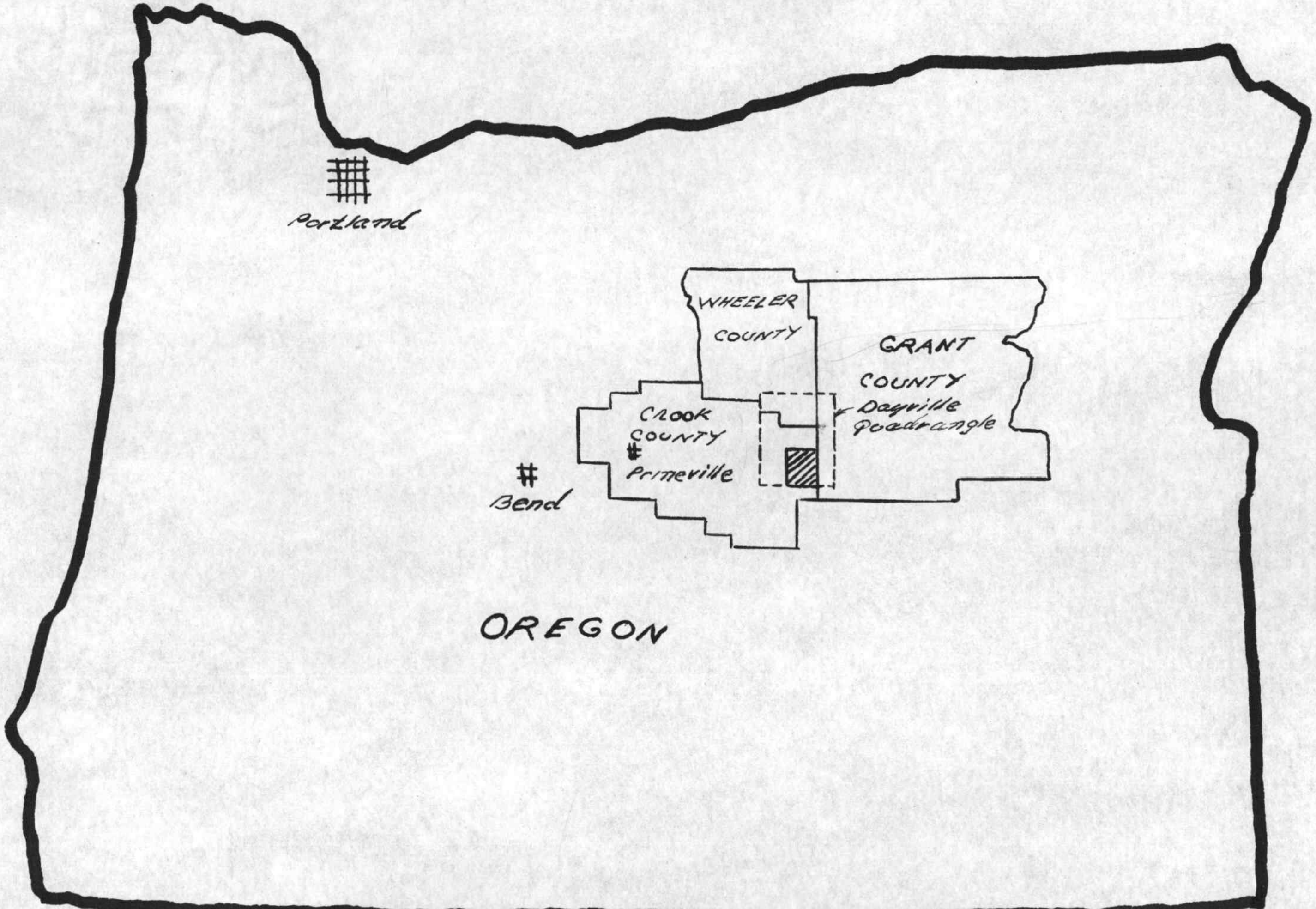


Plate I. Index map showing location of Suplee area, Oregon sediments and plutonic rocks, as well as Tertiary volcanics. Pre-Tertiary outcrops are exposed over 20 percent of the area and the remainder is composed of Tertiary rocks.

Purpose and Method of Investigation

Many years ago this area was found to contain one of the most complete geological columns in the state of Oregon. It is of primary interest, therefore, that the several formations be studied and accurately mapped with observation of the stratigraphy, lithology and structural relations, to provide additional information. After completion of the field work, it becomes possible to interpret the available facts and, consequently, partly to understand the various conditions and environments of deposition, sources from which sedimentary and volcanic material were derived, and to ascertain times of compressional and tensional stresses which produced folding and faulting. This work is largely of a scientific interest, but conceivably may lend itself to economic use such as petroleum or non-metallic exploration.

Field work consisted of mapping formational contacts and plotting them on a base map. Exception to this procedure was in the area of upper Paleozoic sediments where contacts were not readily recognizable because of lack or discontinuity of outcrops. A 30 minute U.S.G.S. map of the Dayville Quadrangle enlarged to approximately two inches to the mile with a contour interval of 100 feet was used as a base map. The survey for this map was made in 1930-32.

Aneroid and Brunton compasses were used to determine elevations and dip and strike of strata, respectively. Aerial photographs were not available during the early period of work, but were used after leaving the field.

Laboratory work entailed, mainly, the cutting and examination of thin sections and construction of geologic profiles. Because of their indurated nature the Upper Paleozoic and Mesozoic sediments subjected themselves conveniently to this thin sectioning. Textures and mineral content which could not have been determined in the field were identified. Several petrographically distinct intrusive igneous rocks, intruded during pre-Tertiary times, were recognized. Cenozoic extrusive igneous rocks and welded tuff were examined carefully under the petrographic microscope. Poorly indurated tuff samples obtained from the Shaw Formation were first impregnated with canadian balsam and later sectioned to determine structure and mineral content.

Paleontological research consisted mainly in identification and comparison with determinations made by earlier workers. Molluscan and brachiopod collections, representing pre-Tertiary faunules, were made and partly identified, as were fusulinids, radiolarians and some floral material. Several thin sections were made of fusulinid bearing limestones. A collection of bone fragments from the Shaw Formation was made and a partial generic identification established.

Previous Work

Geologic attention was first directed to the Suplee region in 1893 when A. Hyatt (7, p.401) reported that fossil invertebrates, received from Thomas Condon, were correlative with the fauna from the Hardgrave Sandstone of California and, hence, of Jurassic age. The invertebrates were actually seen as early as 1864 when Captain John M. Drake made a collection in the area and subsequently gave them to Condon (12, p.36). Drake's work was more of a reconnaissance nature and specimens were collected at random with little attention given to locality. In 1899, Chester Washburne (33, p.227) and Mr. John Platts discovered crystalline limestone, which they considered to be of probable Paleozoic age, in the Beaver Creek area.

The theater of geological interest was shifted northward when, in 1901, J. C. Merriam (16, p.436) investigated the geology of the John Day Basin in which are included several of the same formations that extend into the area under consideration. Merriam correlated the Cretaceous rocks with the Knoxville and Chico formations of California. He reported that the Columbia River Basalts were nowhere less than 1000 feet thick and were overlain by at least 1000 feet of Upper Miocene tuffs, conglomerates and ash: this was the Mascall Formation. Merriam recognized that pyroclastics and gravels, which he included in the Rattlesnake Formation after a typical exposure along Rattlesnake Creek west of Dayville, overlie the truncated Columbia River Basalts and Mascall tuffs. The Rattlesnake Formation was described as lying unconformably upon Mascall beds and composed of gravels, soft brown tuff, and a 25 to 30 foot thick rhyolite flow. The rhyolite, at some localities, was noted to be overlain by as much as 100 feet of gravels.

I. C. Russell (29, p.20), in 1903, was the first to use the name Columbia Lava with reference to the Columbia River Basalt Formation, restricting its use to flows of Miocene age.

E. L. Packard (24, p.257) reported several new areas of a Paleozoic inlier in 1925. The largest of these lay southwest from the Suplee postoffice and it was described as containing a characteristic Baird Mississippian fauna. Packard noted the occurrence of a well defined anticline and suggested that this Paleozoic section could scarcely be less than 3000 feet in thickness. At a later date, 1928, Packard (25, p.221,224), after investigation in the Beaver Creek area, stated: "the Cretaceous system is represented by a thin section of sandstone and shales along Beaver Creek near Suplee." He added: "These beds rest unconformably upon Paleozoic and possibly Jurassic rocks and are overlain by middle or late Tertiary sediments and tuff." He found that faunal evidence supported correlation with the Chico Cretaceous.

E. L. Packard's discoveries within the Suplee Paleozoic inlier encouraged B. N. Gonzales and W. E. McKittrick to work on problems in this region. During the summer of 1933, Gonzales (6, pp.22-31) obtained information on the Paleozoic fauna with particular emphasis directed to the Mississippian strata, whereas McKittrick (13) concentrated on the areal geology of the Paleozoic inlier. McKittrick, as did Packard, interpreted the structure as being anticlinal.

In 1939, W. D. Wilkinson (34) mapped the geologic formations of the Round Mountain Quadrangle to the west of the Suplee area. The area included within this quadrangle displays more affinity to the Suplee area than does the region along the John Day River. Wilkinson reported that Columbia River Basalt flows vary in thickness from 20 to 80 feet and generally have well developed columnar structure. In that quadrangle, the Mascall Formation is composed of tuffaceous sandstones, conglomerates and ash. Wilkinson noted the occurrence of a consolidated rhyolitic tuff, lithologically similar to the rhyolite flow reported by Merriam in the Rattlesnake Formation, and considered it Pliocene in age. Stratigraphically above and of probable upper Pliocene or later age are several lava flows which Wilkinson referred to as Ochoco Lavas. He indicated that these flows are generally fine grained and have a basaltic and andesitic composition.

A Pennsylvanian flora found south of the Suplee area was described by C. B. Read and C. W. Merriam (28, p.107) in 1940. In the area studied by these men, the oldest stratum was 100 feet of massive limestone that carried a Mississippian Striatifera and Gigantella fauna. Lying stratigraphically above this bed of limestone, clastic sediments contained fragmentary plant remains that indicated a probable lower Pennsylvanian age for the beds. They estimated the thickness of this Upper Paleozoic section to be approximately 3000 feet.

One of the most comprehensive contributions was made by R. L. Lupher (9, pp.219-269) in 1941. He recognized ten Jurassic formations that accumulated under marine conditions to a thickness of nearly 15,000 feet.

C. W. Merriam and S. A. Berthiaume (15, pp.145-172) studied the Paleozoic inlier near Suplee in 1943 at which time their findings supported the occurrence of strata from three different periods. They named the formations Coffee Creek, Spotted Ridge, and Coyote Butte with an assigned age of Mississippian, Lower Pennsylvanian, and Permian, respectively. The Coffee Creek beds were said to be from 900 to 1000 feet thick, whereas the Spotted Ridge Formation was between 1000 and 1500 feet, and Coyote Butte strata were approximately 900 feet thick. An estimated thickness of from 3500 to 4000 feet for the Triassic sandstones and conglomerates was suggested by Merriam and Berthiaume.

Other references include descriptions of Carboniferous and Permian corals from Central Oregon (14, pp.372-381), a discussion of the late Paleozoic history of Central Oregon (15, p.1935), a report on the Cretaceous of Central Oregon (25, p.166), and a description of a rudistid-like pelecypod from the lower Jurassic of the Suplee region (10, pp.203-212).

GEOGRAPHY

Relief

Moderate relief is characteristic of the area in which 1500 feet in two miles between Beaver Creek and Powell Mountain is the maximum local change of elevation. In general, the topography is characterized by near horizontal tables that rise from 50 to 500 feet above the bottom lands. Occasionally, larger and higher masses of Columbia River Basalt, such as Powell Mountain, Mud Spring Butte, and Wade Butte, dominate the topographic control. Streams incised through the basalt have produced steep canyons up to 500 feet deep. In contrast to the nearly flat or gently sloping relief controlled by Tertiary formations is the pre-Tertiary inlier located in the southeast portion of the area. Here, the average elevation is considerably higher and it is marked by rounded hills and ridges that are separated by a network of V-shaped valleys. The change in relief is not so abrupt as the canyons cut into Tertiary basalts, but is consistently more rugged.

The highest point in the area is 5500 feet above sea level on a ridge composed of pre-Tertiary rocks in the extreme southeastern corner of the area. The lowest portion is about 3800 feet above sea level along Beaver Creek.

Drainage

Beaver Creek, that joins Crooked River farther west, is the final receptor of all drainage within the area. Grindstone and South

Fork Beaver creeks are the chief tributaries to this stream. Lesser streams that feed into these two creeks, and will be referred to frequently in the text, are White Butte, Trout, Camp, and Rock creeks. Many smaller intermittent creeks are active during the wet season or during summer thunderstorms.

The stream gradients generally increase from northwest to southeast. In the Beaver Creek area, and in the lowlands, about 50 feet per mile is the average. The gradient reaches nearly 100 feet per mile on the South Fork Beaver Creek and approximately 250 feet per mile is characteristic of the forks of Trout Creek. Meandering of the streams is prominent under 4000 feet and is occasionally seen where the stream has reached a temporary base level at higher elevations.

Climate

The area has a semi-arid continental climate characterized by large seasonal and daily ranges of temperature. On nearly a third of the nights in any year the temperature falls below freezing and several times during December and January the temperature falls below zero. Even a few of the summer nights have below freezing temperatures, which may be followed by a daytime maximum in the 90's. On a few days the temperature exceeds 100 degrees.

This climate is semi-arid with about 12 inches of rainfall per annum. Prineville (to the west) receives an average of approximately 8.50 inches, whereas Canyon City (to the east) has an average of about

16.30 inches of precipitation per year. The greater part of this precipitation falls during the winter and early spring. Intense spring and summer thunderstorms may bring as much as an inch of precipitation within 30 minutes. Much of the winter precipitation is in the form of snow, which may stay on the ground from late November until February and may be two to four feet deep.

Vegetation

The vegetation in this area is generally sparse and only the hardier plants are able to grow. This area is nearly barren of trees and even juniper (Juniperus occidentalis) is scarce. Along the streams and near springs, alder (Alnus tenufolia), birch (Betula fontinalis), poplar (Populus trichocorpa), and willow (Salix lasiolepis) flourish. Most of the area is covered by sagebrush (Artemesia tridentata) and bunch grass (Agropyrum spicatum). Western yellow pine (Pinus ponderosa) grows in thin stands on the uplands of Powell Mountain and in the adjacent Beaver Creek canyon.

Part of the area is under cultivation, principally the southeast portion of the area and Beaver Creek valley where hay and grain are grown mainly for livestock feed. Cattle and sheep are the chief livestock and form the basis for the region's main industry.

STRATIGRAPHY AND PETROGRAPHY

General Statement

The oldest strata observed are those of upper Paleozoic age and they are the Mississippian Coffee Creek, and Upper Pennsylvanian Spotted Ridge and Coyote Butte formations. Very highly compressed and steeply tilted beds, averaging 65 degrees in dip and striking in a northerly direction, are characteristic of the Paleozoic. Massive limestone is associated with both the Coffee Creek and Coyote Butte formations. Clastic sediments occur with these formations but are most abundant in the Spotted Ridge beds. The combined thickness of the upper Paleozoic formations is estimated to be between 3000 and 4000 feet.

Dacitic and dioritic rocks, that were intruded into Paleozoic strata, crop out sparsely over the inlier. It is probable that the time of intrusion was near the end of the Paleozoic, therefore marking the earliest intrusive stage recognized in the area.

Bordering the eastern margin of the highly folded Paleozoic rocks and to a limited extent on the western flank near Wade Butte are marine sediments of Mesozoic age. A marked unconformity between Paleozoic and Mesozoic beds is, in part, recognized by the fact that the directions of the compressional axes of the eras are almost at right angles to each other. Triassic and Jurassic rocks are composed of limestone, calcareous clastics, and graywacke which have only a moderate dip.

SYNOPSIS OF THE EXPOSED ROCK FORMATIONS IN THE SUPLEE AREA

TABLE I

AGE	FORMATION	CHARACTER	THICKNESS IN FEET
QUATERNARY		silts, gravels, and volcanic ash	0-25
	Ochoco Formation	Diabase flow	12
	unconformity		
PLIOCENE	Harney Formation	Welded tuff, delta deposit, and fanglomerates	15-200
	unconformity		
UPPER MIOCENE	Shaw Formation	Volcanic tuff, tuffaceous ss., conglomerate, and vitrophyric rhyolite flow	100-375
	unconformity		
MIDDLE MIOCENE	Columbia River Basalt Formation	Diabase and normal basalt flows	600
	unconformity		
EOCENE ?	Clarno Formation	Rhyolite	?
	unconformity		
UPPER CRETACEOUS	Unnamed	Shale, subgraywacke, & quartzite conglomerate	500-600
	unconformity		
MIDDLE JURASSIC	Colpitts Group	Arenaceous and argillaceous ls., limestone, conglomerate, and subgraywacke	500
	unconformity		
	Intrusives	Rhyolite porphyry and basalt vitrophyre	
	unconformity		
UPPER TRIASSIC	Bailey Formation	Arenaceous and argillaceous ls., limestone, and conglomerate	800
	unconformity		
PERMIAN	Intrusives	Porphyritic dacite, dacite porphyry, and diorite	
	unconformity		
	Coyote Butte Formation	Limestone, cherty ls., chert breccia, graywacke, and conglomerate	1000
	unconformity		
PENNSYLVANIAN	Spotted Ridge Formation	Graywacke, breccia, conglomerate, and bedded chert	1200-1700
	unconformity		
MISSISSIPPIAN	Coffee Creek Formation	Limestone, arenaceous and argillaceous ls., and calcareous ss.	1200

Lying along the Paleozoic-Mesozoic contact in the Camp Creek area and roughly paralleling the contact is a sill composed of rhyolite porphyry. In the same area is a dike of basalt vitrophyre. They were emplaced during the Triassic-Jurassic interval and represent the dominant system of intrusives in the area.

The Upper Cretaceous is represented by shale, subgraywacke, and conglomerates. The conglomerate usually contains quartzite pebbles and cobbles which are very characteristic of the formation. The main exposures are concentrated along South Fork Beaver Creek near the Andrew Bernard Ranch, and here were found several beds that contained many invertebrate fossils.

Partly surrounding the pre-Tertiary inlier through an arc from north to west are basaltic and acidic extrusive rocks, as well as pyroclastic material, which accumulated during the Cenozoic era. A small rhyolitic intrusive, that may be of Eocene age, is exposed near Soda Spring and is the only exception to the otherwise continental nature of Cenozoic deposits. Several flows of the Miocene Columbia River Basalts crop out extensively over the area and are particularly prominent where exposed as fault block hills or mountains. Mud Spring Butte and Powell Mountain are composed of typical upwarped and faulted Columbia River Basalt flows. Within the basins formed by faulting and warping of basaltic flows, lie the pyroclastic materials of the Shaw Formation. This formation is similar in lithology and stratigraphic position to the Mascall Formation along the John Day River and so the two were probably deposited contemporaneously. A thin bed of welded tuff, possibly deposited by a form of nuee ardente, overlies the Shaw tuffs and Columbia basalts, and is overlain by gravels. In the Suplee area, the welded tuff and gravels have been named the Harney Formation and correlated with the Rattlesnake Formation in the Dayville area. This tuff appears to be Pliocene in age. A thin flow of diabasic rock rests unconformably upon the Harney Formation in the Beaver Creek area and has been called the Ochoco Formation. A late Pliocene or Pleistocene age has been assigned to this lava flow.

COFFEE CREEK FORMATION

The type locality for rocks of Mississippian age, described by C. W. Merriam (15, p.149) in 1943, is one and one-half miles southwest of Wade Butte on Coffee Creek. This creek is a minor tributary that enters Grindstone Creek south of Wade Butte. The exact location of the type locality is in section 30, T 18 S, R 25 E, 1/4 mile east of a spring at Mill's sheep camp. Beds of Mississippian age occurring in the Suplee area are included in a northward extension of at least two anticlinal folds from the type area.

Areal Distribution and Topographic Expression

An area of approximately one and one-half square miles is underlain by calcareous Mississippian sediments. The main occurrence of these outcrops is in the south-central portion of the inlier where massive limestone is seen on the surface. One of the largest massive limestone outcrops is locally called White Butte and is located on the South Fork of Trout Creek in the NW1/4 Section 16, T 18 S, R 25 E. Several other lesser outcrops of limestone are included in a strip trending northeasterly through section 10, T 18 S, R 25 E.

The limestone crops out in low rolling hills or occasionally low abrupt bluffs. These outcrops are particularly conspicuous because of the contrast of their grayish white color with that of the surrounding brownish soil mantle. Little relief is displayed by other calcareous sediments and they are generally covered by soil and vegetation. (See fig. 1 & 2, p.17)

Figure 1. Looking northwest along South Fork Trout Creek. Fault parallels this creek and cuts diagonally across the Paleozoic structure. Outcrop of bedded chert in left foreground.

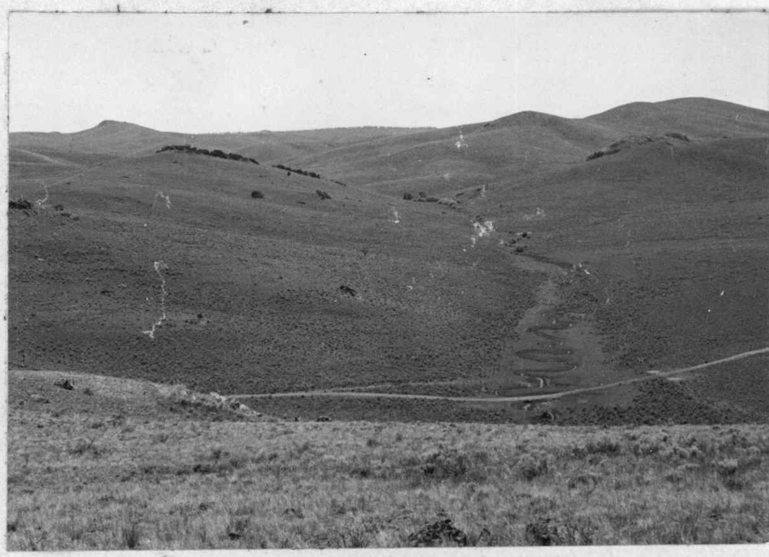


Figure 2. Southeast along North Fork Trout Creek in area of Paleozoic outcrops. White Butte, composed of Permian (?) limestone to right of stream, resistant bed of brecciated chert pebbles on the left.

Bedding is generally absent from the pure massive limestones, but is present at outcrops of carbonaceous, argillaceous and arenaceous limestone. That these lithologic members are frequently lens-shaped is suggested by the discontinuity of their outcrops.

Lithology of the Coffee Creek Formation

Limestone is conspicuous but of greater areal extent are various compositional and textural gradations of calcareous sediments. Other recognized lithologic units are argillaceous to arenaceous limestone and calcareous sandstone.

Limestone. These massive crystalline limestones show little evidence of bedding although they are usually well jointed. Silicification has occurred along parallel planes, but whether these are bedding planes is unknown. Since an occasional silicified plane is at right angles to the more abundant parallel planes, it is probable that they represent joints later filled by siliceous material. The color of these siliceous planes varies from brown to gray. The limestone itself is grayish on the weathered surface and ofttimes contaminated with a reddish-brown limonitic stain. On breaking the rock and obtaining a fresh surface, a medium gray color is seen as well as the crystalline nature of the rock.

The limestones are fossiliferous at some localities and at others seem to be completely barren of any faunal evidence.

Under the microscope this rock is seen to fine grained and composed entirely of moderately clouded calcite grains with an average diameter of about 0.1 mm. The calcite is generally subhedral to anhedral; however, recrystallized calcite in grains 1.0 mm. to 1.5 mm. in diameter is euhedral to subhedral. Shell material is abundant to absent in this variety of limestone.

A heavily fossiliferous, coarser grained limestone is predominantely composed of anhedral to subhedral calcite grains averaging 0.25 mm. in diameter and ranging in diameter to 2 mm. This limestone has 2 percent magnetite which is surrounded by globular masses of secondary limonite. Anastomosing white streaks in the rock are fractures rehealed with secondary crystalline calcite. (See figs. 3 & 4, p.20).

Other limestone facies. The less pure varieties of limestone are generally bedded and occur interbedded with the limestone. In comparison to the limestone, the argillaceous to arenaceous limestone and calcareous sandstone are darker in color and have a color range from dark gray to black. These varieties of limestone have a heterogeneous composition and are subject to rather rapid weathering.

The arenaceous and argillaceous limestones contain 60 to 70 percent detrital calcite grains and the remainder is made up predominantely of chert fragments along with some feldspar, quartz, and chlorite.

Angular to subangular chert fragments are the principal constituent of the calcareous sandstone, but there is a notable quantity of detrital calcite. Some feldspar, quartz and chlorite are also included.

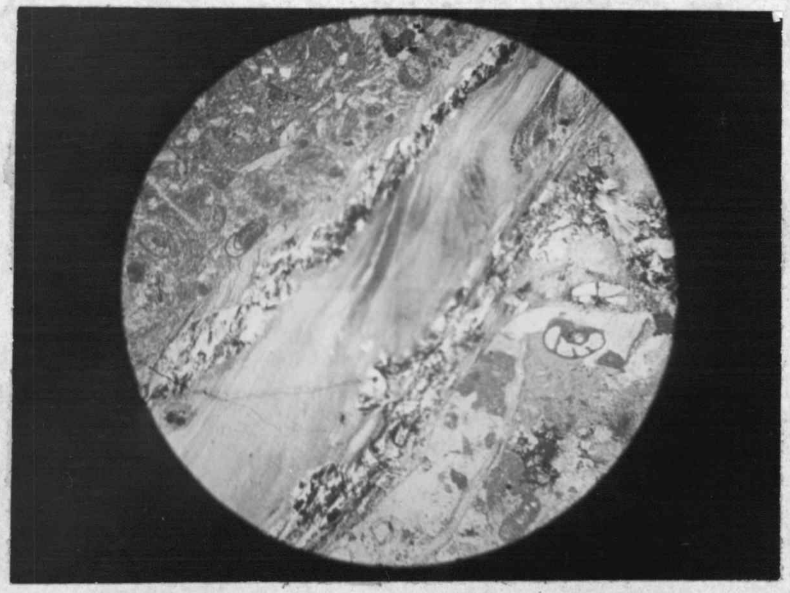


Figure 3. Foraminifera bearing limestone. Fibrous structure diagonally across the section is shell wall of a brachiopod. Crossed nicols. x37.5

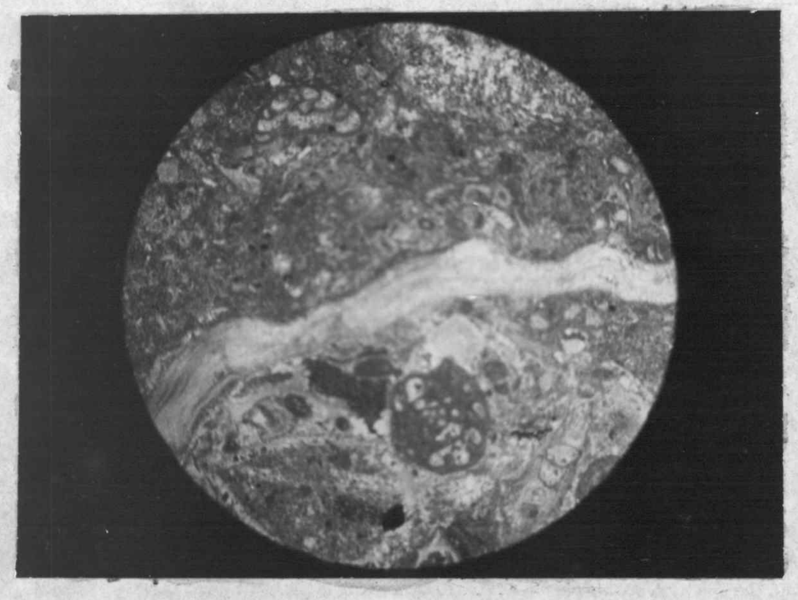


Figure 4. Foraminifera bearing limestone. Crossed nicols. x37.5

Thickness

The estimated thickness of the Coffee Creek Formation is about 1200 feet. This estimate has been based upon the section along line B-B'. (See map, Plate II)

Origin and Conditions of Deposition

Without exception all of the outcrops considered to be of a Mississippian age are of a calcareous nature. The texture, composition, and mode of occurrence of these calcareous rocks are suggestive of a varying genesis. Two, or possibly three, methods of accumulation may explain their existence. The methods of formation, that may be applicable to calcareous Coffee Creek beds, are deposition of detrital material, accumulation by accretionary means, and, possibly, chemical precipitation of calcium carbonate.

The argillaceous and arenaceous limestone, and calcareous sandstone are of a clastic nature and were derived, for the most part, from pre-existing rock sources. The fine grained nature of the argillaceous limestone may suggest offshore deposition while the presence of arenaceous limestone and calcareous sandstone possibly implies a neritic to littoral environment. It seems that the sea waters were relatively quiet and that high rugged land masses, if any were present within the region, were at great enough distance so as not to effect this area.

The second mode of deposition deals with accretionary limestone: Limestone, with included accumulation of fossil shells, that is formed in situ. Bioherms and biostromes are varieties of accretionary limestone and it appears probable that these types are represented in the area. Massive, more or less circumscribed bodies of limestone that contain coral and other invertebrate representatives are possibly biohermal in origin. They crop out in the area and are generally interbedded with arenaceous limestone. By definition, biostromes are generally well bedded and composed of pelagic and benthonic types of marine organisms. This type is apparently represented by the bedded limestones in the area that some time carry an abundant Gigantella fauna and are interbedded with clastic limestones.

The third possible mode of deposition, and the method that has the least amount of supporting evidence, is by chemical precipitation of the calcium carbonate. It is to the massive limestones without evidence of included organic material that this method seems most applicable in order to explain their formation. Chemical precipitation may be accomplished by either inorganic or organic means.

Inorganic chemical precipitation within a marine environment may be brought about by two, generally accepted, processes: By heating of the water and by mingling of solutions of different composition. The first process involves an increase in water temperature that causes precipitation of calcium carbonate. Source of the heat may be direct, eg., sun's rays heating shallow water in the equatorial region, or indirect. Indirect heating occurs in the ocean when lower and colder water is forced upward by the current in order to pass over a shallow bottom. It seems possible locally that vulcanism may also be a direct source of heat in this process. The second method of inorganic precipitation is concerned with the mingling of waters of different composition. In application to marine conditions, streams rich in dissolved calcium enter a saline body of water, such as the ocean, and thereby bring about a precipitation of calcium carbonate. Pettijohn (27, p.308) states conditions for inorganic precipitation as follows:

> "Conditions are most favorable for direct precipitation in which the water has high temperature and a high salinity and where the activity of plants has reduced the carbon dioxide content of the water; such conditions are found in low latitudes over shallow bottoms."

Organic precipitation may occur where carbonate is precipitated as a consequence of certain vital activities of organisms, as by animals and plants, and through bacterial processes. Twenhofel (32, p.372) has set up three postulations relative to the manner in which calcium carbonate may be precipitated by bacteria:

> (1) "Nitrites in solution are first reduced to nitrates, which ultimately are changed to ammonia. This reacts with carbon dioxide to form ammonium carbonate, which, reacting with calcium sulphate in solution, leads to precipitation of calcium carbonate."
>
> (2) "Ammonia may act directly with calcium bicarbonate, combining with the carbon dioxide and precipitating the carbonate."
>
> (3) "Organic salts of calcium are used by bacteria for food. This releases calcium oxide, which may unite with carbon dioxide and precipitate calcium carbonate."

The merits of the theories of chemical precipitation by either inorganic or organic methods are not readily recognizable. This status was realized by Pettijohn (27, p.308) in his statement: "Whether calcium carbonate ever was precipitated extensively from sea water except by organic agencies is not known." He goes on to say: "Inasmuch as precipitation by organisms does not require that the sea water be saturated with calcium carbonate, it seems probable that most limestone is due to organic action and that direct precipitation is and has been rather limited in importance."

In summation of the various modes of accumulation, it is the author's opinion that most of the calcareous Coffee Creek strata were deposited as detrital clastics and accretionary limestones. If chemical precipitation does enter into the problem, particularly in the case of the unfossiliferous non-clastic limestones, then the most favorable explanation seems to be through precipitation by organic agencies.

A general picture of the Mississippian environment may be drawn from the field information. Biohermal and biostromal limestones suggest accumulation in the littoral zone or upon a shallow shelf of the sea. This is inferred from the fossils of marine animals that require a rather shallow and probably warm environment. Clastic materials were deposited contemporaneously and their generally fine grained nature is suggestive of either a deeper environment than the bioherms or lack of relief along the shore region.

Stratigraphic Relations and Age

Rocks of the Coffee Creek Formation represent the basement as exposed in this region.

An angular unconformity is exhibited at one locality between Coffee Creek sediments and the overlying clastic rocks of the Spotted Ridge Formation. There are only a few degrees deviation between the attitudes of the two formations and at some localities the discordance is not readily discernible at all. This situation may suggest only a relatively short depositional lapse between the two.

The age of the Coffee Creek Formation is Lower Carboniferous, as determined by C. W. Merriam (15, p.151), and roughly correlative with the British Visean division. The productid *Striatifera* is not known from any beds older than Carboniferous, therefore definitely establishing the lower time limit. Following is the preliminary faunal list as determined by Merriam.

Dibunophyllum oregonensis Merriam
Lithostrotion (Lithostrotion) packardi Merriam
Lithostrotion (Siphonodendron) oregonensis Merriam
Campophyllum readi Merriam
Gigantella sp.
Striatifera sp.
Spirifer cf. *striatus* (Martin)
Tetrataxis sp.
Small loxonemoid gastropods
Lithistid sponge spicules

SPOTTED RIDGE FORMATION

The Spotted Ridge Formation was named by C. W. Merriam (15, p.153) and includes those sediments of a Pennsylvanian age which crop out on the west flank of Spotted Ridge. The type locality is two miles south of the Suplee area and rocks occurring at the type location continue northward into the Suplee area.

Areal Distribution and Topographic Expression

Occupying an area of a little more than four square miles, these rocks are located in the central and eastern portions of the Paleozoic inlier. They are also seen to crop out near Suplee in a region composed mainly of Mesozoic sediments and intrusive rocks.

Bedded chert and graywacke sandstone crop out on the eastern flank of the Paleozoic area along a narrow high ridge that trends in a northerly direction. The heterogeneous nature of the graywacke sandstone, which is commonly interbedded with the chert, makes it susceptible to comparatively rapid physical disintegration so as to leave the more resistant chert standing a few inches to three or four feet above the surface. These chert beds are usually from six inches to one foot thick and only rarely exceed a thickness of two feet. Where erosion has kept the surface clear of soil mantle, the intervening beds of graywacke may be seen, but seldom do they project above ground level.

Resistant conglomerate beds occasionally protrude 5 to 15 feet above the surface; a fine example of this is along South Fork of Trout

Creek. Here, a bed 300 feet long of a silicified chert pebble conglomerate, reaches a height of 15 feet. This represents the maximum expression of any single stratum within the area of Spotted Ridge sediments.

Lithology of Spotted Ridge Formation

Two important lithologic groups are contained in the Spotted Ridge Formation, these being chert and clastic materials. The latter group includes conglomerates, breccias and graywackes of which graywacke is the most predominant clastic sediment. A third grouping, of minor importance, includes clastics altered by contact metamorphism.

Bedded chert. The greatest concentration of bedded cherts is on the eastern flank of the Paleozoic inlier and one mile southwest of the Henry Bernard Ranch. This is near the Spotted Ridge contact with overlying Mesozoic sediments and in an area of intrusive igneous rocks. Beds of chert occur throughout the formation, but often are represented by only a single thin layer interbedded with the more predominant clastic graywacke. Vertical jointing in nearly rectangular sets is prominent in the cherts.

A color range from brown to tan is predominantly exhibited by the chert, but various shades of green and red were seen as well as a black variety. These cherts are tough splintery to conchoidal in fracture and are characteristically very brittle. The rocks have a fine grained texture and occasionally contain an inclusion of crystalline pyrite. Thin veinlets of white secondary silica, typical of the brown cherts, sometimes penetrate the rocks.

The following description is based upon sections cut of the more abundant brown chert.

Although the rock appears homogeneous in the hand specimen, the thin section reveals angular fragments of cryptocrystalline quartz in a matrix of microcrystalline quartz. These two varieties of quartz are common constituents of chert and were noted by Keller (8, p.1283) to occur predominantly in the Permian Rex Chert of Idaho. The angular fragments are contaminated with a brownish cloudiness, possibly an iron stain. They range in diameter from about 0.01 mm. to 12 mm. The interstices between larger fragments are crowded with minute angular particles of cryptocrystalline quartz which impart the appearance of a microbreccia. Siliceous radiolarians and sponge spicules are conspicuous in the fragments and allude to its primary nature. Closely interlocking crystals of quartz are characteristic of the secondary microcrystalline quartz matrix. Chalcedony, represented by fibrous aggregates, makes up less than 2 percent of the rock and denotes a third stage in the rock's history. This chalcedony fills small fractures that cut both the fragments and the matrix of the rock. (See fig. 6, p.29)

Conglomerates. The conglomerates are not laterally extensive and occur as a cobble or boulder facies in the beds of graywacke composition. The composition of the conglomerates is variable; however it is generally made of fragments of igneous rocks or of chert. Mixtures of the two produce intervening gradations. These conglomerates are predominantly composed either of one derivative or the other and the conglomerate of mixed composition is scarce.

Figure 5. Vertical bed of Mississippian Coffee Creek limestone on right at contact with Pennsylvanian Spotted Ridge graywacke on left.

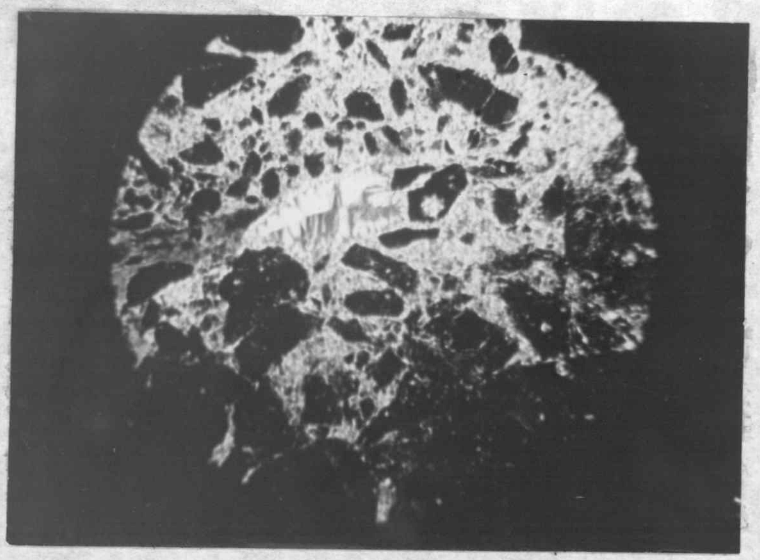


Figure 6. Bedded chert. Dark areas are radiolarian bearing cryptocrystalline quartz, light matrix is microcrystalline quartz, and fibrous structure in center is chalcedony. Crossed nicols. x37.5

Conglomerates of chert are noticeably more abundant than the other varieties. A siliceous matrix is common to all varieties. Stratification and sorting of these coarse clastics are absent.

In those conglomerates of igneous derivation, pebbles, cobbles, and boulders as much as 14 inches in diameter, are rounded to subrounded and generally bound by a sandy matrix comparable to the graywacke. Acid and basic phaneritic igneous rocks of the following types are present: Rhyolite porphyry, tonalite, diorite porphyry, dacite porphyry, and quartz gabbro. Occasionally a limestone cobble or boulder is included, but such an occurrence is not common.

The chert pebble conglomerate is another clastic sediment which occurs in the Spotted Ridge section. This rock displays a brownish colored weathered surface that has a grayish hue when freshly broken. This conglomerate is composed of rounded to subrounded pebbles of chert in colors of brown, black, pale green and cream. Size of the individual grains and pebbles ranges from 0.5 mm. to 10 mm. in diameter with a weighted average diameter of about 4 mm. An outcrop of this material is shown in figure 7, p.31.

The resistant character of the conglomerate is exemplified by the fact that jointing planes and fractures do not follow the outline of the pebbles but rather cut directly across them.

Conglomerates with mixtures of chert, igneous rock, and other material occur in the area of Spotted Ridge outcrops, but are in the minority. They contain well rounded to sub-rounded pebbles, cobbles, and boulders of vari-colored chert, quartzite, limestone, graywacke,

Figure 7. Near vertical bed of chert pebble conglomerate.

Figure 8. Brecciated chert pebble conglomerate. Cryptocrystalline and microcrystalline quartz fragments, wedge shaped fragment is chalcedony with secondary microcrystalline quartz penetrating it. Crossed nicols. x37.5

and igneous rock. This type of conglomerate is related more closely to the graywacke than are the boulder and pebble conglomerates composed of igneous and chert derivatives, respectively. This is shown, not only by the overall composition, but specifically, by the graywacke matrix.

A unique variation of the chert pebble conglomerate is the conglomerate composed of pebbles of brecciated chert. At one locality, previously referred to as occurring along South Fork Trout Creek, a massive outcrop 75 feet thick with a lateral extent of 300 feet is composed of this brecciated chert. The weathered surface is reddish brown to greenish gray with a mottled appearance. Angular to subangular cream, green, and black chert fragments vary in size from 0.5 mm, to 3.0 mm. in diameter.

Microscopically, the rock is seen to have angular to subangular fragments of microcrystalline quartz, up to 1.5 mm. in diameter, embedded in a siliceous isotropic matrix. As seen in transmitted light, the fragments are clear, whereas the matrix has a light brownish color. There is no indication of the presence of micro-fossils. (See fig. 8, p.31)

Graywacke. Clastic sediments of a graywacke nature occur interbedded with cherts, conglomerates, and breccias of Pennsylvanian age. The classification of these rocks is based upon Pettijohn's (27, p.244) description:

> "Graywacke is a petrographically distinct type of sandstone that is marked by its induration and dark color. It is composed of large very angular detrital grains, mainly quartz,

> feldspar, and rock fragments (chiefly chert, phyllite, and slate). These grains are set in a prominent-to predominant 'clay' matrix which was, on low-grade metamorphism, converted to a mixture of chlorite and sericite and partially replaced by carbonate."

In this area a dirty brown surface is characteristic of the weathered material, whereas the fresh piece is lighter in color and mottled in appearance. The degree of induration varies from moderate to poor. The texture is also variable from medium to coarse grained. The angular grains in the coarser grained graywackes impart a gritty texture and because of this feature these rocks are occasionally called grits. Subangular grains of vari-colored chert, feldspar, and calcite may be seen in the hand specimen.

The thin section reveals an inequigranular medium grained texture with fragments from 0.1 mm. to 1.5 mm. in diameter. About 40 percent of the rock is composed of subrounded to rounded grains of chert. The chert has the typical microcrystalline quartz aggregate structure. Approximately 10 percent of the rock is detrital calcite, 10 percent moderately altered andesine, 5 percent quartz, 3 percent magnetite altering to limonite, 15 percent rock fragments of igneous derivation, and 15 percent chlorite. Secondary chlorite acts as the binding medium and has apparently developed through hydrothermal alteration of included "clayey" minerals. The presence of chlorite is suggestive of low-grade metamorphism (27, p.244).

A variation in composition of the graywacke is expressed by another sample in which there is a higher percentage of quartz and feldspar. It contains 30 percent of sub-rounded to rounded microcrystalline quartz (chert), 25 percent rounded to angular quartz, 15 percent angular calcite, and 10 percent of chlorite cement. Considerable hydrothermal alteration of the feldspars has occurred. Some secondary silicification has taken place along the chlorite-filled interstices.

Intrusive effects upon the graywacke. Graywacke sandstone one mile southwest of the Henry Bernard Ranch has been visibly affected by intrusion of a rhyolite porphyry sill. The effects of this intrusion are shown by a 30-inch contact zone in which the normally dark-colored graywacke has been "baked" to a yellowish brown color. Increase in degree of induration, within the contact zone, is worthy of note.

This contact rock has a medium-grained inequigranular texture. The largest fragments are about 1.0 mm. in diameter and range down to 0.1 mm. In transmitted light, many of the fragments are seen to be brownish yellow, whereas other fragments are clearly transparent. Clastic chert, that is both microcrystalline and cryptocrystalline, composes nearly 30 percent of the rock. Fragments derived from aphanitic igneous rocks make up an additional 20 percent. These fragments are rounded to subrounded in contrast to the angular to subangular chert. About 20 percent of this rock is composed of moderately altered subrounded feldspar of the albite-oligoclase range. Angular to subangular quartz makes up about 15 percent, and magnetite less than 1 percent. Nearly 15 percent of this rock is sericite that is partly in the feldspars, but is predominantly found in the interstices.

As might have been expected, no profound metamorphic effects are shown by the petrographic analyses. The only apparent difference between the contact rock and the nearby graywacke is that chlorite is absent from the contact rock and sericite is present. It then appears probable that the rhyolite porphyry intrusion had little effect on the sediments as a whole other than to bring about the characteristic "baked" effect as seen in the outcrop.

Thickness

The thickest concentration of Paleozoic strata is represented by the Spotted Ridge beds. They are estimated to be between 1200 to 1700 feet thick. This estimate is based upon the structure section along line B-B' (See Plate II).

Origin and Conditions of Deposition

The clastic materials of the Spotted Ridge Formation were derived from a nearby highland and the large amount of igneous derivatives, particularly within the boulder conglomerates, seems suggestive of this high terrain. The large amount of chert fragments contained in the graywacke, as well as the pebble conglomerate and breccia, may have been derived from chert beds of Mississippian, or older, age.

Some difficulty is encountered with regard to the mode of origin of the bedded cherts. The accumulation of this chert is particularly complicated by its alternation with graywacke sandstone. Whether the chert was a clastic accumulation, accumulated from precipitated colloidal silica, or was the result of metasomatic action is not clearly understood. With reference to the petrographic analyses of the bedded chert, angular fragments of cryptocrystalline quartz are embedded in a matrix of microcrystalline quartz. A primary origin for the fragments is suggested by the presence of siliceous radiolarians, whereas it seems probable that the matrix is secondary. The angular fragments can be explained by two different processes. In the first case, fragments were derived from a primary bed of chert and subsequently cemented by silica or calcium carbonate. If it was cemented by calcium carbonate, then replacement by silica occurred at a later time. The second case would have the bed of radiolarian chert precipitated within the Spotted Ridge sea followed by disturbance of the semi-solid mass or fracturing some time after burial and subsequent re-healing of chert by silica.

The foregoing evidence supports direct precipitation upon the sea floor, in part, but implies that there was a secondary effect concerned. The latter may or may not support the theory of metasomatic formation of bedded cherts. Pettijohn (27, p.330), in summing up the mode of formation of bedded cherts, states: "These more spectacular forms are more commonly ascribed to direct precipitation rather than to replacement."

Two principal environments of deposition are inferred from the Spotted Ridge sediments. Considering radiolarian-bearing cherts as having been deposited in the sea and presuming that floral material accumulated in a fluvial or subaerial environment, then a fluctuating shoreline can be visualized. The depth at which chert formed is obscure since some authorities contend that radiolaria live in an abyssal environment while others believe they have a shallow water habitat. Where medium- and coarse-grained graywacke alternate with bedded chert, the depth of accumulation probably was not great, thus partially substantiating a neritic or shallow water radiolarian environment. As to the second, or terrestrial environment, Calamites stalks and black carbonaceous material of a vegetative origin generally are ascribed to a land habitat and their occurrence in the graywacke suggests fluvial deposition. This terrestrial environment, at least in part, is further indicated by conglomerate lenses which are attributed to stream action.

Stratigraphic Relations and Age

Clastics of the Spotted Ridge Formation are angularly unconformable with underlying limestone of the Coffee Creek Formation; however, the angular nature of the contact is not particularly evident. It appears that there is no great depositional break between the two, nor was diastrophism of any great consequence.

Overlying rocks of the Coyote Butte Formation rest unconformably on the Spotted Ridge bedded cherts and clastics. The difference in dip between the two is occasionally as much as 25 degrees. Tertiary Columbia River Basalts rest on Pennsylvanian rocks at several points and are conspicuously unconformable thereon.

C. W. Merriam (15, p.155), in determining the age of the Spotted Ridge Formation, refers to his earlier work with C. B. Read which reported that floral material suggested a Lower Pennsylvanian age, but didn't eliminate the possibility of an Upper Pennsylvanian age.

The following floral assemblage was taken from the type locality, south of the Suplee area, and identified by Read and Merriam (28, p.109).

Sphenopteris sp.
Dactylotheca sp.
Calamites stems
Asterophyllites sp.
Phyllotheca stems, leaves, and strobili
Dicranophyllum sp.

The writer found molds of Calamites characterized by their jointed stems and vertical ribs. Other unidentifiable floral material was found, as well as carbonized vegetable matter. These were obtained from beds of graywacke. With reference to marine microfossils, radiolarians, which are exclusively marine planktonic organisms, were seen in some of the bedded cherts, but they are not diagnostic of the age.

COYOTE BUTTE FORMATION

Coyote Butte Formation is the name given by C. W. Merriam (15, p.156) to those sediments of a Permian age. These rocks crop out more or less continuously from the type locality at Coyote Butte, five miles south of Wade Butte, into the Suplee area.

Areal Distribution and Topographic Expression

Outcrops of rocks belonging to the Permian system occur scattered throughout the inlier, over an area of about four and one-half square miles, or about as much as the area covered by Pennsylvanian rocks.

Light-colored massive limestones form low bluffs and caps on moderately rolling hills in the area south of and adjacent to Smith Basin. Lack of vegetation on the outcropping limestones contributes to their conspicuous appearance. Cherty limestones crop out almost as frequently as do the massive limestones and appear very similar.

Knobs and short ridges of beds composed largely of a coarse grained indurated subgraywacke are prominent at the headwaters of the North and South Forks of Trout Creek. One such thick bed is arched up in an anticlinal fold and forms a low promontory in that area. Difficulty was experienced in differentiating these clastics from nearby Spotted Ridge graywacke; however, there is generally a marked difference in dip and strike.

Other beds of the Coyote Butte Formation occur about two miles east of Wade Butte near the headwaters of White Butte Creek where interbedded calcarenite and fossiliferous limestone show slightly above the surface. There a gently rolling surface controlled by underlying Permian beds is predominantly covered by residual soil and alluvium.

Lithology of the Coyote Butte Formation

The lithologic sequence in the Coyote Butte Formation was not determinable because of discontinuity and lack of outcrops. Various rock types were recognized in the section of which limestone and graywacke are areally most important. Following are descriptions and discussions of the rocks as they occur in the field and, in part, microscopic descriptions of them.

Limestone. Limestones are generally confined to the area adjacent to and south of Smith Basin for a distance of two miles where they crop out between North Fork of Trout Creek and the high ridge paralleling the Paleozoic-Mesozoic contact.

A light grayish color is characteristic of this crystalline limestone that is massive and shows no bedding. Many fractures that have been rehealed with pure white calcite impart a streaked appearance to the rock. Although generally appearing unfossiliferous, small fragmentary crinoid stems, circular in cross-section and averaging about 4 mm. in diameter, are sparsely scattered through the limestone.

Cherty Limestone. Many of the Coyote Butte limestones contain prominent to predominant amounts of chert. There are two general modes of occurrence of chert within the limestone. First, there is the dark gray chert that occurs along jointing and bedding planes and as elliptical nodules within the mass of the limestone. Nodules three feet long and eight inches thick were observed. Secondly, and of more importance, are the fragments of chert more or less disseminated through the mass of limestone. It is the latter occurrence with which we are now concerned.

Chert breccia. The chert breccia has a weathered surface which is dark gray in color and rough with protruding angular fragments of grayish black chert. These fragments are as large as 20 mm. in diameter and are embedded in a fine-grained grayish crystalline carbonate. The ratio of the volume of the chert to that of its calcitic matrix appears to be approximately 2 to 1 as seen in the hand specimen.

Presence of chert fragments in a calcareous matrix is verified in the thin section. These fragments are generally large, as was noted megascopically, but the interstices are filled with smaller fragments of chert which range in diameter from 0.05 mm. to 2.00 mm. The chert fragments, actually microcrystalline quartz, are shot with small rhombs and anhedral crystals of calcite. The contacts between larger fragments of chert and the calcareous matrix are ragged. The ratio of chert to calcite is approximately 4 to 1, but it is probable that there are gradations in either direction. Less than 1 percent of this rock is composed of pyrite altering to limonite.

The genesis of the cherty limestone is somewhat obscure, but it would seem that either a primary or a secondary mode of formation might include most of the possibilities. Considering first the primary origin, two conditions can be postulated: That a siliceous gel layer formed in marine waters and heavier detrital calcite was deposited on top of the gel and settled down into the mass, or that chert fragments accumulated in the sea and calcium carbonate was precipitated around them. Petrographic characters supporting the primary origin are as follows:

1. Angular chert fragments in a calcareous matrix
2. Corrosion or embayment of calcite metacrysts not evident
3. Individual chert fragments apparently isolated; hence, no trace of inter-connecting sources of silica.

The secondary mode of formation may be tectonic or metasomatic. First, considering a tectonic process, the breccia may be the result of crushing or folding where crushing was caused by static means or a fold breccia brought about by compression of the beds. Since these Permian beds are moderately folded, it may be that this breccia is the result of folding.

Taking into consideration the possibility of a metasomatic origination of the chert breccia, the postulation may be made that the carbonate was wholly of a primary nature, but during and after lithification silica invaded the rock and began a process of replacement from calcite to dolomite and finally to quartz. Petrographic characters suggestive of a late replacement are as follows:

1. Ragged contacts between dominant chert and calcite (in part dolomite?)

2. Metacrysts or inclusions of rhombic dolomite (?) and anhedral calcite (?)

3. Interstices dominantly calcite, but shot with minute fragments of microcrystalline quartz, hence suggesting active replacement of the calcareous matrix.

The evidence is, by no means, conclusive for any one of these processes; however, it appears to the author that the chert breccia is principally of a tectonic origin, possibly by folding, with a minor amount of late replacement. The sharp angular nature of the chert fragments seems unexplainable by a complete metasomatic process.

Fossiliferous limestone. Two miles east of Wade Butte in an area otherwise nearly barren of outcrops are several thin beds of fossiliferous limestone and calcarenite. None of these beds exceeds a thickness of ten feet. Generally, the beds are three to four feet thick. That these beds have undergone considerable stress is shown by minute folds and minor displacements.

This rock has many fossil shells imbedded in a dark gray crystalline calcitic groundmass. White stringers of calcite bear witness to the anastomosing system of fractures that have been re-healed. These seams vary in thickness from 0.5 mm. to 6.0 mm.

As seen through the microscope, the texture is typically in-equigranular medium-grained with individual crystals sometimes at-taining a diameter of 1.0 mm. The calcite occurs as primary detrital grains and also in interlocking subhedral to anhedral crystals, in the latter occurrence, possibly suggesting recrystallization or primary deposition of a calcareous precipitate. Other detrital minerals are feldspar and quartz which constitute less than 2 percent of the rock. Some secondary silicification has occurred and is illustrated by microcrystalline aggregates of quartz. About 3 percent of the rock is composed of this cherty material.

Cross-sections of calcareous generally clouded shell material are very abundant. An occasional endothyrid or fusulinid type microfossil occurs in this limestone. (See fig. 9, p.45).

Calcarenite. Beds alternating with the fossiliferous limestone are composed of this grayish black arenaceous limestone. Parting parallel to the bedding planes gives a platy appearance to the outcrop. Crinoid stems up to 3 mm. in diameter are distributed profusely through the rock, thus imparting a speckled appearance.

The rock has a medium-grained inequigranular texture with the individual grains ranging up to 1.0 mm. in diameter. The composition is predominantly calcareous, of which rounded to subrounded detrital calcite and spherical concretionary oolites are representative. Angular to subrounded fragments of quartz and feldspar are present in the amount of 1 percent each, whereas a smaller amount of magnetite and titanite, the latter altering to leucoxene, is included. The interstices are filled with pale greenish chlorite that composes about 10 percent of this rock. Nearly 2 percent microcrystalline quartz, a variety of chert, is present and may be indicative of a minor amount of replacement.

A few small fusulinids, not over 0.5 mm. in diameter, are scattered sparsely through the rock.

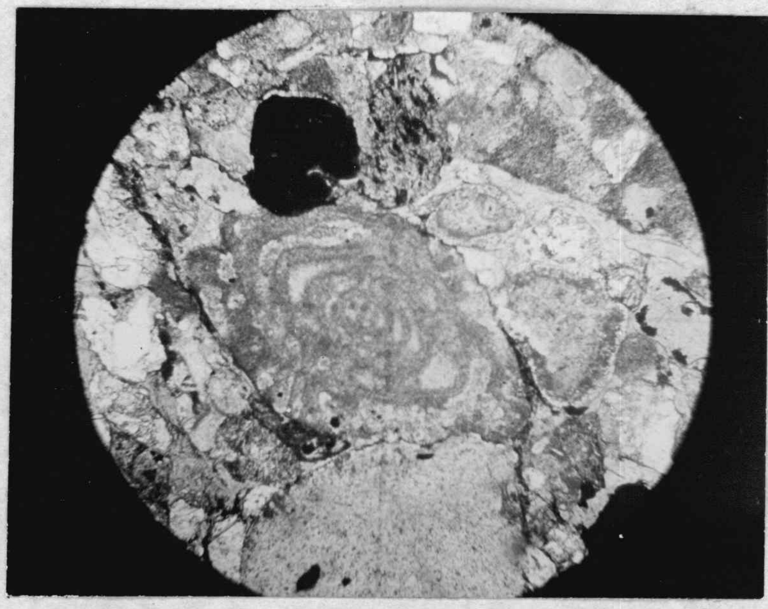


Figure 9. Permian Coyote Butte arenaceous limestone. Cross-section of fusulinid. Crossed nicols. x75

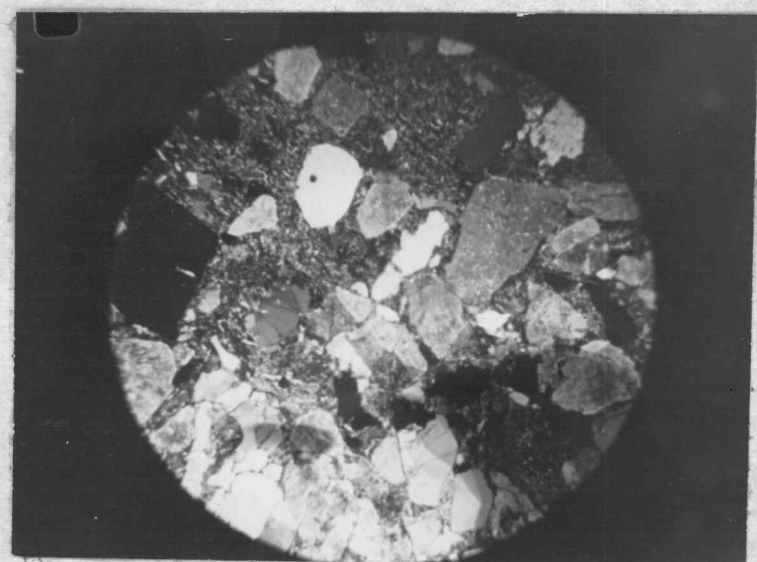


Figure 10. Coyote Butte graywacke. Crossed nicols. x37.5

Graywacke. In the eastern portion of the Paleozoic inlier are numerous outcrops of a very indurated bed of graywacke that lies unconformably over Spotted Ridge Bedded chert and clastic sediments.

The weathered surface of this rock is reddish brown and dotted with light spots of chert and clear angular fragments of detrital quartz. The fragments are generally sub-rounded to angular with dimensions ranging from 0.5 mm. to 2 mm. in diameter. A siliceous cement is in part responsible for the compact nature of these rocks.

Microscopically, the average sample of this rock is seen to have a medium-grained texture. Subrounded to subangular fragments of minerals and rocks have a diameter ranging between 0.5 mm. and 1.0 mm. The rock contains 30 to 35 percent of moderately sericitized plagioclase feldspars of the oligoclase-andesine range, 20 to 35 percent quartz, 15 percent microcrystalline quartz, 5 percent orthoclase, 3 percent magnetite, and 10 to 20 percent chlorite in the matrix. Along with the chlorite in the matrix are microscopic fragments of quartz, chert, and feldspar (See fig. 10, p.45).

In comparison with graywackes of the Spotted Ridge Formation, the most striking difference is the smaller amount of chert that has apparently given way to the now prominent feldspars occurring in the Coyote Butte graywacke. Other constituents occur in approximately the same percentages.

Thickness of the Coyote Butte Formation

The estimated thickness of the Coyote Butte Formation is 1000 feet, this figure having been based upon the structural cross-section (See Plate II). C. W. Merriam (15, p.157) has estimated the thickness of this formation, south of the Suplee area at Coyote Butte, to be approximately 900 feet.

Origin and Conditions of Deposition

The beds of the Coyote Butte Formation are predominantly of a calcareous nature, but are occasionally interbedded with beds of graywacke. Whether the limestone is the result of chemical precipitation or deposited by organic means is unknown; however, the fossiliferous limestones are probably accretionary and were formed in situ. The cherty limestone probably differs little from the pure limestone, relative to mode of deposition, and is considered to be of a primary nature (see discussion on cherty limestone). The calcarenite, for the most part, is composed of detrital calcite derived from the shore region.

That upwarped beds of chert supplied a component part of the graywacke is evident from the average of 15 percent microcrystalline quartz in these beds. Igneous derivatives, at least the plagioclase and orthoclase feldspars, are present in abundance and were probably reworked from the Spotted Ridge Formation. Also, a large amount of quartz fragments may owe its source to the Spotted Ridge beds.

Conditions during Permian times were probably little different than those previous, despite an apparent hiatus of considerable magnitude between Spotted Ridge and Coyote Butte times. Limestones containing crinoid stems, pelecypods, brachiopods, and fusulinids are indicative of a marine environment. Fusulinids occurring in a calcarenite may be significant of relatively shallow water. Pelecypods and brachiopods probably lived in a shallow to nertic environment. With reference to climatic conditions as might be indicated by the limestones; formation of limestones during recent times is confined between latitudes 32 degrees North and 29 degrees South, a tropical to subtropical region.

Metamorphic and metasomatic effects may be recorded in the Coyote Butte Formation, but they are not readily recognizable. A possibility of regional low-grade metamorphism is suggested by the chloritic matrix of the graywacke and the calcarenite. As already mentioned in the discussion on the cherty limestone, some limestone may have been replaced by silicon dioxide, but the evidence is not conclusive.

Stratigraphic Relations and Age

The moderately to steeply dipping beds of the Coyote Butte Formation overlie the underlying Spotted Ridge and Coffee Creek Formations with a marked degree of discordance.

Stratigraphically higher Triassic Bailey beds are not in direct contact with Coyote Butte strata, but differences in dip and strike of the two formations is indicative of the existing unconformity.

At Smith Basin, Jurassic Colpitts beds were deposited unconformably on folded Coyote Butte strata and this unconformity is evident at the contact in that area.

The age of the Coyote Butte Formation is reported by C. W. Merriam (15, p.158) to be Lower Permian. This determination was made on the basis of G. Arthur Cooper's identification of the following brachiopods:

Productus cf. *P. mammatus* Keyserling
P. aff. *P. porrectus* Kutorga
Avonia tuberculata Schellwien
Linoproductus cf. *L. sinuata* King
Juresania aff. *J. juresanensis* Tschernyschew
Waagenochoncha n. sp.
Krotovia pustulata Keyserling
Keyserlingina sp.
Marginifera cf. *M. involuta* Tschernyschew
Rhynchopora n. sp.
Camarophoria mutailis n. var.
C. biplicata Stuckenberg
C. karpinskyi Tschernyschew
Notothyris nucleola Kutorga
Notothyris n. sp.
Martiniopsis sp.
Spiriferella n. sp.

C. W. Merriam (14, p.372) also determined some rugose corals from this formation in 1942 and his identifications are as follows:

Waagenophyllum washburni Merriam
Waagenophyllum ochocoensis Merriam
Waagenophyllum sp. a.
Waagenophyllum sp. b.
Lithostrotion (*Lithostrotionella*) *occidentalis* Merriam
Lithostrotion (*Lithostrotionella*) *berthiaumi* Merriam

Merriam reported that these corals are indicative of a Permian age.

Several fusulinids found and identified by Merriam included several new species of *Parafusulina* and *Schwagerina*, and some forms tentatively referred to *Fusulinella* and *Triticites*. These fusulinids imply that the Coyote Butte Formation is not lowest Permian (15, p.158).

INTRUSIVE IGNEOUS ROCKS

Three groups of intrusive igneous rocks have been recognized within the Suplee area. The first recognizable time of intrusion was in late Permian or early Triassic when diorites and dacites (Pda, see Plate II) were injected. Second and more extensive, was the intrusion of rhyolite porphyry and basalt vitrophyre (Trb, see Plate II) probably during late Triassic or early Jurassic. A third intrusive period represented by rhyolite (Tcl, see Plate II) has rather indefinite time limits, but it here is assigned to the Eocene as a possible relative of the Clarno Formation.

Dacitic and Dioritic Intrusives

Three small sill- or dike-like intrusive rocks crop out within the Paleozoic inlier. They are confined entirely to the extreme southern portion of the inlier between White Butte Creek and South Fork Trout Creek. Each of the outcrops differs either in texture or composition, but the main rocks are porphyritic dacite, dacite porphyry, and diorite.

Porphyritic dacite. Porphyritic dacite is limited in extent and is known to occur at only one locality in the NE$\frac{1}{4}$ SE $\frac{1}{4}$ Section 16, T 18 S, R 25 E. This outcrop is a sill 3 to 4 feet thick and has a lateral extent of about 200 feet. It was intruded into Spotted Ridge graywacke and differs little in appearance from them. This likeness suggests that the porphyritic dacite may be more extensive than shown on the map and with additional detailed work might be differentiated from graywacke beds at other localities.

This rock is brownish on the weathered surface, but is typically gray onthe fresh fracture. It has a porphyritic medium grained texture. Phenocrysts of light-colored sodic plagioclase and quartz occur in a size range from 0.5 mm. to 1.5 mm. Platy jointing parallel to the plane of intrusion is a characteristic feature and these joint planes are discolored with a light brownish stain.

As seen microscopically, phenocrysts of plagioclase and quartz impart a porphyritic texture to the otherwise medium-grained equigranular rock. The predominant groundmass exceeds the phenocrysts by a ratio of approximately 3 to 1. Nearly 60 percent of the phenocrysts are plagioclase of the oligoclase-andesine range that have been slightly to moderately sericitized; quartz accounts for the remaining percentage of phenocrysts. The groundmass is composed mostly of microcrystalline quartz in interlocking crystals. Secondary chlorite occurs in the interstices between grains of quartz as well as along the many small irregular fractures.

Dacite porphyry. The exposure of dacite porphyry protrudes about eight feet above the surface and forms an outcrop with dimensions of 30 feet by 60 feet. It is located one-half mile southwest of the Clemmons Ranch in the NE$\frac{1}{4}$ NE$\frac{1}{4}$ Section 18, T 18 S, R 25 E. It was intruded into Coffee Creek limestone of Mississippian age but no metamorphic effects were observed at the contact. (See fig. 11, p.52)

Figure 11. Outcrop of the intrusive dacite porphyry within the Paleozoic inlier. Erosional escarpment of Columbia River Basalt in background.

Figure 12. Looking northwest across Smith Basin. Outcrop of intrusive Basalt vitrophyre on right. Shaw Table in distance.

A pale greenish hue is imparted by the groundmass of the rock and is typical of the fresh specimen. The rock has a porphyritic medium-grained texture. Phenocrysts of pinkish orthoclase, up to 3 mm. in diameter, compose about 15 percent of the rock while phenocrysts of magentite have a maximum diameter of 1 mm. and constitute marly 5 percent.

The thin slice displays a porphyritic hypautomorphic granular texture with phenocrysts exceeding the volume of the groundmass in a ratio of approximately 3 to 1. The groundmass is predominantly composed of interstitial microcrystalline quartz. Phenocrysts of feldspar make up 60 percent of the composition of which plagioclase in the oligoclase-andesine range accounts for 45 percent and orthoclase the remaining 15 percent. Both are slightly to moderately corroded and have been somewhat sericitized. They are euhedral to subhedral and predominantly lath-shaped with a maximum length of 2 mm. Accessory minerals, magnetite and apatite, are present in the amount of 3 to 1 percent, respectively. Secondary hydrothermal alteration products, chlorite and sericite, compose about 7 percent of the rock.

Diorite. The greatest areal extent of any of the three intrusive types embraced within the dacitic-dioritic group is that of the diorite. A small butte rising about 75 feet above the surrounding terrain and covering an acre is composed of this rock. The intrusive is located on the headwaters of South Fork Trout Creek in the NE$\frac{1}{4}$ NE$\frac{1}{4}$ Section 22, T 18 S, R 25 E. As was the porphyritic dacite, the diorite also was intruded into graywacke of probable

Pennsylvanian age. Soil mantle obscures much of the diorite, but its presence is easily recognized by the locally strong magnetic influence upon the compass needle.

A brownish limonitic stain occurs on the weathered surface but a fresh specimen displays a grayish speckled color. The rock has a medium-grained phaneritic texture with gray laths of plagioclase, greenish pyroxene, and black magnetite crystals visible to the unaided eye. The maximum grain size is represented by the plagioclase which is commonly 2 mm. in length.

As seen under the petrographic microscope, the texture is hypautomorphic granular with individual crystals reaching a maximum length of 2 mm. Euhedral and subhedral laths of plagioclase, in the oligoclase-andesine range, are predominant and compose 70 percent of the rock. The presence of sericite within the plagioclase laths is indicative of moderate to extreme hydrothermal alteration in which the feldspar is occasionally obliterated. Surrounded by the plagioclase are embayed euhedral to subhedral crystals of pigeonite, making up 5 percent of the composition, and fibrous green chlorite that constitutes an additional 10 percent of the rock. Chlorite, apparently, is a replacement of earlier pyroxene and feldspar, at least in part, was replaced by this mineral. The accessory mineral magnetite composes about 10 percent and occurs in euhedral to subhedral crystals that are enclosed by thin rims of secondary limonite. Sericite is present as a hydrothermal alteration product of the feldspars in the amount of 3 percent.

Width of Intrusives

Porphyritic dacite has the least width of the three types, being only 3 to 4 feet wide. The dacite porphyry has a maximum width of 30 feet and the mean diameter of the diorite intrusion is approximately 200 feet.

Structural Relations and Time of Intrusion

The porphyritic dacite strikes parallel to beds of Spotted Ridge graywacke and is otherwise also considered to be concordant. Concordant relations are expressed also by the dacite porphyry. The diorite, it appears, bears no concordant relations to enclosing Spotted Ridge graywacke and is presumably a dike. At none of these intrusive contacts was seen any indication of contemporaneous metamorphic effects.

Rocks of dacitic and dioritic composition were injected into strata of Pennsylvanian or older age, thereby establishing a post-Pennsylvanian age as the lower limit of the time of intrusion. In defining the upper limit, considerable difficulty is encountered and a negative approach becomes a necessity. As intrusives of this composition do not occur in beds of Mesozoic or younger age, the intrusions occurred after deposition of the youngest Paleozoic formation and before accumulation of the Triassic Bailey Formation. Based upon this reasoning, the time of injection tentatively has been placed in the Permian; however, a Lower Triassic intrusive age cannot be disproved.

Rhyolitic and Basaltic Intrusives

In comparison with other intrusives of the Suplee area, the rhyolite porphyry and basalt vitrophyre are very much more extensive. The rhyolite porphyry pluton strikes in a northerly direction and is located, generally, in the extreme southeastern portion of the area, whereas the basalt vitrophyre cuts diagonally to the rhyolite and is confined to the Smith Basin area, north of the rhyolite.

Rhyolite porphyry. This intrusive rock crops out over approximately one square mile and occurs in three roughly lens-shaped northerly-striking strips through sections 2, 11, and 14 of T 18 S, R 25 E. The outcrops may be seen along a rather high ridge which stands from 500 to 700 feet above the surrounding terrain; the highest of these outcrops is 5500 feet above sea level. Massive bluff-forming outcrops sparsely dot the entire area of the intrusion.

The weathered rock is dark brown to nearly black, whereas the fresh surface is tan to light brown. The rock has a porphyritic texture with phenocrysts, set in an aphanitic groundmass, occasionally attaining a diameter of 2 mm. These phenocrysts of light-colored plagioclase are locally abundant, but generally do not exceed the volume of the groundmass.

The thin slice substantiates the porphyritic aphanitic texture that was seen in the hand specimen. In transmitted light, phenocrysts of quartz, albite, and orthoclase, each averaging about 15 percent of the composition, are relatively clear in sharp contrast to a greenish spattered groundmass of glass and interstitial quartz.

Orthoclase and albite are fresh and occur in euhedral to subhedral crystals which are occasionally embayed. Much of the quartz is euhedral and has a border of second generation quartz absorbed from the groundmass in a ragged rim about the original prismatic crystals. (See fig. 15). Interestingly enough, this absorbed second generation quartz has the same orientation as the euhedral crystal. Nearly 15 percent of the rock is composed of chlorite occurring in the groundmass and apparently caused by hydrothermal action. The accessory minerals are apatite and magnetite which make up about 2 percent of the rock.

Basalt vitrophyre. Intrusive basalt vitrophyre crops out over an area approximately equal to that of the rhyolite porphyry, or one square mile. It occurs in three disconnected bodies roughly surrounding Smith Basin with the larger body extending eastward to the Henry Bernard Ranch. The area intruded by basalt vitrophyre is included within sections 27, 33, 34, and 35 of T 17 N, R 25 E. The underlying intrusive is expressed on the surface by rugged bluffs and low abrupt cliffs which are particularly in evidence on the ridge between Smith Basin and the Henry Bernard Ranch. (See fig. 12, p.52)

A reddish brown dull vitreous surface is typical of this very brittle igneous rock. The fresh specimen is black, almost glassy, and has a porphyritic aphanitic texture. Phenocrysts of dark prismatic plagioclase make up about 20 percent of the rock; these have a maximum length of 7 mm. and a median of 2 mm.

In the thin section, the rock is seen to be a porphyritic aphanite with a hyalopilitic texture in the groundmass. Phenocrysts are prominent, but do not exceed the volume of the groundmass; the ratio of groundmass to phenocrysts is about 3 to 1. Euhedral labradorite laths have a maximum length of 7 mm., and a 2 mm. width, although they are generally smaller. The labradorite is fresh, slightly to moderately embayed, contains inclusions of anhedral pyroxene and magnetite, and accounts for 25 percent of the rock. Amounts of other minerals are 4 percent pigeonite, 2 percent antigorite, and 1 percent magnetite. These are found partly as inclusions in the plagioclase laths and partly as individual phenocrysts. Euhedral to anhedral pigeonite is considerably embayed and partly to completely replaced by antigorite. The latter mineral is a very brilliant greenish-yellow in polarized light and under crossed nicols appears in aggregates of fibrolamellar structure. Since antigorite is, practically in all cases, an alteration of some other silicate mineral such as olivine, enstatite, augite, etc., it may follow that its association with pigeonite in this basalt indicates partial replacement of the pigeonite by antigorite. Magnetite occurs as euhedral crystals embedded in larger phenocrysts of labradorite and pigeonite and also finely disseminated through the groundmass. This groundmass appears nearly black in transmitted light, but crystallites, microlites (labradorite?) and trichites, may easily be seen with aid of the high power objective lens. (See figs. 13 & 14, p.59)

Figure 13. Basalt vitrophyre. Phenocrysts of labradorite and pigeonite in a hyalopilitic groundmass. Crossed nicols. x37.5

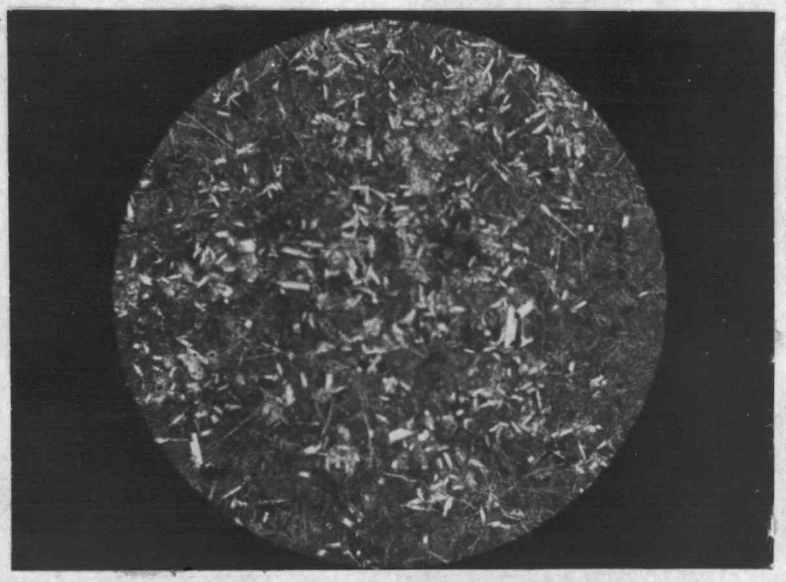


Figure 14. Basalt vitrophyre showing the hyalopilitic groundmass. Note the microlites and hair-like trychites. Plain light. x75

Width of Intrusives

The widest part of the rhyolitic pluton, as measured on the surface, is approximately 3000 feet. Since the sill is apparently concordant with nearly vertical beds of Paleozoic age, it seems probable that the figure is representative of the maximum width.

The attitude of the basalt vitrophyre is obscure and so it is not known whether this pluton is a dike or sill. The maximum surface exposure is approximately 2000 feet wide.

Structural Relations and Time of Intrusion

A portion of the rhyolitic intrusion is in contact on the west with rocks of Paleozoic age and on the east with those of Jurassic age; however, most of it is confined within one or the other. The pluton is generally parallel in strike to Paleozoic strata but slightly discordant with reference to Jurassic beds. In terms of shape, it is probable that this pluton is a sill intruded into Paleozoic and, possibly, Triassic strata.

Discordance is expressed by the basalt vitrophyre at all outcrops trending diagonally across the strike of Paleozoic and Triassic sediments. A nonconformity exists where Jurassic Colpitts sediments were deposited upon the intrusive. A crustal weakness in the Smith Basin-Henry Bernard Ranch area is indicated by a northwest-striking fault through that region; whether this weakness is the result or cause of the basaltic intrusion is a matter of speculation.

The intrusion is younger than the Upper Triassic Bailey Formation which it invaded. That both the rhyolite and basalt were already in place before deposition of the middle Jurassic Colpitts Group is indicated by rhyolite porphyry cobbles occurring in the Colpitts conglomerate and by the nonconformable relations between overlying Colpitts sediments and the basalt vitrophyre. According to these relations the intrusion of both rock types must have occurred during late Triassic or early Jurassic times. For purely conventional reasons, a late Triassic intrusive episode is preferred.

BAILEY FORMATION

Triassic rocks occurring near Suplee were named the Bailey Formation by Edward Schenk (30, pp.1-53) who made a paleontologic and geologic study of these beds. Although limited in extent in the Suplee area, the Bailey Formation is quite prominent farther to the east.

Areal Distribution and Topographic Expression

Occurring on a very small scale in comparison to the extensive outcrops farther east, the Triassic rocks cover only two square miles in the vicinity of Suplee. Another half a square mile area of Triassic sediments is located near Wade Butte.

With the exception of two small limestone "knobs" at the Henry Bernard Ranch, the presence of these steeply dipping, truncated beds is recognized only by a few beds of resistant sandstone which protrude slightly above the surface. Roadcuts have facilitated the observation of fissile calcareous shale and fine-grained sandstones that are interrupted occasionally by thin beds of coarse conglomerate. A coarse conglomerate probably of Triassic age lies stratigraphically above Permian rocks in the Wade Butte area.

Lithology

Clastic sediments predominate, and of these the most abundant are arenaceous and argillaceous limestones. These two varieties of limestone are included with calcareous sandstone, limestone, and conglomerate of various composition to form the recognized lithologic types of the Bailey Formation.

Limestone. A bed of massive limestone crops out at two points on the Henry Bernard Ranch two miles south of Suplee. It is a dark gray compact crystalline calcitic limestone that weathers to a lighter shade of gray. Fracturing of this compact limestone produces sharp edges. Well preserved brachiopods and pelecypods are present and are representative of an abundant fauna.

Argillaceous limestone. The argillaceous limestone is a light brownish colored calcareous rock that occurs in the Bailey Formation. It is well bedded, poorly indurated, and easily broken down through physical weathering. Since it effervesces easily in cold acid, the composition is probably, for the most part, fine particles of detrital calcite. Other minerals are no doubt present but were not identified.

Similar material occurs as the matrix of conglomerates, but the argillaceous limestone is generally found interbedded with indurated arenaceous limestone. The incompetent nature of this argillaceous limestone is shown by minute folds and displacements.

Arenaceous limestone. The arenaceous limestone is a light colored medium-grained calcareous rock that has a faint greenish cast on the fresh surface. Weathering has produced a yellowish brown limonitic stain on the outcrop. Rounded to subrounded grains of quartz, vari-colored chert, and calcite are seen in the hand specimen of which the calcite accounts for about 65 percent of the composition. The diameter of these grains ranges up to 1.0 mm. and averages about 0.5 mm. This variety of limestone is very durable.

A variety of the previously described arenaceous limestone is coarser-grained and has a somewhat different composition. The rock has the same light color, but differs in that fragmental crinoid stems and oolites form an important constituent. Angular fragments of light colored calcite contrast with a pale greenish chloritic matrix, that latter accounts for 10 percent of the composition. Oolites, crinoid stems, and calcite range from 1.0 mm. to 5.0 mm. in diameter.

In the thin section, the arenaceous limestone is seen to have an inequigranular coarse-grained texture. It is composed of angular to rounded grains that range up to 3 mm. in diameter of which 30 percent is clastic calcite, 25 percent oolites showing distinct growth rings, 20 percent igneous rock fragments, 10 percent microcrystalline quartz, 2 percent plagioclase, and 3 percent calcareous organic material. The interstices are filled with pale greenish chlorite that accounts for an additional 10 percent of the rock. Crinoid stems and bryozoa are representative of the organic material that was seen and they appear partially silicified. (See fig. 16, p.65)

Conglomerates. Three distinct conglomerate types occur within the Bailey Formation. The first two differ mainly in the character of the matrix, whereas the third type differs in composition and is predominantly composed of igneous derivatives.

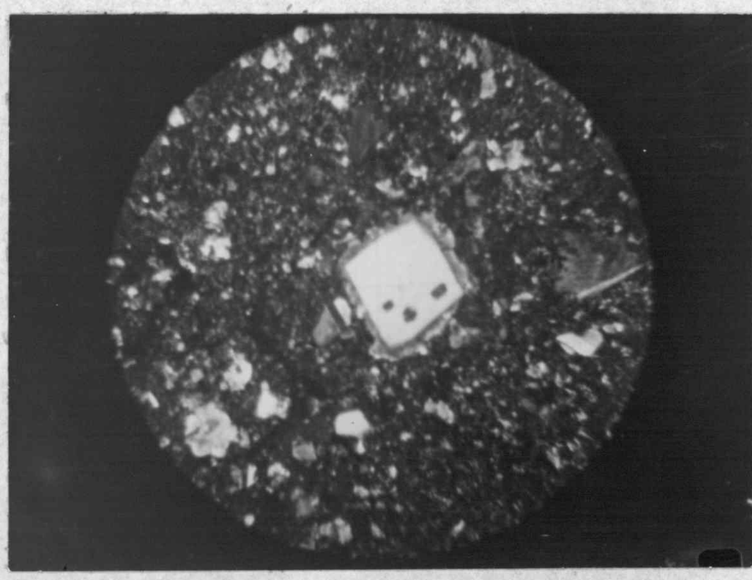


Figure 15. Rhyolite porphyry showing prismatic section of quartz with ragged rim of second generation quartz. Crossed nicols. x75

bryozoa

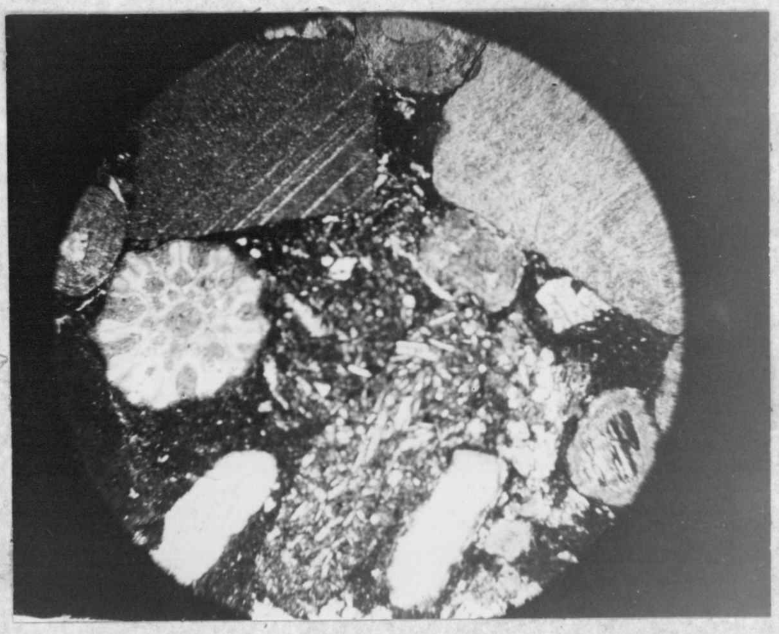


Figure 16. Arenaceous limestone showing crinoid stem and oolites. Note clastic fragments of calcite and igneous rocks. Crossed nicols. x37.5

A poorly indurated conglomerate is composed of pebbles, cobbles, and boulders, which reach a diameter of 12 inches, of grayish black fine-grained crystalline limestone. The matrix is a light brownish incompetent calcareous material.

The well indurated conglomerate is unsorted and unstratified. Its pebbles, as much as 3 inches in diameter, are generally rounded to subrounded and composed of limestone, vari-colored chert, and calcareous sandstone.

Pebbles and cobbles which have a maximum diameter of 8 inches are strewn on the surface in the Wade Butte area, having weathered out of an underlying conglomerate. Approximately 70 percent of them are igneous, dominantly an aplitic granite and subordinately a basalt porphyry. The remainder is composed of pinkish quartzite.

Thickness of the Bailey Formation

The Bailey Formation is estimated to be 800 feet thick in the vicinity of Suplee. The section of Triassic rocks becomes thicker to the east of the area in the main region of their exposures. The sediments there are reported by Robert Nesbit (18, p.11) to be more than 12,000 feet thick.

Origin and Conditions of Deposition

Sediments of the Bailey Formation are predominantly calcareous and contain faunal evidence in support of a marine environment of deposition.

Detrital quartz, feldspar, calcite, chert, limestone, and igneous rock occur in the Bailey beds, having been derived from older rocks in the region. Limestone cobbles containing fossils of Permian age suggest that a large portion of this material probably was obtained directly from upwarped beds of the Permian; however, it appears likely that all the Upper Paleozoic beds known to occur in this area were exposed and made some contribution to the formation of the Upper Triassic sediments.

An accretionary origin is postulated for the massive limestones that crop out in the Henry Bernard Ranch area and it is believed that these limestones may represent Triassic biostromes. These limestones are heavy with pelecypods, brachiopods, and crinoid stems.

The climatic conditions during deposition of the Bailey sediments may have been tropical or subtropical if the biohermal limestone is considered to be the key as biostromes and bioherms now are limited to areas between latitudes of 32 degrees north and 29 degrees south. It also appears that deposition occurred in shallow coastal waters. According to Pettijohn (27, p.301), oolites, which occur in some of the arenaceous limestones, are very characteristic of shallow, strongly agitated waters as would be found along the beaches. The occurrence of interbedded argillaceous and arenaceous limestones is indicative of the fluctuating nature of the epeiric Triassic sea.

Stratigraphic Relations and Age

The Bailey Formation is unconformable with both underlying Paleozoic and overlying Jurassic rocks as shown by distinct angular differences of dip and strike between the Bailey Formation and other formations. An intrusion of basalt vitrophyre was injected, with probable discordance, into the Bailey Formation as may be seen south of Suplee at the Henry Bernard Ranch.

The age of the Bailey Formation has been determined by E. T. Schenk (30, pp.18-19) which was based upon paleontologic work. One of Schenk's localities was near the Henry Bernard Ranch and this section was correlated with the Upper Triassic of Brock Mountain, Shasta County, California. The section is correlative with the *Juvavites* subzone, *Tropites subbullatus* zone of the Karnic stage. The Karnic is of Upper Triassic age.

COLPITTS GROUP

Sediments of Jurassic age which occur in the Suplee area were named the Colpitts Group by R. L. Lupher (9, p.229). The Weberg and Warm Springs formations are divisions of the Colpitts Group, but were not mapped separately. These sediments are an extension of the more extensive Jurassic outcrops known farther east.

Areal Distribution and Topographic Expression

Marine sediments of the Jurassic system here crop out over an area of approximately two square miles. Most of the exposures are in the southeast portion of the area between the Weberg Ranch and the Henry Bernard Ranch and in Smith Basin. Another very small area of outcrops occurs near Wade Butte.

The most notable topographic feature in the area of Jurassic rocks is the northwest-southeast trending ridge that lies one-half mile southwest of Suplee. The more resistant part of the ridge is held up by a graywacke sandstone that projects along the summit. This ridge is 5200 feet above mean sea level and about 500 feet above the surrounding terrain. Similar resistant sandstones produce rugged flatiron-like outcrops in the Weberg Ranch area.

Smith Basin is underlain by calcareous shales and sandstones which can be seen on the scraped road, but otherwise crop out very little.

Lithology

The Colpitts Group is predominantly composed of clastic sedimentary rocks formed by accumulation and compaction of detrital minerals and rock fragments. The beds are characterized by a series ranging in texture from fine-grained shales to conglomerate and in composition from limestone to graywacke. Argillaceous and arenaceous limestone, conglomerate, and subgraywacke are the principal lithologic types of the Colpitts Group. Megafossils were seen at many of the outcrops, but these fossils generally were poorly preserved.

Limestone. This pure variety of accretionary limestone is extremely scarce. Only one bed that had a thickness of 4 inches was seen within the Colpitts beds and it was found on the southeastern periphery of Smith Basin one mile southwest of Suplee in the SE$\frac{1}{4}$ SE$\frac{1}{4}$ NE$\frac{1}{4}$ Section 34, T 17 S, R 25 E.

The rock is light brownish on the weathered surface and dark grayish black on the fresh fracture. It is compactly crystalline and has a subconchoidal fracture. This limestone has a fine-grained sugary texture. The composition is predominantly calcium carbonate, as no other minerals were noted in the hand specimen.

This thin bed of crystalline limestone is the only source of cephalopod fossils seen in the Suplee area of Jurassic outcrops.

Argillaceous limestone. The argillaceous limestones are abundant in the Colpitts Group and occur at most outcrops. They are particularly notable in the Smith Basin area.

Some beds of argillaceous limestone are well lithified and very fissile, but many are poorly resistant and break down easily under the weathering elements. They are variable in color from light to dark brown.

The laminated character of this rock is strikingly revealed under the petrographic microscope. These laminae range between 0.25 mm. and 3.00 mm. thick. The texture is fine-grained with individual particles usually under 0.2 mm. in diameter. The rock is composed predominantly of calcite that has undergone some recrystallization, but minor amounts of very angular quartz and feldspar are included. The individual lamina are bounded by what appears to be a limonitic stain.

Arenaceous limestone. The arenaceous limestones are prominent in the area and are generally brownish gray in color. At one locality, this rock was found unsorted and unstratified within a bed four feet thick. The arenaceous limestone is well lithified and displays good fissility parallel to the plane of bedding. Calcite in rounded grains is the only mineral visible to the unaided eye. A few pelecypods are present, but are not well preserved. Some of the arenaceous limestone beds contain concretions of limestone as much as 12 inches in diameter. (See fig. 17, p.72)

As seen under the petrographic microscope, this rock has a typical medium-grained inequigranular texture. Rounded to subrounded calcite is the principal constituent and composes about 80 percent of the rock. Some of the detrital calcite fragments have a diameter of 1.5 mm., but are generally under 1.0 mm. Quartz and plagioclase

Figure 17. Outcrop of Colpitts small cobble conglomerate overlying a bed of medium grained arenaceous limestone. Nøte concretions in arenaceous limestone.

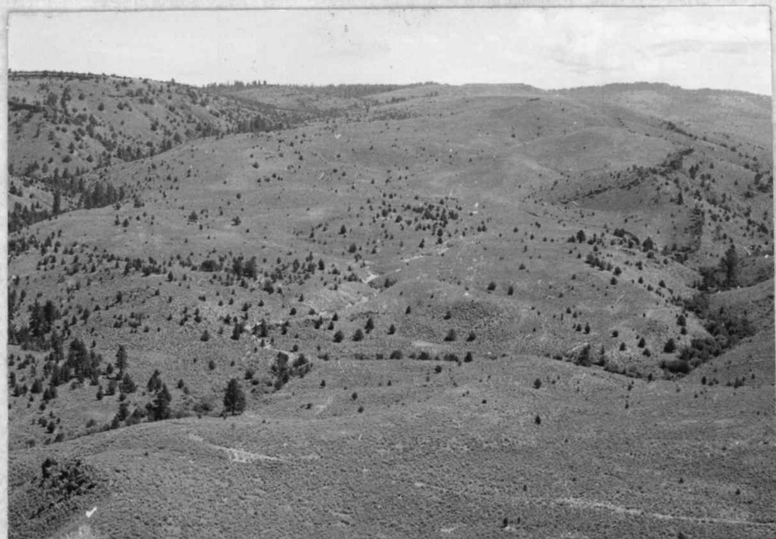


Figure 18. Looking east along South Fork Beaver Creek. Cretaceous sediments are exposed under Columbia River Basalts in the extreme right. Basin formed by displacement along central and Beaver Creek faults.

occur in the amount of 8 percent and 2 percent respectively and are found in small angular to subangular fragments about 0.1 mm. in diameter. The matrix accounts for the final 10 percent of the composition and is predominantly made up of greenish chlorite. A brownish limonitic stain occurs along the fractures.

Subgraywacke. The subgraywacke crops out half a mile southwest of the Suplee Post Office on a high ridge between Smith Basin and the post office. Beds of similar composition and texture occur at many other Colpitts localities and are interbedded with conglomerates, and argillaceous and arenaceous limestones.

The typical subgraywacke has a light brownish color and a medium-grained texture. Its resistant character is directly attributable to the high degree of induration. A few of the grains are 2 mm. in diameter, but the average diameter is a little less than 1 mm. It is visibly composed of rounded and subrounded grains of gray to black chert, some reddish chert, and quartz. Very poorly preserved invertebrate fossils are present.

The texture, as seen in the thin slice, is medium-grained inequigranular. The larger fragments are rounded to subrounded, whereas smaller fragments are angular to subangular. Chert is the principal component, accounting for 50 percent of the rock. Quartz occurs in the amount of 15 percent while 10 percent is rock fragments of igneous derivation, 5 percent is represented by detrital calcite, and less than 2 percent of feldspar and magentite occur. A chloritic matrix is present in the amount of 15 percent.

Conglomerates. Although not particularly conspicuous or abundant, conglomerates are present within the Colpitts Group and of these, pebble conglomerate is most predominant. The less important boulder conglomerates contain subrounded boulders that attain a maximum diameter of 3 feet. The colors are not distinctive, but generally vary from buff to a dark reddish brown on the exposed surface. These conglomerates are characteristically unstratified and usually unsorted, although some sorting is evident in the pebble conglomerates. Durability of the outcrops is controlled by the type of matrix, whether calcareous or graywacke. Calcareous matter binding the conglomerate is fairly well indurated, but the subgraywacke matrix produces a high degree of induration.

Three compositional types of conglomerate were recognized: Those containing chert, those made up of limestone, and a variety in which there is a mixture of both more or less supplemented with igneous rock derivatives. The chert is distinctively vari-colored and is to a large extent the main constituent of the pebble conglomerates. Igneous rocks found in conglomerates of mixed composition are rhyolite porphyry and presumably from the intrusive sill in the same area.

Pebbles, cobbles, and boulders of limestone are rounded to subrounded, whereas the more resistant chert is not so well rounded. An exception is the chert pebble conglomerate that contain well rounded materials.

Thickness of Jurassic Sediments

There are no less than 500 feet of exposed Jurassic sediments within the area and Lupher (9, p.227) reports more than 16,000 feet in the main region of exposures situated to the east.

Origin and Conditions of Deposition

The sediments of the Colpitts Group were deposited principally in a marine basin of accumulation as is indicated by an abundance of invertebrate marine fossils.

Clastic sediments predominate, although one bed is composed of an accretionary limestone with a very prolific ammonite fauna. These clastic sediments are high in chert and limestone content, suggesting that they may have been reworked from Triassic beds and probably, in part, from Paleozoic strata. That some of the limestone pebbles, cobbles, and boulders were extracted from pre-Mesozoic rocks is proved by the included Paleozoic fossils.

Marine fossils which occur in the subgraywackes, as well as in the argillaceous and arenaceous limestones, bear witness to a marine environment of deposition. According to Pettijohn (27, p.257), subgraywacke is the most characteristic sediment of post-orogenic belts and is mostly marine. Krumbein and Sloss (31, p.134) state:

> "Subgraywacke occurs under conditions of moderate subsidence in unstable depositional areas, and in sedimentary basins where the rate of bureal is rapid enough to prevent thorough winnowing action by transportational agents. Common associations include silty shale and thin, nodular limestone."

Much of the sedimentary material must have been deposited in very shallow water along the beaches; although a greater depth is suggested by the limited ammonite faunule. According to Scott (2, p.43), ammonites seemed to have thrived best in the water between 20 and 100 fathoms deep. Although 100 fathoms is still fairly shallow, and if these ammonites accumulated at the depth in which they lived, the fluctuating depth can be visualized.

In conclusion, it is probable that seas inundated this Central Oregon area much as they had done during previous ages. That the waters were relatively shallow is inferred from prominent coarse clastic sediments and sedentary marine organisms. There were, probably, moderate highlands composed of Triassic and Paleozoic sediments, as well as intrusive rocks, which were material sources for the accumulating Jurassic beds.

Stratigraphic Relations and Age

A distinct unconformity separates rocks of Triassic age from those of the Jurassic as shown by a very notable discrepancy between dips and strikes of Triassic and Jurassic strata.

The contact with overlying Cretaceous sediments was not seen in the field, but the stratigraphic break, lacking Upper Jurassic and Lower Cretaceous rocks, is indicative of a long period of non-deposition or else subsequent stripping of those beds. Significantly lower dips of Cretaceous rocks, as compared to those of the Jurassic, support the existence of an unconformity.

In the western portion of Smith Basin, Tertiary Columbia River Basalts rest unconformably upon argillaceous and arenaceous limestones of Jurassic age.

The sediments of the Colpitts Group were deposited non-conformably on and around the rhyolite porphyry and basalt vitrophyre intrusives while they stood above the surrounding Triassic and Paleozoic strata.

Lupher (9, p.254) found an abundant ammonite fauna within the Colpitts beds and used these ammonites as the basis for his correlations. He determined that the time corresponded to the Upper Aalenian and Lower Bajocian stages of Europe. These stages may be regarded either as earliest Middle Jurassic, or as latest Lower Jurassic. Following is the characteristic ammonite fauna found in the Colpitts Group of Central Oregon as determined by Lupher.

Tmetoceras n. sp., cf. *T. scissum* (Benecke)
Emileia sp.
Deltostrigites sp. Buckman
Hebetoxyites sp. Buckman
Euhophoceras sp. Buckman
Docidoceras, several new species
Deltostrigities n. sp., cf. *D. deltotus* Buckman
Zugophorites, several new species
Zuggela, several new species

UPPER CRETACEOUS

Rocks of Cretaceous age occur in the Suplee area. They have not been formationally named in this area.

Areal Distribution and Topographic Expression

The total area covered by Cretaceous sediments is approximately three square miles. These exposures trend in a southerly direction from South Fork of Beaver Creek, over a divide, and into the Camp Creek valley where they terminate one-half mile southwest of Soda Spring.

The most prominent exposures of Cretaceous strata occur on the north side of the South Fork Beaver Creek where fairly well indurated beds of light colored medium-grained sandstones and pebble conglomerates protrude from the steep canyon slope. Outcrops in other portions of the area are not so pronounced. Sandy shales and conglomerates are exposed in roadcuts and only rarely break the surface where undisturbed. These conglomerates, for the most part, are composed of quartzite pebbles and cobbles which may be seen strewn on the surface and suggest the presence of underlying beds of conglomerate. (See fig. 18, p.72)

Lithology

Shale, subgraywacke, and conglomerate constitute the principal Cretaceous lithologic types. These beds represent the only pre-Tertiary formation in the area in which there apparently is complete absence of calcareous materials.

Shale. Shales, with a thickness from 200 to 300 feet, were seen along the graded road between Suplee and the Andrew Bernard Ranch. They are occasionally interbedded with thin beds of subgraywacke.

These friable shales are light brownish in color and have a fine grained texture. They are, in part, finely laminated. Exposure to physical forces reduces these poorly lithified shales to soil within a short period.

Subgraywacke. Medium- to coarse-grained sandstones of a subgraywacke composition are the most prominent Cretaceous rocks. They occur as individual beds from 2 to 40 feet thick interbedded with shale and conglomerate. The subgraywackes are most distinctive on the north side of South Fork Beaver Creek canyon.

A dark reddish brown limonitic stain is typical of the weathered surface. In sharp contrast is the light grayish colored fresh piece. The most conspicuous constituent is biotite. Subrounded grains of vari-colored chert also are apparent. Cleavage flakes of biotite range between 0.5 mm. and 1.0 mm. in diameter and lie parallel to the plane of bedding. Subangular to subrounded quartz is typical of this sandstone. This rock, at one locality, was seen to grade downward into a coarser-grained sandstone and then into a pebble conglomerate. Biotite and chert fragments are still present, but the degree of angularity of pebble size fragments increases markedly. These coarse grained subgraywackes and pebble conglomerates frequently contain many fossil pelecypods and gastropods.

With the aid of the petrographic microscope, this rock is seen to have a medium-grained texture and a grain size that ranges from 0.5 mm. to 1.0 mm. in diameter. Subangular rock and chert fragments compose 60 percent of the rock and are present in an equal proportion. Rock fragments are detrital products of both aphanitic and phaneritic igneous rocks. Chert is represented by grains of microcrystalline and cryptocrystalline quartz; the latter variety is clouded with a brownish color. Quartz makes up an additional 15 percent of the rock. Less important, but nevertheless characteristic, is biotite, that composes about 5 percent. Other minerals present are 5 percent magnetite, 3 percent oligoclase, and 3 percent olivine. The matrix composes about 10 percent of the rock and is predominantly chloritic. A small portion of the chlorite is detrital, but it is mainly a hydrothermal alteration product.

Thin slices cut normal to the bedding plane show linear arrangement of the grains. This characteristic is shown particularly by cleavage flakes of biotite that have their C-axes normal to the bedding plane.

Conglomerate. The compositional aspects of the conglomerates are fairly uniform. Variation in rock size is the most important criteria for differentiation. Pebbles and cobbles within the conglomerates are usually rounded or subrounded. Larger rounded rocks of boulder size occur as float and were probably derived from underlying beds of conglomerate. These conglomerates have undergone fair sorting and where interbedded with graywacke appear stratified. One of the best exposures of Cretaceous conglomerate is at a borrow pit near Soda Spring.

Light-colored quartzite pebbles and cobbles are prominent to predominant within the conglomerates. Other constituents include chert and igneous rock fragments. The igneous rocks are usually lighter in color than the chert and range from an acid to medium basic composition. The matrix is generally a sandy material. The quartzitic materials, which are very resistant, weather out of the sandy matrix and may be seen strewn on the surface over much of the area of underlying Cretaceous rocks.

Thickness of Cretaceous Sediments

As estimated from the difference in elevation between bottom and top exposures in the Beaver Creek canyon, there are 500 to 600 feet of shales, sandstones, and conglomerates of Cretaceous age exposed in the Suplee area. The maximum thickness occurs along a northeast-striking fault that crosses South Fork Beaver Creek near the Andrew Bernard Ranch. The thickness decreases southward and on the south side of Camp Creek only a thin layer of it covers the older rocks.

Origin and Conditions of Deposition

It seems probable that the various mineral and rock constituents in the Cretaceous strata were derived, in part, from the older formations that have been discussed. That they were not derived solely from uplifted and folded Jurassic beds is inferred from the stratigraphic position of the Cretaceous rocks upon both Triassic and Paleozoic formations.

Speculation as to the source of the quartzitic materials can be made, but the origin is definitely obscure. These quartzite pebbles and cobbles are a prominent constituent of the Cretaceous beds in the Spanish Gulch area of the north portion of the Dayville Quadrangle and so are not a local aspect (2, p.31). Thick beds of Triassic conglomerates, including quartzitic materials, occur in the Wade Butte area and were also noted by Merriam (15, p.159) south of the Dayville Quadrangle. Quartzite pebbles and cobbles were not found in the Jurassic sediments so, possibly, can be directly attributed to a Triassic source. The physical and chemical stability of the quartzite material suggests that it may have undergone several periods of reworking and may have been formed as a bed of quartzite far back into Paleozoic times.

The absence of calcareous materials in the Cretaceous beds suggests the probability that calcium carbonate may have gone, at least in part, into solution to be precipitated elsewhere at a later time. If this was the case, then the more resistant silicates and oxides may have been the residual product which accumulated in the shallow Cretaceous sea.

Marine deposition of these Cretaceous sediments is clearly indicated by the occurrence of fossils of marine invertebrates. Several species of pelecypods and gastropods are present of which the pelecypod *Trigonia* is particularly abundant.

The sediments were deposited both in very shallow and in deep water, perhaps neritic or bathyal. This is implied from sedimentary grain size and from invertebrate fossils. In using the subgraywacke as a key to the depositional environment, Pettijohn (27, p.257) believes that the subgraywacke may occur in geosynclines, but suggests that they may be more typical of the post-orogenic phase of the orogenic cycle. Fossils imbedded in a pebble conglomerate with a matrix of subgraywacke strongly indicate deposition along the shore in shallow water. Well rounded quartzite cobbles also suggest near-shore deposition.

That a shallow sea extended over this portion of Central Oregon during Cretaceous times is apparent. As in previous periods, there was general subsidence before and during sedimentary accumulation. This subsidence probably was, in part, brought about by the weight of thickening sediments.

Stratigraphic Relations and Age

Steeply dipping Paleozoic, Triassic and Jurassic strata have been truncated and are now overlain unconformably by Cretaceous beds. There is, as well, a sharp stratigraphic and lithologic demarcation between Cretaceous strata, and overlying Tertiary basalts and tuffs. These unconformities are best seen along South Fork Beaver Creek where Columbia River Basalts rest unconformably on the Cretaceous sediments, and these, in turn, lie unconformably upon folded Triassic strata.

Several species of pelecypods and gastropods were collected from two localities. These localities are located on the South Fork Beaver Creek near the Andrew Bernard Ranch and on Camp Creek near Soda Spring. Positive identification was made on the following species although several other less distinct species are present.

Trigonia deschutensis Packard
Acila (Truncacilla) ? demessa Finlay
Trigonia leana Gabb
Bittium duprei Packard
Aprodina nitida Gabb
Corbula sp.

The Trigonias and Acilas are particularly abundant and were found at all invertebrate localities.

This Cretaceous faunule is similar to faunules from both Rock Creek (1, p.37) and from near Dayville (2, pp.43-63) which are found on the north flank of the Ochoco Range and within the Dayville Quadrangle. E. L. Packard (20) reports that the Beaver Creek (Suplee area) and Rock Creek faunules are correlative, and that the faunule from Rock Creek can be correlated with the Chico Formation of California. The age is, therefore, Upper Cretaceous.

CLARNO FORMATION

The Clarno Formation occurs in the northern portion of the Dayville Quadrangle but previously has been unreported in the Suplee area. The formation was named by J. C. Merriam (16, p.71) after Clarno's Post Office on the John Day River east of Antelope, Oregon, where beds of erupted and sedimentary materials occur above Cretaceous marine sediments and below the lowest bed of the John Day Formation.

The rhyolite occurring west of Suplee is without definite limits which are needed to bracket it within a specific time interval, but, lithologically, it is comparable to Clarno rhyolites elsewhere. Its assignment, therefore, to an Eocene age is questionable.

Areal Distribution and Topographic Expression

This formation, as it occurs in the Suplee area, is composed entirely of rhyolite that crops out between Camp Creek and Smith Basin one mile west of the Suplee Post Office and covers one-third of a square mile.

Tan-colored massive outcrops of rhyolite dot the gentle slope to the west of Suplee. Several of the outcrops stand as high as 8 feet above the surface, but generally are less distinct and nearly flush with the surface. Hexagonal columnar structure parallel to the surface is in evidence at a few of the more extensive outcrops.

Petrography of the Rhyolite

The color of the exposed rock surface is predominantly tan; however, green and purple hues occur to a minor extent. The fresh surface is generally a lighter tan color. Limonitic staining is evident, particularly along the fractures. The groundmass has an aphanitic texture and a few phenocrysts impart a porphyritic texture to the rock. Phenocrysts of quartz and feldspar range up to 1 mm. in diameter and constitute less than 5 percent of the rock. The rock has a typical subconchoidal fracture.

The porphyritic texture is verified in the thin section. The aphanitic groundmass is composed predominantly of microcrystalline quartz and, as seen in transmitted light, appears contaminated with a brownish limonitic stain. Phenocrysts of subhedral albite are corroded and compose less than 5 percent of the rock. Less prominent are phenocrysts of crystalline quartz aggregates. Small irregular veinlets are filled with microcrystalline quartz which is apparently of secondary origin. Magnetite occurs finely disseminated through the mass and accounts for approximately 3 percent of the composition.

Stratigraphic Relations and Time of Intrusion

A lenticular shaped body of rhyolite about 4500 feet long and 2000 feet wide, elongate in a northerly direction, is bordered by Paleozoic, Jurassic and Cretaceous strata. Unfortunately, the actual contacts are not visible, and the lack of knowledge about these contacts makes it impossible to establish accurate stratigraphic relations.

The southern portion of the intrusive area displays considerable evidence of movement. This is suggested by slickensides that occur on closely spaced, nearly vertical planes.

The close proximity of this intrusive body to Cretaceous beds forms the only possible basis for a post-Cretaceous time of intrusion and even the relations of the Cretaceous beds and rhyolite are unknown. The rhyolite is petrographically distinct from the rhyolite porphyry which was intruded during late Triassic times, but it may, conceivably, be an aspect of the rhyolite porphyry. The positive time of intrusion is not determinable, but is here tentatively assigned to the Eocene and considered to have affinities with the Clarno Formation.

COLUMBIA RIVER BASALT FORMATION

This formational name was first used by I. C. Russell (29, p.20) to apply to the prominent lava formations that appear in the drainage system of the Columbia River. J. C. Merriam (16, p.467) pointed out that the name should be restricted to the Miocene basalt flows that occur along the Columbia River.

Areal Distribution and Topographic Expression

Columbia River Basalt is the most extensive formation in the Suplee area and covers one fourth of the entire area, or approximately 27 square miles. Powell Mountain and vicinity represent the greatest concentration of basalts, but they are to be found throughout the area. These basaltic flows form the western boundary of the pre-Tertiary inlier, except for about one mile of the 12-mile contact. Basalt is prominent at Wade Butte, Mud Spring Butte, and the south portion of Shaw Table.

The dominant regional topographic control is expressed by Columbia River Basalts flows. Steep walled canyons, particularly along South Fork Beaver Creek and both forks of Trout Creek, expose several dark-colored flows of basalt that generally show vertical columnar jointing. Several low escarpments striking in a northwesterly direction appear in the Wade Butte-Coyote Spring-Trout Creek area. A high cliff is exposed on the west side of the butte that lies on the western edge of Smith Basin. Two outliers of basalt form caps on buttes within the Paleozoic area. Typical of the weathered edges of the formation are narrow talus slides which, particularly as seen from a distance, appear like black stringers in a background of grayish sagebrush.

Petrography of the Columbia River Basalts

Random samples were obtained from the Columbia River Basalt Formation and these, generally, were confined to the top two flows. Only in the Beaver Creek canyon could samples from lower flows be obtained. Diabase and normal basalt are representative of the two top flows, whereas only normal basalt was found in the lower flow in the Beaver Creek canyon.

Diabase flows. These flows are light gray to grayish black in color. The lava has an aphanitic texture and is slightly to moderately vesiculated. A platy parting parallel to the flow surface is characteristic of these flows.

In the thin slice, the texture is seen to be aphanitic inequigranular with a diabsic arrangement of the essential minerals; elongate laths of andesine-labradorite surrounding anhedral augite. Andesine and labradorite are each present in the amount of 30 percent, whereas augite is responsible for 35 percent of the rock. The only other mineral recognizably present is 3 percent magnetite which occurs shot through the mass. (See fig. 22, p.92)

Normal basalt flows. These flows appear very black and have a sub-vitreous lustre on the fresh surface. The rocks are slightly

Figure 19. Looking northwest along South Fork Beaver Creek. Note dipping flows of Columbia River Basalt.

Figure 20. Looking northwest along Camp Creek near its confluence with South Fork Beaver Creek. Butte of Columbia River Basalt.

porphyritic with an aphanitic groundmass. Phenocrysts of olivine, up to 2 mm. in diameter, make up about 3 percent of the rock. Some of these basalts contain zeolite amygdules which are as large as 5 mm. in diameter and are considerably more conspicuous than the smaller phenocrysts of olivine.

The thin slice shows a medium-grained inequigranular ophitic texture. Augite occurs in anhedral crystals from 2 to 3 mm. in diameter with a network of included feldspar laths. The feldspar is labradorite and occurs in elongate prismatic crystals that have a maximum length of 1 mm. and average approximately 0.25 mm. Augite and labradorite are present in nearly equal portions and account for about 90 percent of the rock. Early euhedral magnetite makes up about 3 percent of the rock and it is scattered through the groundmass. Olivine accounts for 2 percent of the rock and it occurs in anhedral crystals. Some of the normal basalt flows contain pale greenish palagonite which constitutes as much as 5 percent of the total composition.

Thickness of Basalt

The estimated maximum thickness of the Columbia River Basalts within the area is 600 feet where it is exposed in South Fork Beaver Creek canyon. There are at least six flows exposed in this canyon, but talus covers the lower slopes, possibly obscuring additional flows. The individual flows vary in thickness from a minimum of 20 feet to a maximum of 65 feet.

Figure 21. View northward along canyon of South Fork Trout Creek cut through Columbia River Basalt. Fault parallels this canyon. Wolf Mountain in distance.

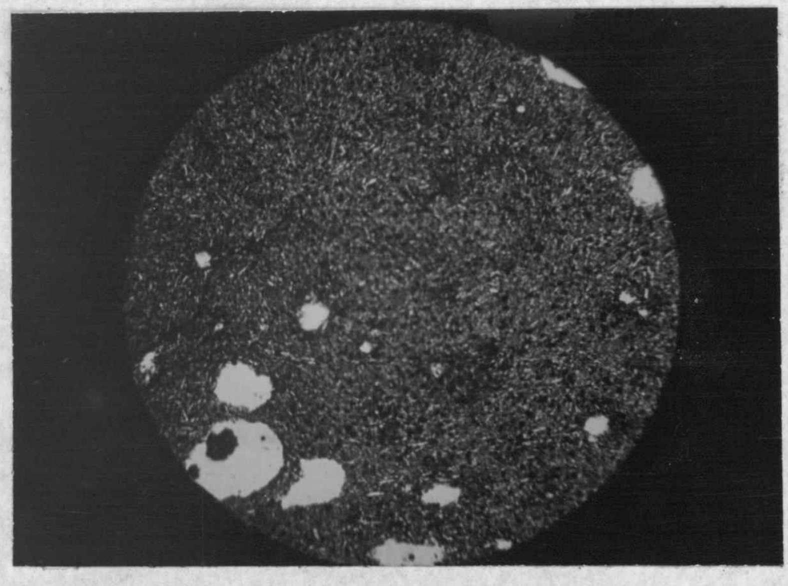


Figure 22. Vesiculated Columbia River Basalt showing high magnetite content. Plain light. x37.5

Source and Mode of Deposition

Earlier workers have concluded, their conclusions based upon information from other localities, that the Columbia River Basalts were fissure type flows which were exuded onto the surface from an underlying magma chamber. Feeder dikes, that must have been the source for the many basaltic flows, were not recognized in the area; however, they have been noted elsewhere within the Dayville Quadrangle (16, p.467).

The rate at which these flows accumulated is partially indicated by thin layers of baked soil which occur between some of the flows. The presence of soils between some flows suggests periods of relative quiescence of sufficient duration for the accumulation of these soil layers. The absence of soil between any two flows does not necessarily indicate a rapid succession of extrusions, since accumulation of a soil mantle may have been prevented by erosion. It appears, however, that these basalts were in the process of accumulation during most of the middle Miocene time.

The accumulation was greatest over negative areas where thicknesses of more than 1000 feet have been reported (16, p.467). This thickness can be contrasted to a single flow 20 feet thick and to localities barren of the formation within the Suplee area. The 20 foot thick flow occurs where these basalts are exposed in an erosional scarp and in contact with pre-Tertiary rocks. This situation may suggest that there were one or more positive areas that stood above the flood of basalts during Miocene time. Support for the existence of a pre-Tertiary "steptoe" may be gained from the fact that the two flows bordering the inlier have not been extensively dissected and retain a relatively constant thickness. This condition may indicate that they are the top, or last, flows of the Columbia River Basalt which abutted against the pre-Tertiary inlier near the end of this period of basaltic accumulation.

Stratigraphic Relations and Age

With the possible exception of the very limited rhyolite of supposed Clarno age, the Columbia River Basalts form the bottom unit of the Tertiary column within the area and are everywhere angularly unconformable upon the folded Mesozoic and Paleozoic rocks. This relation is best observed along the western perimeter of the pre-Tertiary inlier and also in the Beaver Creek canyon near the Andrew Bernard Ranch where these lavas overlie Cretaceous marine sediments.

A distinct unconformity exists between the basaltic flows and the overlying Shaw Formation. The angular nature of this contact is not everywhere obvious. Shaw dips are seldom more than 5 degrees, whereas the Columbia River Basalts at many places dip 10 degrees and at a few places 25 degrees. Wherever the overlying Harney rim is in contact with the basalts, there is a conspicuous angular unconformity.

The very nature of this formation almost precludes the possibility of finding fossils; however, meager collections have been made between flows in other areas (16, p.561). The age, therefore, is generally based upon the stratigraphic limits formed by underlying John Day beds and overlying Mascall (Shaw Formation?) strata in which are found abundant fossils for a paleontologic correlation. Hence, the time of extrusion and accumulation is limited to the Middle Miocene.

SHAW FORMATION

The Shaw Formation was named by R. L. Lupher (18, p.43) to apply to those tuffaceous sediments that occur at Shaw Table. This formation is similar lithologically and stratigraphically to the Mascall Formation along the John Day River near Dayville; however, insufficient paleontologic collections have delayed correlation.

The name, Shaw Formation, is used here for beds of light-colored volcanic tuff and a thin rhyolite flow member that are stratigraphically above the Columbia River Basalt Formation and below the welded tuff member of the Harney Formation.

Areal Distribution and Topographic Expression

The areal extent of the Shaw Formation is slightly in excess of 25 square miles, second only to that of the Columbia River Basalts. Most of the outcrops lie in the western portion of the area and are exposed beneath the rim of Harney welded tuff as well as on the open bottom lands. The lowland exposures grade, almost imperceptibly into the recent reworked materials referred to as valley alluvium.

This formation displays little relation to the topography except where a few, more indurated beds of tuffaceous sandstone form low escarpments as in the vicinity of the Angell Ranch. The very easily eroded material sometimes appear as grotesque forms molded by wind and water ofttimes referred to as "hoodoos." These may be seen best on the fairly steep slope underlying the Harney rim.

A vitrophyric rhyolite member forms prominent and distinct rims above underlying soft tuffs (See figure 23, p.98). The highest point on Shaw Table, approximately 4700 feet above sea level, is composed of this rhyolite rim-rock. The morphological similarity of the Shaw rim to the Harney rim of Pliocene time requires close inspection in order to make an accurate distinction.

The poorly indurated nature of the tuffaceous materials of this formation contributes to its rapid physical disintegration. This feature is well demonstrated by numerous gulleys and ravines which, by work of fast moving water from torrential downpours, are carved on escarpments and canyon walls underlying either the Harney rim or the Shaw rhyolite flow. An unstable condition results when the tuffaceous materials become saturated with water. The effects of its unstability are expressed by slumping one mile northwest of Soda Spring on Camp Creek. The slumping is especially evident at that locality because the overlying Harney rimrock was displaced as well.

Lithology

The principal lithologic types recognized in the Shaw Formation are tuff, tuffaceous sandstone and conglomerate, and a vitrophyric rhyolite flow. The tuff and tuffaceous materials are predominant, whereas the rhyolite member constitutes only a small percentage of the total thickness.

Tuff. A light color varying from buff to cream is typical of the Shaw tuffs in this region. The texture ranges from fine- to coarse-grained. The high porosity and poor induration of these soft

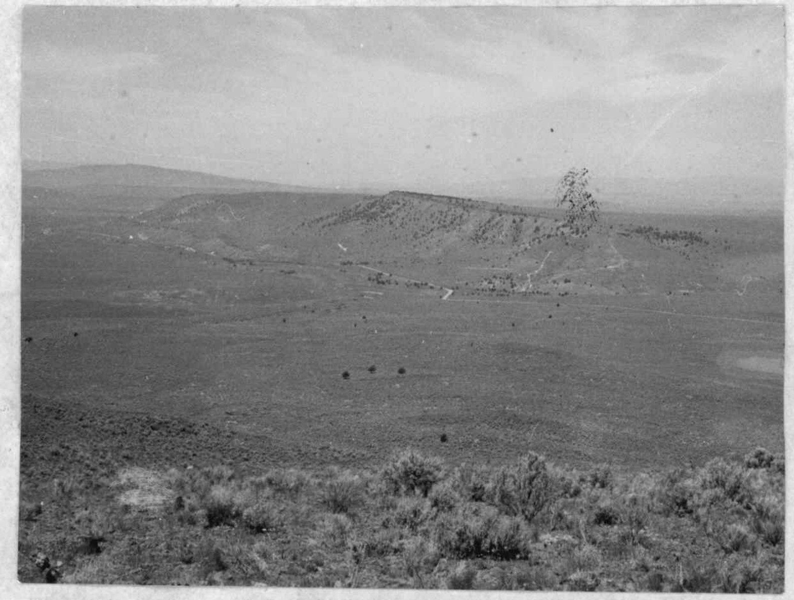


Figure 23. Looking northwest toward Shaw Table. High point in table is rim of vitrophyric rhyolite overlying tuff, both of the Shaw Formation. Lower rim to the left is Harney welded tuff.

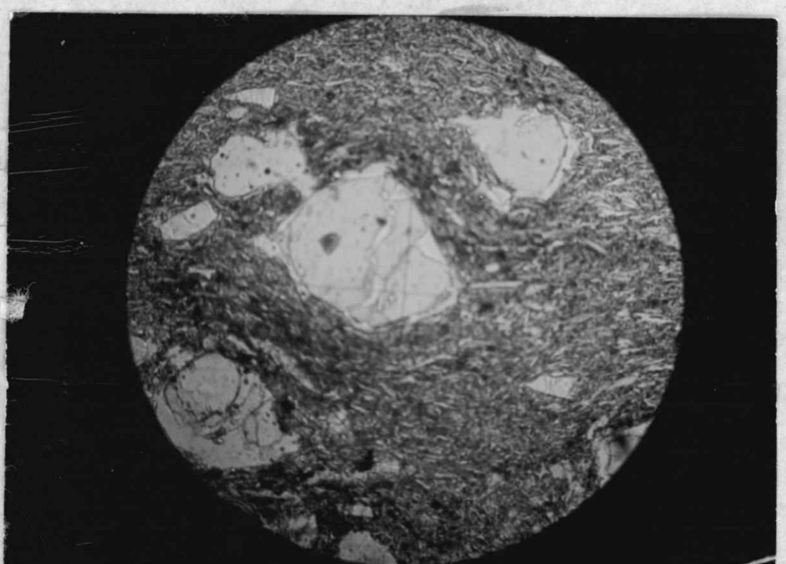


Figure 24. Vitrophyric rhyolite. Note flow structure around quartz phenocrysts. Plain light. x37.5

beds of tuff is conducive to rather rapid weathering and subsequent erosion. Sorting within the mass is not evident. However, stratification is apparent where the tuffs grade into tuffaceous sandstones and conglomerates. In general, the tuffs are composed largely of glass fragments of volcanic ejectamenta.

Typical of the more indurated tuff beds is one which is prominent in a low erosional escarpment in the Grindstone Valley one mile east of the Brennan Ranch. The material there is a grayish white, medium-grained, fairly well indurated volcanic tuff. Set in a matrix of broken glassy bubble-wall fragments are angular fragments of brownish lapilli, pumice shards, and quartz grains which are usually from 2 to 3 mm. in diameter.

Under the microscope, the composition of the rock was found to be predominantly (90 percent) isotropic glass bubble fragments. Subangular to angular fragments of igneous rocks, of albite, Sanidine, and quartz are embedded in the glassy mesostasis. Albite and sanidine have undergone slight corrosion.

A softer tuff that is more abundant is characteristically poorly indurated, fine-grained, and cream-colored. It is speckled with black carbonaceous material suggestive of organic decompositional products. When water is added to the specimen, it assumes clay-like properties and is quite plastic. Under the petrographic microscope, the fine-grained character is substantiated. Almost completely isotropic, the glass bubble walls, which were typical of the tuff described above, are seen to have been almost completely altered to a siliceous colloid. Numerous minute angular fragments of sanidine, albite, and quartz are dispersed through the siliceous matrix.

Tuffaceous sandstone and conglomerate. Somewhat darker in color than the tuffs, these tuffaceous sandstones and conglomerates have included volcanic sands, pebbles, cobbles, and occasional boulders of basalt. Generally, they are more indurated than the tuff and stand out as resistant beds 8 to 10 feet thick. Sorting of the constituent materials is not good, but stratification is usually prominent. Basaltic pebbles are rounded to subrounded, cobbles appear subangular to angular, and boulders, up to 14 inches in diameter, generally exhibit the highest degree of angularity.

Vitrophyric rhyolite flow. This extrusive rhyolitic flow member is perhaps one of the most interesting aspects of the Shaw Formation. It is generally found near the top of the section and, in many places, is the highest stratigraphic portion. The highest point on Shaw Table is represented by this vitrophyric rhyolite. Robert Nesbit (19, p.10) reported this flow to occur east of the Suplee area where it caps buttes of Jurassic and Triassic rocks, particularly on Windy Ridge. Two northwesterly trending escarpments that protrude from the south part of Shaw Table are capped by this rhyolite. A thickness of 8 to 35 feet was observed in the flow. The maximum thickness occurs at the high point on Shaw Table.

The color of the rock is typically light gray, but at one locality it was seen to be red. This rock has an obvious porphyritic texture with a glassy aphanitic groundmass. Quartz occurs in phenocrysts up to 2 mm. in diameter along with light colored feldspars.

As seen under the microscope, nearly 70 percent of the composition is accounted for by the glassy isotropic groundmass. Euhedral to anhedral phenocrysts of albite imbedded in the groundmass composes 15 percent, sanidine 10 percent, and quartz 5 percent of the rock. The phenocrysts show slight corrosion, but are otherwise fresh. Twinning occurs only rarely in the optically positive albite. The extrusive nature of the rock is best supported by the flow structure of the groundmass. (See fig. 24, p.98)

Thickness of Shaw Formation

The Shaw Formation was observed, by use of the aneroid, to be 375 feet thick at Shaw Table, the thickest section within the Suplee area. The only other comparable section is on the western side of Grindstone Creek near the Angell Ranch. Only a thin layer, probably less than 100 feet, of tuffaceous material is present over most of the area included within the boundaries of the Shaw Formation.

Origin and Conditions of Deposition

There is no suggestion as to the source of the volcanic ejectamenta within the area. It is certain only that the tuffaceous materials were the result of volcanic activity somewhere in the region. Possibly, several volcanoes erupted light acidic pumiceous material that may have been carried many miles by the wind. That at least one of the sources was nearby, is indicated by the rhyolite flow that was extruded late in the period of accumulation.

Basaltic pebbles, cobbles, and boulders were probably derived from adjacent masses of Columbia River Basalt; the large size of some of the boulders suggests the proximity of the source.

Sedimentary basins of accumulation were provided by downwarped and faulted Columbia River Basalts. The stratified nature of tuffaceous sandstones and conglomerates containing, in part, rounded materials seems to indicate fluvial and lacustrine conditions. The materials were primarily moved by explosions and deposited on the land, and in streams and lakes. Stripping of these primary deposits from the highlands and subsequent deposition in basins was the cause for thicker concentrations in some areas and their absence in other places.

Despite the apparent amount of volcanic activity during deposition of the Shaw Formation, vegetation and animal life was able to survive at least part of the rigours. Several poorly preserved and broken leaf imprints were found, as well as a few concentrations of fossil vertebrate material was disjointed, but apparently had suffered little movement. This condition might suggest subaerial rather than fluvial or lacustrine deposition. Other fragmentary vertebrate remains found scattered through the beds were probably reworked.

Stratigraphic Relations and Age

Although not strikingly apparent, a general angular discordance of 2 to 8 degrees exists between underlying Columbia River Basalts and the Shaw Formation. This relation is particularly evident at Shaw Table.

The Pliocene Harney Formation overlies truncated tuffaceous strata of the Shaw Formation, but there is little discordance. The most obvious evidence of discordancy may be seen at, or near, Camp Creek where this stream cuts through basalts along the eastern edge of Shaw Table.

At several localities the Shaw rhyolitic flow is overlain directly by Harney welded tuff, whereas 100 feet of tuff separates the Harney rim from the Shaw flow in the Camp Creek canyon.

Paleontologic correlation of the Shaw Formation, in the Suplee area, has not been attempted by earlier workers mainly because of the contamination of the surface by reworked fossil material from younger formations. Stratigraphic and lithologic similarity to the Mascall Fprmation in the Dayville area forms the principal basis for comparison.

The Shaw beds can be traced westward from the Suplee area down Beaver Creek and into the Crooked River drainage system within the Round Mountain Quadrangle. Richard Mote (18, p.53), while working on the geology of the south portion of the Round Mountain Quadrangle, identified vertebrate fossils found in the Shaw Formation and found that 60 percent of the fauna contained in the Shaw to be the same as within the Mascall. J. C. Merriam (16, p.472) identified the fauna and flora contained in the Mascall Formation and gave the Mascall an Upper Miocene age. Based upon this correlation, the Shaw Formation is also of an Upper Miocene age.

HARNEY FORMATION

Harney was first used as a formational name for beds of sandstone and conglomerate and a bed of welded rhyolitic tuff which lie unconformably upon the Mascall Formation in the Round Mountain Quadrangle (34). The Harney Formation is stratigraphically and lithologically similar to the Rattlesnake Formation along the John Day River (16, pp.473-475).

Areal Distribution and Topographic Expression

Shaw Table has the principal part of the Harney Formation within the area. Lesser areas of the formation crop out over the northwestern half of the area to make the total formational areal extent about 10 square miles.

The Harney Formation is exposed characteristically as flat-lying mesas or cap-rocks with a rim-like appearance. Over most of the area, the formation consists only of a welded tuff member which accounts for its rim-forming propensity. Shaw Table, as viewed from the Paulina-Suplee road near the Brennan Ranch, has a flat rim, three miles long, standing 150 feet (on the north) to 400 feet (on the south) above the broad flat Grindstone Creek valley. This thin rim, as exposed here, overlies the Shaw Formation. An interesting member of this formation is the delta that occurs near the congluence of South Fork Beaver Creek and Beaver Creek.

Lithology

The Harney Formation is predominantly composed of one member, a nearly horizontal bed of welded tuff. In the northern portion of the area are gravels that have accumulated on the welded tuff, but the conglomerate that underlies these welded pyroclastics in the Dayville area (16, p.473) is absent from the Suplee region. Overlying gravels are alluvial fans, here termed fanglomerates, and a delta deposit both which rest upon the welded tuff.

Welded tuff. Approximately 75 percent of the exposed Harney Formation is represented by a thin bed of welded pyroclastics. The outcrops are best observed on the Shaw Table rim, but they are to be found in almost all parts of the area.

The color of the rock is from light to dark gray. Appreciable variation in texture is apparent from outcrop to outcrop; however, they are predominantly coarse-grained. The most striking variable is the degree of induration exhibited by rocks from different localities. This variation in degree of induration is shown by the contrast between a compact, almost glassy, tuff that has been extremely welded and the poorly indurated tuff that has not been, or has been only slightly, welded. A great percentage of the Harney welded tuff bed falls into an intermediate class in which welding is good but not extreme. These rocks are fairly compact with a cellular structure controlled by glass bubble wall fragments. Unsorted tabular pumice shards and blocks that occasionally attain a length of 12 inches are

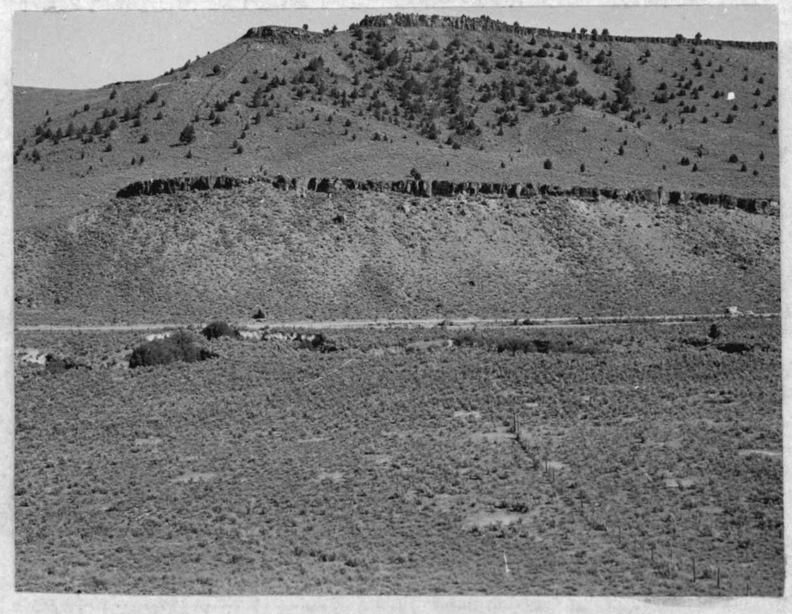


Figure 25. Vitrophyric rhyolite flow member of the Shaw Formation. Lower rim is Harney welded tuff abuting against the Shaw Formation.

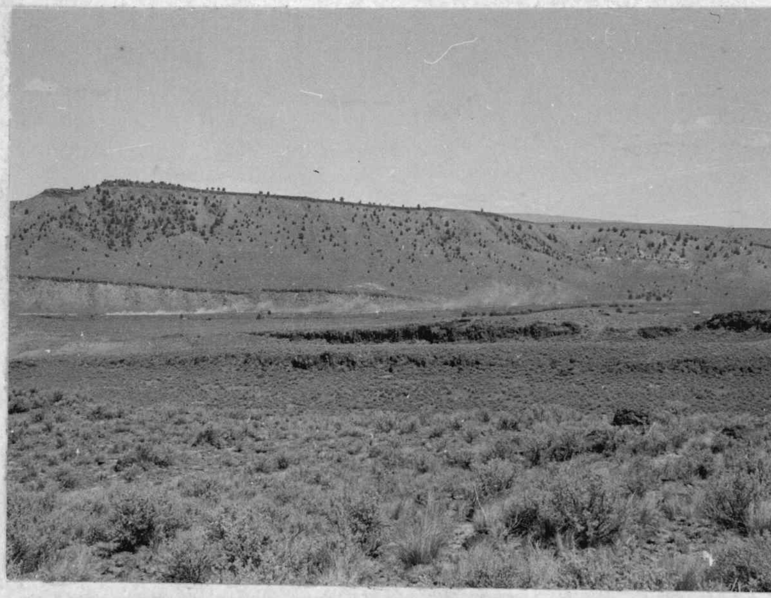


Figure 26. Outcrops of Columbia River Basalt in foreground. Looking north to Shaw Table and rhyolite and welded tuff rims.

locally abundant. Other inclusions are dark basaltic scoria, in pieces as much as 2 inches in diameter, rounded to subrounded basalt pebbles, and subangular to rounded quartz fragments that may be half an inch in diameter. Pumice shards usually have parallel orientation and impart a lineated aspect to the rock.

Under the microscope, the compact nature of some of the welded tuffs is verified. Brownish gray bubble wall fragments that have been fused together display a cellular structure. The individual air-inclosing cells are compressed into ovate forms that are arranged so as to give parallelism to the mass. Glass fragments, bent around rock and mineral inclusions, indicate independent formation of each (See fig. 27,108). When viewed between crossed nicols, the rock is completely isotropic except for inclusions of mineral fragments. Representative of the nearly 10 percent non-glassy material are rock fragments, euhedral orthoclase, subhedral quartz, and microcrystalline quartz aggregates. Sanidine and albite as well as amphibole are apparently abundant in some of the sections.

The tuff that has been poorly welded has essentially the same composition but varies in physical properties, that is, the porosity is considerably higher, lineation not marked, and individual glass fragments are only slightly fused.

Other pyroclastics. A coarse-grained bed of pyroclastic material, stratigraphically equivalent to the welded tuff, differs in that it has not undergone the characteristic welding. It is exposed

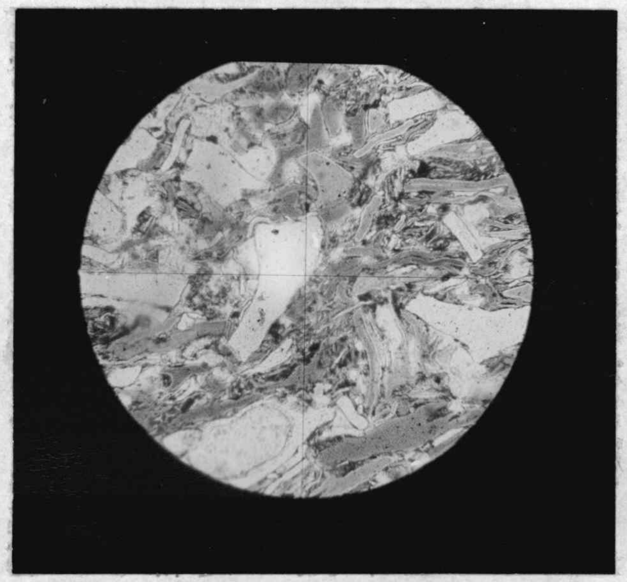


Figure 27. Welded tuff from the Harney Formation. Plain light. x50

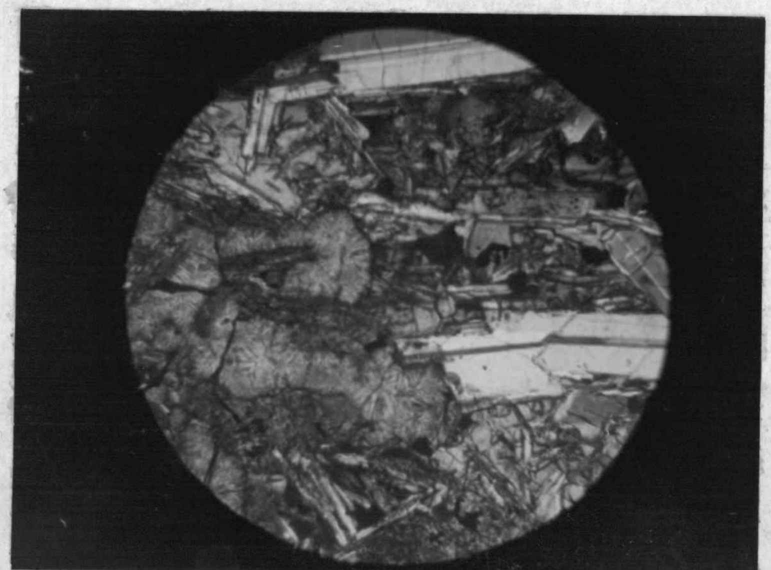


Figure 28. Diabase from the Ochoco Formation. Note radiating structure of palagonite. Crossed nicols. x75

northwest of Mud Spring Butte in a man-made excavation. This bed overlies tuffaceous Shaw strata and, in turn, is overlain by fanglomerates.

The bed is composed of subrounded to rounded blocks of pumice with a length prevailingly of 3 inches and exceptionally of 14 inches. Occasional dark-colored scoria fragments are included. The size range is coarser than that of the welded tuff. A grayish white color is typical of the bed. There is no sorting or stratification within the bed. However, parallelism is shown by the arrangement of tabular pumice blocks.

Gravels. Gravels contained in fanglomerates and a delta deposit accumulated on top of the welded tuff in the northern portion of the area. The fanglomerates occur at only two places on the northwest flanks of Powell Mountain and Mud Spring Butte. The delta lies on the lowlands adjacent to Beaver Creek between the two fanglomerate deposits. Two square miles are covered by the delta while the fanglomerates are relatively small.

All gravels in the delta deposit are rounded to subrounded; however, rounding is not so pronounced in the fanglomerates. An average maximum diameter of approximately 6 inches is characteristic of gravels in the delta and flat rhyolitic boulders were seen with a length of 12 inches. Igneous rocks, including rhyolite, andesite, and basalt are present. Quartzite, chert, and sandstone also figure in the composition. Rhyolite is conspicuously the most abundant constituent of the delta. A loose sandy matrix is typical of the poorly lithified gravels. Stratification is evident and probable foreset beds have a dip of about 20 degrees.

The delta is distinguished from the fanglomerates chiefly by the position of reposed. This delta has a uniformly flat surface with an initial dip of $2\frac{1}{2}$ degrees. With the exception of the delta's south edge, there is a rather abrupt slope around the border. The fanglomerates lack the flat low-dipping character of the delta and dip as much as 10 degrees on the north flank of Powell Mountain. The surface of the fanglomerates is uneven. Gravels in the delta are rounded to subrounded, whereas the gravels are angular to subangular in the fanglomerates. Many varieties of rocks are found in the delta, but the fanglomerates are predominantly composed of one type, basaltic material.

Thickness of the Harney Formation

A comparatively uniform thickness of 15 to 35 feet is displayed by the bed of welded tuff and as the major portion of this formation is this welded tuff, these figures generally represent the formational thickness. Where gravels are included, the maximum thickness approaches 200 feet.

Origin and Mode of Deposition

Pyroclastics. The material forming the dominant portion of the Harney Formation is a pyroclastic rather than a pumiceous rhyolitic flow, as had been suggested by J. C. Merriam (16, p.473). Large pumice shards, broken bubble glass fragments, shattered feldspars, and "foreign" material are several features indicating its pyroclastic origin. There is no indication within the area as to the direct source, but the tuff has been extremely welded near Wade Butte in the southern portion of the area and may suggest proximity of this welded tuff to the source. It seems probable that one or more violently active volcanoes were responsible for the ejectamenta.

Because of the character of the material, it then becomes possible to visualize four principal modes of deposition within two environments. The first would have air-borne ejectamenta from volcanic eruptions settle by normal gravitative influence over the area and still retain enough heat to become fused with prior material to form a typical welded tuff. A second hypothesis involves a violent volcanic phenomenom referred to as nuee ardente and typified by the Pelean eruption. Perret (26, pp.63-64), actually observing a Pelee eruption, described it thus:

> "Pelean discharge with its auto-explosive conduit liquid, self expelled in the form of a completely divided mass of still active particles, isolated from one another by vapor films — the whole mass flowing down any slope with incredible speed because it is frictionless; the extreme manifestation of power in explosive action."

He added the following remarks:

> "The nuee ardente is thus a peculiar type of volcanic eruption fundamentally different from those better known. It possesses two essential characteristics: An extremely rapid transport of crater material in a horizontal direction to considerable distances, and a lava in itself highly explosive and continuing to discharge gas throughout its mass as long as its temperature remains sufficiently high. It is the most swiftly destructive agencies with the possible exception of the volcanic earthquakes."
>
> "A speed of 60 mph. generally noted."

The criteria for recognizing material of a possible nuee ardente origin are by no means clear. Perret (26, p.71) speaks of layers of extremely fine ash that are in a more or less dilated condition of quicksand, whereas Moore (17, p.365), in describing deposits of possible nuee ardente origin, does not mention the "quicksand" aspect, but elaborates on the lack of sorting and stratification.

Marshall (11, pp.198-202) described some volcanic rocks from the North Island of New Zealand that appear to be similar to the Harney welded tuff of the Suplee area. He pictures them as having been deposited by a form of nuee ardente, distinct from a rhyolite flow origin. A temperature of 960° C. during deposition is postulated by Marshall.

A third possible mode of formation, in contrast to the foregoing hypotheses, would have the material accumulate by some flow mechanism and not by aeolian accumulation. This interpretation is taken by Fuller (4, pp.371-372) for what he calls "collapsed pumice" that occurs in southeastern Oregon as follows:

> "At several localities in southeastern Oregon, massive tuffs show gradual transition upwards into acidic flows. As the center of the flow is approached, the rock becomes compact and vitreous, but preserving a minute extremely irregular texture caused by the collapse of previously pumiceous structure while it was still plastic. Although the actual mechanism of advance of such flows has not been determined, the syngenetic origin of the tuffs is proven both by this transition and by the fact that the jointing of the flow locally extends downward into the clastic material. Incipient fusion of the glassy particles adjacent to these cracks indicates that they were formed during the consolidation of the lava. The evidence indicates that these tuffs originated as a flow feature and not by aeolian accumulation."

A fourth possible mode of formation, somewhat similar to the previous method, is by "pumice avalanches" or by pumice-scoria flows. This method of accumulation entails rapid flowing of the pumice over the ground possibly either as an avalanche of the pyroclastic material or as a pumice-scoria flow. The movement is dependent upon the evolution of gases and upon the gradient of the surface.

Assuming that one of the four foregoing modes of deposition is applicable to the welded tuff of the Suplee area, the pertinent facts involving this tuff can be weighed and classified. This much is known: That it is unsorted and unstratified, that it shows lineation, that it was in a viscous semi-molten state, and that these pyroclastics were deposited with a generally uniform thickness over much of the area.

The first problem to be solved is whether the accumulation was the result of an aeolian or flow mechanism. Although the criteria for distinguishing aeolian from flow accumulation are not evident, two facts clearly indicate an aeolian deposition. The first is concerned with the uniform thickness of the welded tuff. It seems that if the welded tuff were deposited by a flow mechanism, then there should be irregularities of the thickness where the flow had filled in depressions and old stream channels, but such is not the case. Secondly, where the welded tuff has been deposited in water, as was noted near Dayville (35), it is thinly bedded as might be characteristic of the pyroclastics settling in a body of water. As was reported by Fuller (4, p.372) the mechanism of movement of these pumiceous flows had not been determined. The lack of knowledge about this mechanism is detrimental to an explanation by a mode of flowing. It is the author's opinion that the evidence favors aeolian deposition either by a form of nuee ardente or by settling of air-borne ejectamenta.

Apparently, the greater part of the tuff deposits is accounted for by ordinary processes in which there is no welding, as shown by more than 300 feet of non-welded Shaw tuffs. As the welded tuff is a peculiar deposit so must be its mode of origin. The possibility, therefore, of a not-so-common nuee ardente type is advanced.

Following is a summary of the various conditions as they apply to aeolian transportation, either to ordinary processes of accumulation or to a form of nuee ardente:

<u>Ordinary processes of accumulation</u>

1. Presence of volcanic ejectamenta
2. Poor or no welding in some areas
3. Retained heat had to be great enough to produce fusion

<u>Nuee ardente process of accumulation</u>

1. Presence of volcanic ejectamenta
2. Moderate welding over most of the area
3. Rapid deposition insured sufficient heat for subsequent fusion.

Those conditions stress the element of heat as the key to the mode of deposition and it is the author's opinion that the retained heat would not be great enough in the ordinary process of accumulation to produce welding. In view of this assumption, a nuee ardente is visualized by which the bed of welded tuff was formed from dense clouds of incandescent volcanic glass still in the semi-molten viscous state.

Gravels. The source of gravels is two-fold. Those gravels contained in the fanglomerates are basaltic pebbles, cobbles, and boulders derived directly from nearby highlands of Columbia River Basalt. The gravels found in the delta deposit are of a more varied composition. The prominent porphyritic rhyolite cobbles were probably derived from the Shaw Formation. The presence of basaltic material suggests a Columbia River Basalt derivation, whereas quartzite pebbles and cobbles from the Cretaceous along with Paleozoic chert and sandstone of possible Mesozoic or Paleozoic ancestry were seen in the delta deposit.

The delta deposit may be indicative of a lacustrine environment. If there was a lake, as appears very probable, its extent may be visualized. The delta in the Beaver Creek lowlands has an approximate maximum height of 4100 feet above sea level. If this elevation is considered to be the approximate level of the former lake, nearly 20 square miles of the Suplee area were covered by the lake to a depth approaching 300 feet at some places.

Stratigraphic Relations and Age

The Harney Formation, for the most part, rests unconformably upon Shaw strata, although the Columbia River Basalts are overlain unconformably in some areas. There is only 2 to 3 degrees difference between Shaw and Harney dips, generally, but a 10-degree difference between Harney and Columbia River Basalt dips is not uncommon. Harney Formation at Shaw Table, where its structure is representative of the entire formation, dips fairly uniformly 2½ degrees toward the northwest. About the same dip was recorded for the delta, although it appears certain that this is, in part, initial dip.

The overlying Ochoco Lavas are slightly unconformable on top of the Harney gravels.

The age of the Harney Formation, if correlative with the Rattlesnake Formation, is probably late Pliocene and its relations with the Shaw Formation are such that it cannot be older than early Pliocene (16, p.475). The apparent erosion that took place after deposition of the Shaw Formation and before that of the Harney Formation may substantiate a late rather than early Pliocene age.

The Harney Formation can be traced westward into the Round Mountain Quadrangle and in the latter area Mote collected vertebrate fossils from the Harney Formation. Following is the faunal list, as determined by E. L. Packard (18, p.60), of which none was found in place:

Pliohippus sp.
Alticamelus sp.
Teleoceras sp.
Rodentia sp.
Proboscidea sp.
Rhinoceras sp.

As all of these forms are common in the Rattlesnake Formation in the Dayville area, the correlation seems to be justified.

OCHOCO FORMATION

This late Cenozoic formation was tentatively named by Wilkinson (34) to apply to several basic lava flows in the Round Mountain Quadrangle. These lavas were first recognized on the south flanks of Wolf Mountain, 10 miles north of Mud Spring Butte, and in the eastern and northeastern part of the Round Mountain Quadrangle (34).

Areal Distribution and Topographic Expression

In the extreme north central portion of the area and closely paralleling the 4000-foot contour is a thin diabase flow that forms a flat bench with an abrupt rim-like appearance. The total extent of the flow in the Suplee area is slightly in excess of one square mile, but it is more extensive in the area farther north. A tongue-like protrusion from the main body of the flow crops out near Beaver Creek. (See figs. 29 & 30, p.118)

Petrography of the Flow

The uppermost part of the flow is extremely vesiculated and has well developed horizontal parting. Toward the bottom the flow is denser and in some portions it displays a poor system of columnar jointing.

Hand specimens obtained from the top and bottom of the flow are fresh, vesiculated to dense, and are representative of a medium-grained extrusive igneous rock. It is reddish-brown on the weathered

Figure 29. Looking southwest along Beaver Creek toward Mud Spring Butte. Top rim in the foreground is flow of Ochoco diabase and lower rim is Harney welded tuff.

Figure 30. North along South Fork Trout Creek showing flat-lying rim of Ochoco diabase. Columbia River Basalts may be seen dipping under the valley alluvium in the right foreground. Wolf Mountain in distance.

surface and black on the fresh fracture. The rock has phenocrysts of grayish palgioclase distributed unevenly through a dark, somewhat glassy groundmass that is, in part, composed of augite. In samples taken from the top vesicular portion of the flow, the plagioclase feldspars occur in aggregates, whereas in the denser lower portion of the flow this characteristic is not obvious.

The thin slice reveals the medium-grained ophitic texture of this rock. There is a jackstraw arrangement of plagioclase laths, which are within the andesine-labradorite range, occurring in a mesotasis of augite and palagonite. The plagioclase accounts for 30 percent of the rock, whereas augite and palagonite make up 35 and 30 percent respectively. Another 5 percent is represented by disseminated magnetite. Neither the pyroxene nor the feldspar has undergone any alteration. The devitrified glass, palagonite, is pale greenish colored in transmitted light, and displays a radial structure within its individual cumuliform masses (See fig. 28, p.108).

Thickness

Within the area, the diabasic flow is an average of 12 feet thick.

Source of Diabase

Approximately 2 miles north of the flat-lying Beaver Creek exposure, and outside the area under consideration, is a thicker concentration of the lavas which form a low gently sloping hill. The flow is continuous into the Beaver Creek area and this low hill may represent the local source of these lavas.

Stratigraphic Relations and Age

The flow in the Ochoco rim is horizontal and unconformably overlies Harney gravels. From 75 to 150 feet below the Ochoco rim is the welded tuff member of the Harney Formation that dips about 2 degrees to the northwest (See fig. 29, p.118).

A post-Harney age is evident from its stratigraphic position above that formation, but whether it is late Pliocene or Quaternary is not immediately determinable. It is referred to the Pleistocene in this report.

QUATERNARY ALLUVIUM

The Quaternary alluvium is shown on the map to cover about 5 square miles. Only the larger masses are mapped; it is also found along all the creeks and in the intermittent drainage courses. In many places, particularly along high gradient streams, are accumulations of coarse gravels; however, the main deposits consist of poorly consolidated silts and sands. Locally, there are concentrations of white gritty volcanic ash occurring in pockets and have been washed into the lower areas after volcanic outbursts during Quaternary times. Vertebrate bone fragments, some of which have been reworked from the Shaw and Harney Formations, occasionally appear in the alluvium.

STRUCTURAL GEOLOGY

The structural deformation of the various lithologic units in the Suplee area can be treated in two divisions: First, the highly folded structure of pre-Tertiary rocks and second, the slightly folded and faulted Tertiary structure. Compressional stresses controlled the shaping of pre-Tertiary strata, whereas structural sagging and faulting possibly caused by the extravasation of the Columbia River Basalts exerted the control on Tertiary structure.

Structure of Pre-Tertiary Rocks

Folds. Beds of the Coffee Creek and Spotted Ridge formations have been extremely compressed while the Coyote Butte beds have been deformed to a lesser extent. Dips of 80 to 85 degrees are commonplace and nowhere were dips of less than 25 degrees recorded in Paleozoic strata. These beds are compressed into three tight synclines and anticlines whose axes of folding trend in a north or northeasterly direction. Some idea as to the compactness of these folds is gained from the fact that the 3500 to 4000 feet of Paleozoic sediments occur in the three synclines and anticlines within a distance, normal to the axes of folding, of 4 miles.

The limited areal extent of Mesozoic formations lends difficulty in determining the axes of folding; however, beds of the Bailey Formation dip from 50 to nearly 90 degrees and, in general, strike in a northerly direction. Strata of the Jurassic Colpitts Group generally strike in a northerly direction with dips of 10 to 15 degrees toward the east. In the western part of the pre-Tertiary inlier, and near Wade Butte, the Triassic and Jurassic beds dip toward the west.

The Cretaceous beds dip about 17 degrees to the west near South Fork Beaver Creek and 12 degrees to the east in the Camp Creek area; both strike in a northerly direction. These opposing dips suggest the presence of an anticline; however, vertical displacement along a fault between the two areas may be responsible for the variation in dip.

The small areal extent of Mesozoic rocks in this area prevents a comprehensive structural interpretation. The available information indicates that the Mesozoic folds are concordant, at least in part, with Paleozoic axes of folding. It would appear, then, that persistent east-west compressional stresses were responsible for the present Paleozoic-Mesozoic structures. Contrary to this local situation, Lupher (9, p.228), with respect to the adjacent area to the east, reported such a wide divergence in the axes of folding between Triassic and Jurassic rocks as to suggest the shifting of compressive forces to a north-south direction after Jurassic time.

Faults related to deformation of pre-Tertiary rocks. Physiographic evidence indicates that two northwest-trending faults have disrupted pre-Tertiary beds. They are coincident with and parallel to the South and North Forks of Trout Creek. That the beds have been displaced by faults paralleling these streams is suggested by the discontinuity of beds, that is, no single bed can be traced with certainty, across the stream valleys.

A probable fault, of major significance, strikes southeast through the south part of Smith Basin and eastward past the Henry Bernard Ranch. The upthrown block exposing Paleozoic sediments is on the south, whereas younger beds of Jurassic age are on the north. A major portion of the basalt vitrophyre parallels this crustal weakness and the time of its intrusion was apparently contemporaneous with the faulting.

Structure of Tertiary Rocks

Structures in the Tertiary rocks are controlled by the Columbia River Basalt Formation which has been extensively faulted and moderately warped. The southern limb of a very gentle synclinal fold is present in the Tertiary strata of the Suplee area where several major faults have disrupted Tertiary, as well as older, rocks. These faults are the most important aspect of the Tertiary structure.

Post-Columbia River Basalt fold. The Columbia River Basalts in the Suplee area form the southern limb of a broad synclinal fold having a northeast-striking axis located near Beaver Creek. A maximum dip of 25 degrees to the northwest was observed for the basalts in Powell Mountain. Lesser dips of 12 and 16 degrees to the northwest occur in these basalts on Mud Spring Butte. Dips between 3 and 8 degrees for the basalt are more common in the area between Wade Butte and Shaw Table.

That the broad synclinal fold was present before accumulation of post-Upper Miocene Shaw strata is shown by the position of these beds. Tuffaceous material of the Shaw Formation accumulated within this fault-modified synclinal fold.

Major faults related to deformation of Tertiary rocks. There are four major faults that have resulted in considerable deformation of Tertiary strata. Three faults strike in a northeasterly direction across the area and are referred to as the north, central, and south faults in the following discussion. A fault that strikes west and northwest along South Fork Beaver Creek is referred to as the Beaver Creek Fault.

Vertical displacement along the north fault is responsible for Mud Spring Butte. Mud Spring Butte represents the upthrown block which is on the north side of this northeast-trending fault.

A centrally located fault trends northeasterly from Trout Creek near the Angell Ranch, along the southern edge of Shaw Table, crosses the South Fork of Beaver Creek near its junction with Camp Creek, and continues on through Powell Mountain. The high south part of Shaw Table owes its position to movement along this fault and, like the north fault, the upthrown block is on the north side of the fault.

A scarp just west of Smith Basin is the result of crustal movement along the most southern fault. The greatest amount of movement along this fault occurred near the South Fork of Beaver Creek where the upthrown block is on the south where beds of Cretaceous age are exposed. This fault is indiscernible south of Smith Basin.

The west- and northwest-striking Beaver Creek fault parallels the South Fork of Beaver Creek and, in effect, has horizontally displaced the traces of the central and south faults. (See map, Plate II). This fault has had little vertical displacement; however, the northern block has been horizontally displaced about 1500 feet along the fault toward the northwest, relative to the southern block.

The effects of the central and southern faults are expressed in a graben which has a maximum development southeast of Shaw Table and northwest of Smith Basin. The structure of this graben is complicated by the northwest-trending Beaver Creek fault. This complication is shown by a broken and depressed block that forms a small basin in the Rock Creek-South Fork Beaver Creek area. (See fig. 18, p.72)

Minor faults related to deformation of Tertiary rocks. Several minor faults strike perpendicularly to the central and south faults across the graben area are characterized by fault scarps of Shaw tuff capped by the Shaw rhyolite flow. These occur in the Camp-Trout Creek area and associated with three small northwest-striking faults which have disrupted flows of the Columbia River Basalt (See fig. 18, p.72).

Two north-trending faults having less than 50 feet vertical displacement have broken the Columbia River Basalts along South and North Forks of Trout Creek north of the Clemmons Ranch.

Post-Harney deformation. Several small faults having slight movement have broken the Harney rim, but the displacement is generally not greater than 15 feet. However, a vertical displacement of 200 feet along the central fault is evidence of continued movement along this crustal weakness. This displacement is shown in the Harney rim on the south part of Shaw Table near the Angell Ranch.

Figure 31. Looking southeast from Shaw Table toward the distant Paleozoic inlier. Tuffaceous Shaw sediments in foreground. Minor faults in Columbia River Basalt in center. Fault scarp (south fault) in Columbia River Basalts in left distance.

Figure 32. Looking northwest along North Fork Trout Creek. Butte at left is capped by Columbia River Basalt and is within the Paleozoic inlier. Limestone outcrop in foreground.

GEOMORPHOLOGY

Salient Features

The most prominent topographic features in the Suplee area are the several fault block mountains that interrupt an otherwise comparatively smooth surface. Powell Mountain, Mud Spring Butte, and the south portion of Shaw Table are representative of these mountains. Almost as conspicuous is a topographic unconformity that is marked at the contact of Tertiary and pre-Tertiary rocks. The topography of the area within the pre-Tertiary inlier has reached maturity in the geomorphic cycle and is out of phase with the youthful topography that is characteristic of the Tertiary formations. Other striking features of the area include the mea-like areas, such as Shaw Table, alluvial fans, and an abandoned delta.

Fault Blocks

The largest fault block is the mass of Columbia River Basalt of which Powell Mountain is a part. The dip slope is on the northwest side and the fault scarp crosses South Fork Beaver Creek in the vicinity of the Andrew Bernard Ranch. Other faults have disrupted this block, but not sufficiently to change its attitude appreciably. Mud Spring Butte is characteristic of a small fault block. As at Powell Mountain, the dip slope is on the northwest side and the fault scarp on the southeast side. A minor part of this same block is exposed one-half mile northeast of Mud Spring Butte, but it is not so prominent.

The southern end of Shaw Table is underlain by a block of Columbia River Basalt. This block has a lower dip slope than the others and its northwesterly slope nearly blends in with that of the Harney welded tuff. The fault scarp is quite abrupt, particularly two miles east of the Angell Ranch.

Topographic Unconformity

Where rocks of Paleozoic and Mesozoic age are overlain by Tertiary volcanic materials there is a distinct topographic unconformity. This unconformity is magnified by the presence of an erosional scarp in the retreating edge of the Columbia River Basalts. Outliers of basalt resting on Paleozoic sediments testify to the retreat of this Tertiary formation.

That a mature geomorphic stage has been reached in the pre-Tertiary area is indicated by the rounded hills and well developed drainage. A position of temporary grade has been reached by a few of the streams in this area. This grade level has been produced at the line of demarcation between the two physiographic areas and is the result of the resistant Columbia River Basalts.

The area of Tertiary rocks is physiographically youthful although a temporary level of stream erosion has been reached in the Beaver Creek lowlands, there are steep canyons and sharp ravines upstream, as well as flat-topped buttes and table-lands that are without dissection of any consequence.

Delta and Alluvial Fans

The deposit of late Pliocene or Pleistocene gravels which formed a delta in the Beaver Creek area is one of the most prominent features in the northern part of the area. It is characterized by a nearly horizontal surface and fairly abrupt slopes to the valley floor.

Coalescing alluvial fans occur on the northwest dip slopes of Powell Mountain and Mud Spring Butte. Although they are not as extensive as the delta between the two, they are, nevertheless, characteristic of the gravels overlying the welded tuff member of the Harney Formation.

GEOLOGIC HISTORY

A nearly complete geologic section ranging from Lower Carboniferous to Quaternary is found in the Suplee area. It represents some 300 million years of sedimentation, intrusion, vulcanism and erosion which, when interpreted, give light to the otherwise dark millennia.

The brachiopod Productus giganteus, from the horizon bearing the same name, is indicative of a marine submergence during Mississippian time, the first recorded event in the area. Limy muds were deposited in a gradually sinking basin of accumulation and along the shores were reefs that teemed with invertebrate marine organisms. This was a rather shallow sea, and the hinterland from which fine-grained materials were derived was low and featureless.

A gentle upwarping and emergence followed deposition of the Mississippian Coffee Creek beds, but the uplift was of short duration, and soon Pennsylvanian seas inundated this area again. There was more relief along the coastal area than during Coffee Creek times and higher, more rugged terrain was in the process of development in the interior. Streams carried coarse materials that had been derived from exposed plutonic rocks and deposited them along river channels and in estuaries. Graywackes were also accumulating at a rapid rate. Vegetation, particularly in the form of scouring rushes (Calamites), grew in the swampy areas. Occasionally, there was subsidence below the level of wave action and siliceous muds accumulated along with their included radiolarians.

The Spotted Ridge sea retreated toward the close of Pennsylvanian time and horizontal compressive forces accompanied the general emergence. Erosion began to strip the positive anticlinal areas and proceeded to subdue the topographic features. Finally during late Pennsylvanian time the seas again began to encroach upon the area.

Probably during early or middle Permian the Coyote Butte seas finally inundated those areas that had remained above sea level during the Upper Pennsylvanian. Limestones and graywackes were deposited unconformably upon the truncated Coffee Creek and Spotted Ridge strata. As the seas locally advanced and retreated over a fluctuating shoreline, there was alternation between deep water limy muds and the graywacke materials that accumulated on the beaches and in shallow waters. Many brachiopods, pelecypods, and fusulinids inhabited the coastal waters.

An extensive withdrawal of the seas took place after deposition of the Coyote Butte Formation and during later Permian times, that was brought about by uplift and intense east-west compression. This orogenic movement may have been contemporaneous with the Appalachian and Hercynian revolutions elsewhere. During this orogeny, plutonic dioritic and dacitic rocks were intruded into the Paleozoic sediments. Imposingly high mountains probably developed during this interval from middle Permian to late Triassic times, but were subsequently destroyed, possibly before the late Triassic.

Submergence occurred again during the Late Triassic, and sedimentary materials derived from a remaining highland of Paleozoic rocks were deposited in a sinking basin of accumulation. Brachiopods and pelecypods lived in the offshore waters, as well as along the sandy beaches, and crinoids also found the waters habitable. These sediments of the Bailey Formation were uplifted near the end of the Triassic and were compressed by horizontal forces to form high rugged terrain.

During the emergent interval that followed uplift and compression of the Bailey beds, intrusion of rhyolitic and basaltic rocks occurred, accompanied by normal faulting. A probable highland composed of the intrusive rhyolitic and basaltic rocks remained until the Middle Jurassic.

Inundation of the area occurred during the Middle Jurassic at which time calcareous muds and sands accumulated in a sinking basin. Gravels of calcareous and igneous composition were dumped on top of muds and sands as the shore retreated. Pelecypods were numerous in the shallow water and ammonites found the deeper water of the neritic zone preferable.

Intense folding, faulting and emergence followed deposition of the Colpitts beds sometime in late Jurassic or early Cretaceous time, possibly as an aspect of the Nevadan orogeny. The uplifted Paleozoic and Mesozoic beds were intensively eroded and channeled until late in the Cretaceous period, at which time a shallow submergence provided a depositional site for the Cretaceous sediments. Coarse graywacke sands and gravels along the beaches were littered with shells of pelecypods, particularly Trigonia and Acila, and gastropods. The withdrawal of

Cretaceous seas closed, at last, the cycle of repetitious marine invasions which began during Mississippian time.

An uplift of considerable moment ushered in the Cenozoic era and the first local activity was the intrusion of rhyolitic material. This occurred during the Eocene, after which there apparently was little activity in the area, except erosion, until Miocene times. Following a relatively long period of such erosion, Columbia River Basalts were extruded over the area and partly covered the highland of pre-Tertiary sediments, as well as the limited area of Eocene intrusion.

Apparently the extravasation of basalts onto the surface during Miocene time resulted in the development of weak areas beneath the surface which in turn caused some subsidence. This subsidence was expressed as warps and normal faults throughout the area, and basins formed by this action provided excellent depositional sites for pyroclastic material that accumulated during the late Miocene. A thin flow of vitrophyric rhyolite spread out over the area late during the period of Shaw accumulation and was covered subsequently by more tuffaceous materials. Horses, camels, rhinoceroses, and rodents inhabited the area despite the volcanic activity.

There were some structural modifications after the close of the Miocene, in which the Shaw Formation, as well as underlying beds, were tilted several degrees. A nearly level erosional surface was produced upon the Shaw strata. After development of this significant erosional surface and during Pliocene times, there came a short interval of extremely explosive vulcanism, and a nuee ardente of hot, viscous glass particles and gasses swept over the region with remarkable speed. These glass particles became welded together upon deposition and formed a bed of welded tuff.

Sometime after the explosive vulcanism that formed the welded tuff member of the Harney Formation, a rather large lake, at least 20 square miles in area, developed in the Beaver Creek lowlands near its confluence with Beaver Creek. The waters of this lake deepened an outlet, probably in the vicinity of Paulina to the west of the area, and this once imposing lake was drained.

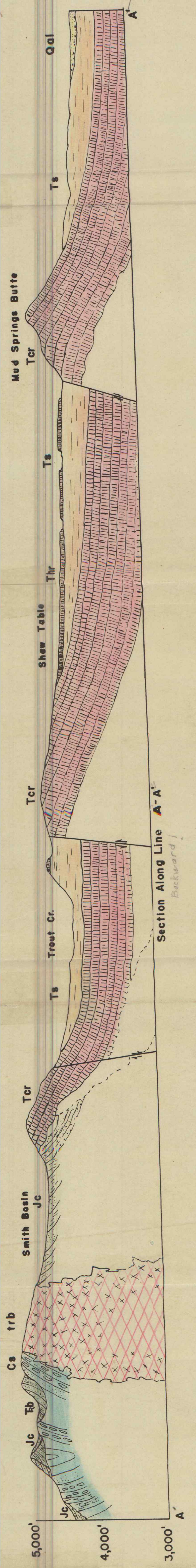
One of the last events recorded in the geologic history was the extrusion of a diabasic igneous rock that poured out onto Harney gravels in the Beaver Creek area. This activity probably occurred during late Pliocene or during the Pleistocene epoch.

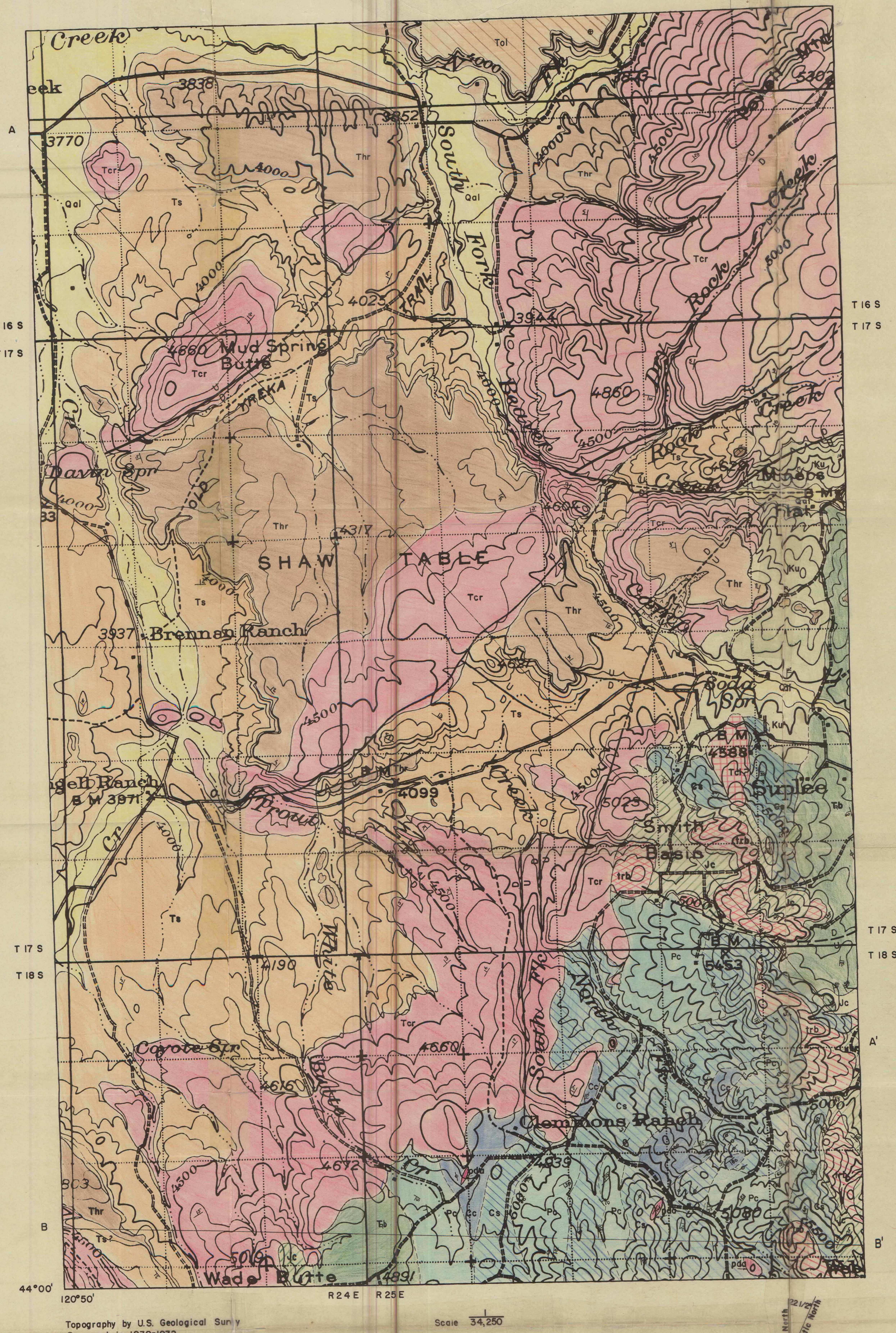
Erosion followed and is proceeding practically unseen even today, but its results are registered by mud leaving the area.

GEOLOGIC MAP OF THE SUPLEE AREA
DAYVILLE QUADRANGLE, OREGON

by

J. PHILIP BROGAN





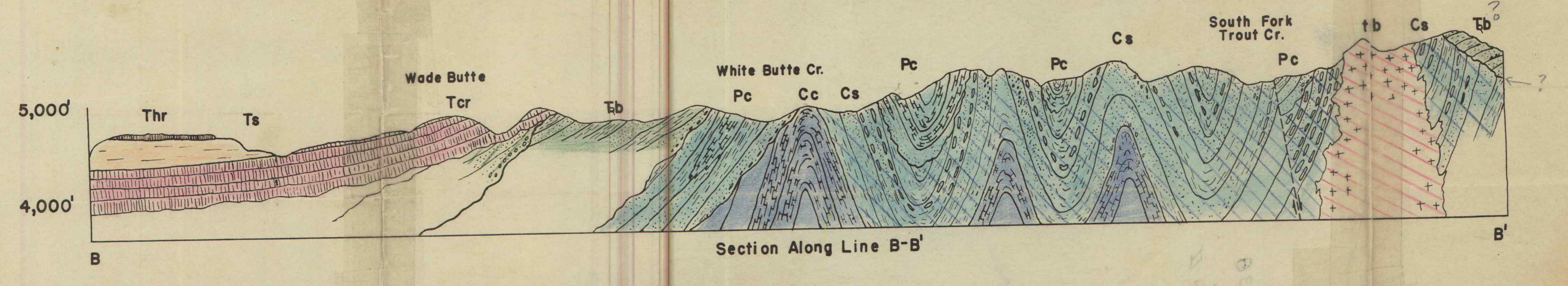
Topography by U.S. Geological Survey
Surveyed in 1930-1932

Scale $\frac{1}{34,250}$

1/4 1/2 0 1 2 3 Miles

Contour Interval 100'

True North
Magnetic North
Mean Declination, 1932



Section Along Line B-B'

EXPLANATION

Qal — **ALLUVIUM** — Silts, gravels, volcanic ash — Recent — Quaternary

UNCONFORMITY

Tol — **OCHOCO LAVAS** — Extrusive basalt flow — Pleistocene — Quaternary

UNCONFORMITY

Thr — **HARNEY FORMATION** (RATTLESNAKE) — Welded tuff, conglomerates, fanglomerates — Pliocene — Tertiary

UNCONFORMITY

Ts — **SHAW FORMATION** (MASCALL) — Buff & white tuffs, tuffaceous sandstone & conglomerate, and rhyolite flow. — Miocene — Tertiary

UNCONFORMITY

Tcr — **COLUMBIA RIVER BASALT FORMATION** — Basic lava flows — Miocene — Tertiary

UNCONFORMITY

Tcl — **? CLARNO FORMATION** — Intrusive porphyritic rhyolite — Eocene — Tertiary — CENOZOIC

RELATIONS UNKNOWN

Ku — **UPPER CRETACEOUS** — Shale, subgraywacke sandstone, & quartzite conglomerate — Upper Cretaceous

UNCONFORMITY

Jc — **COLPITTS GROUP** — Calcareous shales, sandstones & conglomerates; graywacke; and limestone — Middle Jurassic

UNCONFORMITY

trb — **INTRUSIVES** — Rhyolite porphyry & basalt vitrophyre complex — Triassic

UNCONFORMITY

Tb — **BAILEY FORMATION** — Calcareous shales, sandstones, conglomerates; limestone; and graywacke — Triassic — MESOZOIC

UNCONFORMITY

pda — **INTRUSIVES** — Dacitic and dioritic intrusive complex — Permian

UNCONFORMITY

Pc — **COYOTE BUTTE FORMATION** — Massive ls., cherty ls., calcareous ss., graywacke, and orthoquartzite — Permian

UNCONFORMITY

Cs — **SPOTTED RIDGE FORMATION** — Graywacke, chert breccia, conglomerate, and vari-colored bedded chert — Pennsylvanian

UNCONFORMITY

Cc — **COFFEE CREEK FORMATION** — Limestone (carbonaceous, argillaceous & pure) and calcareous sandstone — Mississippian — PALEOZOIC

MAP SYMBOLS

U / D — Fault

Contact

Strike and Dip of Beds

Landslide Area

BIBLIOGRAPHY

1. Dobel, J. P. Geology of the Antone District, Wheeler County, Oregon. Oregon State College, masters thesis, 1948. 102 p.

2. Du Bar, Jules R. Cretaceous faunas from the northern flank of Ochoco Range, Oregon. Oregon State College, masters thesis, 1950. 176 p.

3. Fenner, C. N. The origin and mode of emplacement of the great tuff deposit in the Valley of Ten Thousand Smokes. National Geographic Society, contributed technical papers. 1923. 74 p. (Katmai series)

4. Fuller, R. E. Collapsed pumice. Pan-American geologist 5:no. 61:371-375. June 1934.

5. Gilluly, J., J. C. Reed, and C. F. Park, Jr. Some mining districts of eastern Oregon. United States geological survey bulletin. 1933. 140 p. (bulletin no. 846)

6. Gonzales, B. N. A contribution to the paleontology of the Paleozoic faunas of central Oregon. Oregon State College, masters thesis, 1933. 115 p.

7. Hyatt, Alpheus. Triassic and Jurassic in the western states. Bulletin of the geological society of America 5:394. 1894.

8. Keller, Walter. Petrography and origin of the Rex chert. Bulletin of the geological society of America 52:1279-1297. August 1941.

9. Lupher, R. L. Jurassic stratigraphy of central Oregon. Bulletin of the geological society of America 52:219-270. 1941.

10. ______ and E. L. Packard. The Jurassic and Cretaceous rudistids of Oregon. University of Oregon publications in geology 3:no. I:203-212. February 1930.

11. Marshall, P. Notes on some volcanic rocks of the North Island of New Zealand. The New Zealand journal of science and technology 13:198-202. 1932.

12. McCornack, Ellen Condon. Thomas Condon, pioneer geologist of Oregon. University of Oregon publications 15:36. 1928.

13. McKittrick, W. E. The geology of the Suplee Paleozoic series of central Oregon. Oregon State College, masters thesis. 1934. 85 p.

14. Merriam, C. W. Carboniferous and Permian corals from central Oregon. Journal of paleontology 3:no. 16:372-381. 1942.

15. ______ and S. A. Berthiaume. Late Paleozoic formations of central Oregon. Bulletin of the geological society of America 2:no. 54:145-171. February 1943.

16. Merriam, J. C. A contribution to the geology of the John Day basin. University of California publications in geological sciences 2:270-314. 1901.

17. Moore, Bernard N. Deposits of possible nuee ardente origin in the Crater Lake region, Oregon. Journal of geology 42: 358-375. 1934.

18. Mote, R. H. The geology of the Maury Mountain region, Crook County, Oregon. Oregon State College, masters thesis. June 1939. 122 p.

19. Nesbit, Robert A. The Triassic rocks of the Dayville quadrangle, central Oregon. Oregon State College, masters thesis. June 1951. 37 p.

20. Packard, E. L. Personal communication.

21. ______ Discovery of the Baird Mississippian fauna in central Oregon. Pan-American geologist 4:no. 49:315. May 1928.

22. ______ A new section of Paleozoic and Mesozoic rocks in central Oregon. American journal of science 15:221-224. March 1928. (fifth series)

23. ______ A contribution to the Paleozoic geology of central Oregon. Contribution to paleontology from the Carnegie Institution of Washington 418:105-113. July 1932.

24. ______ Preliminary report of the Cretaceous of central Oregon. Geological society of America bulletin 40:166. March 1929.

25. ______ and R. N. Nelson. Geologic occurrence of the Hardgrave Jurassic fauna of Burns, Oregon. Bulletin of the geological society of America 32:148. 1921.

26. Perret, Frank A. The eruption of Mt. Pelee, 1929-32. Carnegie Institute of Washington publication 458:no. 1935. 126 p.

27. Pettijohn, F. J. Sedimentary rocks. New York, Harper 1949.

28. Read, C. B. and C. W. Merriam. A Pennsylvanian flora from central Oregon. American journal of science 2:no. 238: 107-111. February 1940.

29. Russel, I. C. Preliminary report on the geology and water resources of central Oregon. United States geological survey bulletin 252:20. 1905.

30. Schenk, Edward T. The stratigraphy and paleontology of the Triassic of the Suplee region of central Oregon. University of Oregon, masters thesis, June 1931. 53 p.

31. Sloss, L. L. and W. C. Krumbein. Stratigraphy and sedimentation. San Francisco, Freeman. 1951. 497p.

32. Twenhofel, W. H. Principles of sedimentation. New York and London, McGraw-Hill. 1939. 610p.

33. Washburne, C. W. Notes on the marine sediments of eastern Oregon. Journal of geology 11:224-229. 1903.

34. Wilkinson, W. D. Geology of the Round mountain quadrangle, Oregon. Oregon department of geology and mineral industries. 1939. (geologic map with text on back)

35. ________ Personal communication.