AN ABSTRACT OF THE THESIS OF

Robert Lynn Patterson
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Title GEOLOGY OF PART OF THE NORTHEAST QUARTER
OF THE MITCHELL QUADRANGLE, OREGON

Abstract approved ____________
(Major professor)

The thesis area covers 165 square miles including the greater part of the northeastern quarter of the Mitchell quadrangle in north-central Oregon. The three stratigraphic units exposed in the area consist of a variety of Tertiary volcanic rocks including the Clarno Formation, the John Day Formation, and the Columbia River Basalt.

The Clarno Formation of Eocene to Early Oligocene age is the oldest rock unit in the thesis area. From oldest to youngest, the mapped units include volcanic boulder conglomerates, andesite and basalt flows and flow breccias, tuffaceous sandstones intercalated with lava flows, and twelve plugs and dikes of andesite and basalt. The composition, lack of sorting, stratigraphic and structural features, and the included flora indicate that the volcanic boulder conglomerates were deposited as mudflows on a terrain of high relief in a humid, subtropical climate. Andesite lavas were extruded intermittently during deposition of the mudflows resulting in complex
intertonguing of the two rock types. Later, Clarno lavas poured from numerous isolated fissures and covered the volcanic boulder conglomerates. Near Middle Oligocene time the formation was folded into a broad NE-trending anticline which swings sharply eastward in the north-central half of the area. Following uplift, the Clarno rocks were eroded into a surface of moderate relief and thick fossil soils developed on scoriaceous portions of the lava flows. The John Day Formation of Late Oligocene to Early Miocene age consists of ash flows and ash falls of acid to intermediate pyroclastic material which were deposited unconformably on the deformed and eroded Clarno rocks. These pyroclastics were erupted from unknown local sources, and probably from distant volcanoes to the west. Much of the material deposited on the pre-Miocene anticlinal crest was reworked by streams and formed thick tuff beds on the flanks of the fold. In Middle Miocene time the consolidated John Day Formation was slightly folded parallel to pre-Miocene anticlinal trends and underwent erosion. The Columbia River Basalt was extruded from fissures onto the tuffs during Middle Miocene time. Following deposition the thick layers of basalt were gently folded as the pre-Miocene anticlinal trend again served as the pattern for mild uplift and deformation in latest Miocene time. Rocks younger than Middle Miocene were either never
deposited on the basalt plateaus of the area, or have been completely removed by erosion. In Pleistocene and Recent time the plateaus were dissected and the flows were eroded from the anticlinal crest. Landslide, fluvial, and terrace deposits were laid down in the valleys. White volcanic ash was transported by wind from an unknown source and intercalated with Recent fluvial and slope wash deposits.
GEOLOGY OF PART OF THE NORTHEAST QUARTER OF THE MITCHELL QUADRANGLE, OREGON

by

ROBERT LYNN PATTERSON

A THESIS

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OREGON STATE UNIVERSITY

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APPROVED:

Chairman of Department of Geology
In Charge of Major

Dean of Graduate School

Date thesis is presented

Typed by Trudie Vallier
ACKNOWLEDGEMENTS

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GEOLOGY OF PART OF THE NORTHEAST QUARTER OF THE MITCHELL QUADRANGLE, OREGON

INTRODUCTION

The purposes of this paper are to present a detailed geologic map of the northeastern part of the Mitchell quadrangle, to provide a complete areal geologic description, and to relate these findings to the geology of adjacent areas.

The geology of the Mitchell quadrangle has mostly been mapped and described in several earlier unpublished Oregon State Master's theses (Figure 1). Presentation of this report will bring mapping of the quadrangle nearer to completion and serve as a guide to more detailed studies.

Location and Accessibility

The area of investigation is located in north-central Oregon, and is bounded by north latitudes 44°50' and 45°00' and west longitudes 120°15' and 120°00'. The area covers 165 square miles in the northeast quarter of Mitchell quadrangle, and is entirely within Wheeler County. It includes Townships 7 and 8 South, Ranges 21, 22, and the western one-fourth of Range 23 East of the Willamette Meridian (Figure 2).

The following description refers to roads and landmarks
FIGURE 1. Outlines of Oregon State Master's theses within Mitchell Quadrangle.
FIGURE 2. Index map showing location of thesis area.
which are shown on the geologic map (Plate 1). Paved State Route 19 crosses the area diagonally from the southeast to the northwest corner. The highway known locally as the Kinzua road extends northeasterward from its intersection with Route 19 at a point three miles southeast from Fossil. Gravelled roads extending southward are State Route 218 from Fossil, and the Rowe Creek road from Shelton State Park on Route 19.

In dry weather most parts of the area are accessible from log haulage and fire control roads. However, during the summer fire season permits for travel in forested areas must be obtained from the local State Forestry office. A 4-wheel drive vehicle permits access to within one mile of all outcrops.

Relief and Drainage

Three distinct features characterize the rugged and hilly topography. They are 1) broad-crested ridges, 2) relatively narrow, V-shaped and steep-sided valleys which are 1000 to 1500 feet lower than the ridges where the valleys are measured across their trends, and 3) the isolated knobs of denuded intrusives that stand 400 to 500 feet above the surrounding ridge crests. Topography of the southern half is more intricately dissected and has steeper slopes with more relief than that of the northern half.
The lowest elevation is 2500 feet in the south-central half of the area at a point in Dry Hollow. The average elevation of most ridges is 4000 feet. Rancherie Rock, an intrusive knob near the center of the area, is the highest point and has an elevation of 4899 feet.

Reference to the combined geologic and topographic map (Plate 1) shows that the narrow, V-shaped valleys and the intervening broad-crested ridges are distributed in a moderately-dense, dendritic pattern. All streams join the John Day River within 20 miles of the area.

In the northern half of the area all major streams flow north or west-northwestward. From west to east on the map they are Cottonwood Creek, Butte Creek, and Thirtymile Creek. The west-central part is drained by Pine Creek which flows westward. In the southeastern quarter of the area a southward-flowing intermittent stream occupies Dry Hollow. Southward-flowing Rowe Creek drains the south-central part of the area. In the south-eastern part Service Creek flows parallel to Route 19 from near Rancherie Rock to the John Day River.

**Climate and Vegetation**

Wheeler County has a semi-arid climate with an annual range of ten to 20 inches of precipitation and less than ten inches of snow. There are 120 to 160 days between late spring and early fall that are
frost free. High summer temperatures are around 100°F., dropping to 50°F. at night. Low winter temperatures may drop to around 0°F. According to an isotherm map by Rudd (19, p. 31) the average July temperature is 66°F. and the average January temperature is 28°F.

The northeastern quarter is covered by open forests of dominant Ponderosa Pine, rare Douglas Fir, and some Western Larch. The northwestern and both southern quarters of the area are sparsely covered by juniper, sage, and range grass. A few patches of pine and fir grow in some ravines having favorable soil and moisture. Poplars, cottonwoods, aspens, and willows are abundant near most springs and streams.

Methods of Investigation

Reconnaissance study of 1:63,000 high-altitude and 1:21,000 low-altitude aerial photos was completed during the first week of June in 1963. Maps of adjacent areas by Taylor (24) and Bedford (1) were compared with the photos in order to learn the appearance of rock units on the photographs.

During the ten-week field season all contacts were plotted on both photo sets and on a 1:32,000 enlarged map of the 1926 edition of the Mitchell quadrangle (26). The position of contacts is accurate within the 100 foot contour interval.

Petrographic studies of thin sections were completed during
the 1964-1965 school year. Modal analyses were made with a mechanical stage and point counter. Percentages were calculated to the nearest whole percent on the basis of 500 grain counts. All igneous rocks are designated according to the classifications of Williams (30).

Previous Investigations

Three published reports of a regional reconnaissance nature give complete reference to all minor studies in the area. 1) In 1901 Merriam (14) described the regional stratigraphy in conjunction with an expedition to collect fossils. 2) In 1914 Collier (5) presented a reconnaissance map and a report on the mineral resources of the John Day region with special reference to coal. 3) In 1942 Hodge (8) published the most detailed regional map and report available at present. Geology of the thesis area is treated briefly in each of these reports.

The most recent detailed investigations of adjoining areas are unpublished master's theses by Taylor (24) on the west and Bedford (1) on the south. Published maps of geology in detail do not exist for areas bordering on the north, east, or along the southern border of the southwestern quarter of the area.

The stratigraphic units established by these reports are equivalent to those reported in this thesis.
OUTLINE OF GEOLOGY

An outline of the formations exposed in the northeast quarter of the Mitchell quadrangle is given in Table 1.

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<th>Lithology</th>
<th>Max. exposed thickness in feet</th>
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<td>Quaternary</td>
<td>Landslide deposits, alluvial sands and gravels, and white volcanic ash.</td>
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<tr>
<td>(Unconformity)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle Miocene</td>
<td>Columbia River Basalt</td>
<td>Tholeiitic and olivine basalt flows and inter-flow breccias.</td>
<td>1000+</td>
</tr>
<tr>
<td>(Unconformity)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Late Oligocene-Middle Miocene</td>
<td>John Day Formation</td>
<td>Acid to intermediate volcanic siltstones, sandstones, ash flow and ash fall tuffs.</td>
<td>700+</td>
</tr>
<tr>
<td>(Angular-unconformity)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early Eocene-Late Oligocene (?)</td>
<td>Clarno Formation</td>
<td>Andesite and andesitic basalt flows, tuffaceous sandstones, and volcanic conglomerates.</td>
<td>2000+</td>
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CLARNO FORMATION

General Statement

The name Clarno Formation was first introduced by J. C. Merriam in 1901 (14) for a sequence of "tufts, ashes, and lavas" which crop out "near Mitchell" and "at Clarno's Ferry". The Clarno Formation now includes a variety of lavas and volcanic sediments defined in Mitchell quadrangle by their stratigraphic position above Cretaceous marine sediments and below John Day Formation tuffs. The lower boundary is based on a lithologic break and the upper is arbitrarily placed in a zone between a red fossil soil and a red basal tuff of the John Day Formation.

Although Merriam never designated a type section, the rocks near Clarno and Mitchell have been correlated over much of central Oregon.

Within the northeastern part of Mitchell quadrangle lithology and stratigraphic relations indicate the following divisions of the Clarno Formation: 1) The oldest rocks are intertonguing andesite flow breccias and volcanic conglomerates. 2) Younger, undifferentiated lava flows rest on the volcanic conglomerates. 3) At Straw Fork lacustrine, tuffaceous sandstones constitute a lens within the lavas. 4) Twelve porphyritic basalt and andesite plugs were mapped as intrusives of Clarno age on the basis of their structural relations.
and lithologic similarity to surrounding Clarno lavas.

Clarno Volcanic Conglomerates

Distribution and Topographic Expression

Volcanic conglomerates (6) and sandstones crop out over twelve square miles in the southern half of T. 8 S., R. 21 E. (Plate 1). In the northern part of this township three isolated outcrops, each about one-half square mile in extent, are exposed. One is in the west half of section 7 and is exposed in two ravines which open westward into Robinson Canyon. The other lies along the south slope of Pine Creek valley in section 4. The third patch of volcanic conglomerate crops out at the head of Lone Pine Creek.

The rugged topography of this area underlain by conglomerate does not differ greatly from that underlain by associated flow rocks. Ravines are more closely spaced in the conglomerates along the west side of Dry Hollow than in flow rocks to the north and east. In Dry Hollow the outcrops exhibit pillars and ribs resulting from differential weathering. These boulder-capped "hoodoos" average twenty feet in height.

Lithology

Mottled green and lavender to uniformly tan volcanic
conglomerates are intercalated with thin sandstone beds. This wedge of conglomerates thins and becomes discontinuous north and westward from Dry Hollow. Clasts ranging in size from boulders to pebbles of light gray-green andesite and dark green andesitic basalt make up more than sixty percent of the rock. The matrix consisting of both intact and broken euhedral crystals of plagioclase and mafics constitutes the remaining 40 percent of the rock. Sections of samples from Dry Hollow and the south side of Pine Creek in section 4 have the following matrix components: 1) Unaltered calcic plagioclase euhedra which show oscillatory extinction and bear euhedral apatite inclusions; 2) plagioclase prisms which, altered completely to kaolinite cores, have rims of chlorite; 3) unaltered brown euhedral hornblende crystals; 4) rare unaltered euhedral augite crystals.

The cementing material is not apparent in thin sections, but zeolites from altered feldspar and chlorite from altered amphiboles and pyroxenes are probably important in this respect. These sediments are composed of debris from the associated lavas and are often difficult to distinguish from the lavas in the field.

In addition to volcanic sandstones and conglomerates at least 50 feet of shaly coal crops out along the east side of Dry Hollow in the center of sec. 22, T. 8 S., R. 21 E. The coal has a resinous luster, but its value as a fuel is nullified by thinly interbedded, white tuffaceous siltstones.
FIGURE 3. Volcanic conglomerates of the Clarno Formation in north-facing view of upper Dry Hollow.

Structure and Thickness

Principal bedding surfaces are displayed only in the volcanic sandstone layers. Because these layers are not everywhere present, attitudes and thicknesses are difficult to establish. The best exposures in Dry Hollow dip from 6° to 13° southeast and strike N. 55 E. (Figures 3 and 4). Taylor (24) found the conglomerates in lower Robinson Canyon to the west to have a northwest dip. This indicates a north-northeast trending anticline passing between Dry Hollow and the eastern side of Taylor's area.

Collier (5, p. 10) visited a Dry Hollow coal prospect in 1914. Today the face of the drift is covered by slope-wash material, but his report displays a photograph that shows the thinly bedded coal and volcanic siltstone dipping 5° to 10° southeastward. These attitudes are comparable to those westward across the hollow. However, overlying massive volcanic conglomerates exhibit stratification which dips 30° southwestward (Figure 5). This structure is interpreted as cross bedding within the massive mudflow-type deposits. The southwestward dip suggests the conglomerates were deposited onto the coal swamp from the north and northeast. This idea is supported by the fact that flow breccias which are composed of the same material as the conglomerates crop out one mile to the north and appear to be a source of rocks composing the conglomerates. Only one
FIGURE 5. Volcanic conglomerates of the Clarno Formation. Center, sec. 22, T. 8 S., R. 22 E. Note cross-stratification dipping SW in view looking SE. Waste dump is from prospect in coal beds within the conglomerates.
fault was mapped because it is impossible to trace a particular bed more than a few thousand feet and offsets could not be clearly distinguished from primary discontinuity (Plate 1).

A maximum thickness of 2000+ feet is obtained if the entire outcrop area is assumed to dip uniformly 60° southeast. The unit thins to the east, north, and west. Thinning is abrupt except to the south where thickness is maintained for at least one mile outside the area.

Paleontology

Plant fossils are common in the Dry Hollow conglomerates (Figure 6). Fragments of petrified trees were found at the NE corner, SW 1/4, section 36 and the center of section 34, T. 8 S., R. 21 E. A well-preserved, three foot section of a tree was collected near the northeast slope of Sugarloaf Mountain. Several good leaf prints were collected from the center of section 8. These were compared with plates figured by Knowlton (11) and identified as specimens of Quercus ?, Hickoria ?, and Juglans ? sp.

Stratigraphic Relations and Age

The volcanic boulder conglomerates rest on porphyritic andesites exposed immediately north and west of Dry Hollow. The irregular contacts between lava flows and sediments indicates that
FIGURE 6. Fossilized tree fragment in volcanic conglomerates of the Clarno Formation; center of sec. 34, T. 8 S., R. 22 E.
the two units are often intercalated. The conglomerates are overlain unconformably by platy Clarno lavas west of Dry Hollow and at the head of Lone Pine Creek (Plate 1).

These conglomerates are probably part of the Lower Member of the Clarno Formation which ranges from Late Eocene to Early Oligocene in age. Outside the area these ages are based on a rhinoceras tooth dated as Middle Eocene by Stirton (22), and floral assemblages described by Chaney (2).

Source and Mode of Deposition

The intertonguing lavas and flow breccias north of Dry Hollow are probable source rocks for the volcanic conglomerates. An abundance of feldspar euhedra in the matrix, poor sorting and stratification, and abrupt changes in thickness suggest these are mass transport deposits from an area of high relief. Probably the sandstone beds are the result of superficial reworking of coalescing mudflow and alluvial fan deposits by streams. The abundant tree fragments suggest that landslides commonly buried entire forests.

Clarno Lavas

Distribution and Topographic Expression

Undifferentiated Clarno flows and flow breccias crop out over 131 square miles and underlie 80 percent of the map area. The
expanse of these lavas is almost uninterrupted inside the contacts with older and younger rocks exposed along the margins of the area. (Plate 1). Minor gaps in the distribution of the lavas are underlain by three rock types of the Clarno Formation that differ widely in their stratigraphic relations to the Clarno lavas. 1) In the western half of the area two separate, elongate patches of intercalated volcanic conglomerates are exposed. Each has an area of less than half a square mile. One is at the head of Lone Pine Creek and the other is on upper Pine Creek one-half mile west of the old Beard Ranch site. 2) An elongate belt of intercalated tuffaceous sandstone covers less than one square mile at Straw Fork. 3) Rancherie Rock is an elongate plug of hornblende andesite which occupies less than one-tenth square mile near the center of the area.

Topography developed on the Clarno lavas reflects their wide range of resistance to erosion. In general the distinctly layered, dense flows underlie broad, smooth-topped ridges having steep slopes which display medium-fine drainage texture (25, p. 127). Cliffs which are discontinuous laterally are common along the sides and at the heads of deep ravines. Sheer cliff faces are as great as 200 feet high in Robinson Canyon. Less resistant flow breccias underlie smoother topography that also exhibits a medium drainage texture. Isolated buttes are developed from resistant flow units which occur within and on top of the flow breccias (Figure 7). Clarno lavas
FIGURE 7. Clarno lavas in view looking southwest from hill at an elevation of 4142 feet at head of Robinson Canyon.
underlie the greater part of this area, thus the description of topography presented in the introduction to this paper need not be repeated.

**Lithology**

A twofold division of Clarno lavas is indicated from studies of their lithology in outcrops, hand specimens, and thin sections. This division is supported by stratigraphic and structural relations which will be presented following this discussion of lithology. For convenience the two units are referred to as lower and upper Clarno lavas.

**Lower Clarno Lavas**

The lower flows are deeply weathered, light green, tan, or lavender porphyritic pyroxene andesites. Thin sections reveal phenocrysts of euhedral calcic andesine and subhedral clinopyroxene. The groundmass is holocrystalline and the plagioclase laths are molded around the phenocrysts in a pilotaxitic texture. Modes of three porphyritic andesites from the lower Clarno lavas are presented in columns C, D, and E of Table 2. A summary of detailed thin section mineralogy for both upper and lower lavas follows Table 2.

**Upper Clarno Lavas**

The upper Clarno flows include two distinct rock types. 1) The most widespread rocks are fresh-appearing, dark gray to black,
finely-crystalline basaltic rocks. Occasional phenocrysts of euhedral, lavender-stained plagioclase are visible beneath the hand lens. Platy jointing is typically well developed and is accentuated by undulating bands of hematite which are less than one mm thick. In the northern half of the area the upper Clarno lavas grade into dark red scoriaceous layers. Red clay soil about twenty feet thick results from weathering of the scoria. This regolith is well exposed in a narrow band extending from the north edge of Dutch Flat northeastward across Service Creek (Plate 1).

In thin sections the upper basaltic flows exhibit a pilotaxitic texture and are composed of euhedral laths of calcic andesine and disseminated magnetite grains altered to hematite. Mafic constituents are entirely resorbed and are recognized from granular iron ore which retains the crystal outlines of pyroxenes and amphiboles. An average mode for upper Clarno lavas is tabulated in column A of Table 2. 2) The second type of upper Clarno flows consists of light yellowish-brown felsitic flows which occur only along the sides of the Rowe Creek valley. Some flows are massive, but others exhibit horizontal platy jointing. The massive flow from which sample B was taken has a pseudoconglomeratic appearance. Light green oval patches averaging three inches across are randomly distributed throughout the light yellow-brown matrix.

Microscopically, the felsite is 60 percent euhedral plagioclase
TABLE 2. Modes of Clarno Lavas (%).

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plagioclase</td>
<td>82</td>
<td>60</td>
<td>76</td>
<td>88</td>
<td>92</td>
</tr>
<tr>
<td>Clinopyroxene</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Clinopyroxene + actinolite</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>7</td>
<td>-</td>
</tr>
<tr>
<td>Actinolite</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>Magnetite</td>
<td>6</td>
<td>-</td>
<td>15</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Hematite + chlorite</td>
<td>12</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hematite</td>
<td>-</td>
<td>10</td>
<td>-</td>
<td>2</td>
<td>2</td>
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<tr>
<td>Chlorite</td>
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<td>-</td>
<td>-</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Calcite</td>
<td>-</td>
<td>-</td>
<td>6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Clay minerals + chlorite</td>
<td>-</td>
<td>30</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

A)  1. Ridge-capping flow in C., N 1/2, sec. 20, T. 7 S., R. 21 E.
    2. Flow in ravine N. of Pine Creek at SW cor., sec. 33, T. 7 S., R. 21 E.
    3. Flow on N. slope of Skyline Ridge at SW cor., NW 1/4, sec. 19, T. 7 S., R. 23 E.

B) Flow capping ridge on west side of Rowe Cr., NE 1/4, sec. 25, T. 8 S., R. 21 E.

C) Flow at entrance to Shelton State Park in SW 1/4, sec. 4, T. 8 S., R. 22 E.

D) Flow capping conical hill marked elev. 4142 at C., S 1/2, sec. 17, T. 8 S., R. 21 E.

E) Flow capping bench at C., SW 1/4, sec. 14, T. 7 S., R. 21 E.
laths averaging one-third mm in length. The green patches make up 30 percent of the rock and consist of concentrations of chloritic and clay minerals which are alteration products. The original pilotaxitic texture is obscured by advanced alteration of the groundmass plagioclase to montmorillonitic clays. Hematite clots make up ten percent of the thin section and are probably derived from biotite. The composition of this rock is similar to that of the Sugarloaf Mountain intrusive, and both are leucoandesites. The mode is restated in column B of Table 2.

**Petrography**

**Plagioclase.** In microcrystalline upper Clarno lavas euhedral plagioclase laths are less than one-fourth mm long. Most crystals are untwinned, but a few exhibit Carlsbad twinning. Measurement of extinction angles on a few albite twins using the Michel-Levy method (10, p. 257) indicates a plagioclase composition of An\textsubscript{44}. Chlorite occurs along the plagioclase crystal boundaries. Inclusions of subhedral magnetite are infrequently present in the plagioclase. On the basis of plagioclase composition that is transitional between andesine and labradorite and their dark color, the upper Clarno lavas are classified an andesitic basalts.

In porphyritic lower Clarno lavas plagioclase is present in two generations. 1) Calcic phenocrysts range from An\textsubscript{44} to An\textsubscript{48}. 
Deeply embayed crystals that were formerly euhedral are up to 1 1/2 mm long. They exhibit prominent zoning and broad albite twinning. Inclusions of glass, anhedral pyroxene, and subhedral magnetite are frequently aligned parallel to the directions of twinning. Minute needle-like crystals, probably apatite, are randomly oriented throughout some phenocrysts. In sample B calcite replaces the cores of many crystals. Chlorite and kaolinite in trace amounts are principal alteration products along fractures in plagioclase of samples D and E (Table 2). 2) Groundmass plagioclase is rarely twinned, but extinction angles measured on some albite twins suggest a composition of An\textsubscript{42}. Euhedral crystals average one-third mm in length. Alteration of the groundmass clinopyroxene results in a slight concentration of chlorite within interstitial spaces of the groundmass plagioclase.

**Clinopyroxene.** In upper Clarno lavas clinopyroxenes are completely resorbed or were never present in more than trace quantities. In lower Clarno lavas clinopyroxene phenocrysts differ mostly in regard to the principal type of alteration product. 1) Subhedral clinopyroxene in sample B is altered completely to actinolite cores with rims of opaque hematite. This form of actinolite, which is a late magmatic alteration product of clinopyroxene, is called uralite. 2) In sample C, clinopyroxenes exhibit eight-sided outlines that average one-third mm in cross section. Alteration to actinolite and rims of opaque hematite is incipient. Euhedral magnetite inclusions are
rare. 3) In sample D sparse relics of clinopyroxene are completely replaced by cores of fibrous actinolite and rims of opaque hematite. These relics average one-third mm in cross section.

**Alteration Products.** Low birefringent chlorite occurs chiefly as dense aggregates along crystal margins of groundmass plagioclase and in altered cores of clinopyroxene phenocrysts. Magnetite is common in finely crystalline basaltic flows represented by composite modal analysis A in Table 2. Alteration of magnetite to hematite yields the characteristic red staining of the andesitic basalts. In porphyritic andesites of the lower Clarno lavas hematite commonly forms rims around altered clinopyroxenes. In specimen C, blood-red hematite fills fractures in the plagioclase phenocrysts and makes them purple beneath the hand lens. Fibrous actinolite frequently replaces the cores of altered clinopyroxenes. In specimen B calcite is a common alteration product of both calcic plagioclase and clinopyroxene. No zeolites were recognized under high magnification, but X-ray analysis would probably reveal their presence.

**Thickness**

The base of the Clarno Formation is not exposed within this area. It is not feasible to measure thickness directly because persistent key layers are lacking. A maximum thickness of between 2500 and 3000 feet is estimated from the cross section A-A' across
the southeastern flank of the broad, NE-trending anticline which dominates the structure of the area. West of the area Taylor (24, p. 27) estimated the Clarno Formation to be 1500 feet thick including the lavas and intercalated volcanic conglomerates.

**Structure**

Structure of the Clarno lavas is well exposed along the south side of Club Hollow (Figures 8 and 9), 1 1/2 miles south of Fossil along both sides of Cottonwood Creek, and east of Sugarloaf Mountain along Rowe Creek. Generally the upper Clarno lavas exhibit the best flow layering and provide the best structural information.

Attitudes within the Clarno lavas are obtained from widely spaced exposures of distinct flow layering. Relative consistency among these attitudes suggests the following points regarding structure. 1) Wherever flow layering is well developed, initial dips were usually low. 2) Attitudes and trends recorded on the map represent the approximate amount of post-depositional tectonic deformation.

The axis of the prominent anticline in this area lies within the Clarno lavas. Flow layering dips 20° northwestward on the northwestern flank of the anticline. Along the southeastern flank dips are 10° to 15° southeastward. The trace of the anticlinal axis crosses the western boundary of the mapped area at Pine Creek and trends

northeastward to a point near the old Cottonwood School site. Here the axial trace swings east-northeast and continues eastward from Straw Fork to the eastern boundary where the fold plunges at a low angle to the east and abruptly dies out within the nearly flat-lying Columbia River Basalt which is peripheral to the northeastern corner of the area.

**Stratigraphic Relations and Age**

The Clarno Formation rocks are typical of thick, rapidly deposited volcanic sequences. Individual flow units and intercalated volcanic sediments are discontinuous both laterally and vertically. The basis for dividing the Clarno lavas into upper and lower units may be summarized as follows:

1) Near the center of the northwestern quarter of the area at the head of Lone Pine Creek andesitic basalt flows less than 200 feet thick rest on coarsely stratified andesitic conglomerates.

2) Near the crest of the anticline at the head of Robinson Canyon the andesitic conglomerates rest on porphyritic andesite flows.

3) One-half mile south of Craggy Rock the upper andesitic basalts rest with an erosional unconformity of at least 100 feet of relief upon the andesitic conglomerate of Dry Hollow.

4) Along the east side of Rowe Creek felsitic flows rest upon
Clarno andesitic basalts. The felsites are overlain by John Day tuffs and are also in contact with the Corral Mountain sequence of Columbia River Basalts.

The base of the Clarno Formation is not exposed in this area. Near the eastern boundary in the northern half, John Day ash flow tuffs rest upon the Clarno lavas. In the vicinity of Lake Creek an erosional unconformity with a relief of a few hundred feet exists between the John Day and underlying Clarno Formations. At Prairie Ranch an angular discordance of at least 5° is recorded between the two formations. A similar angular discordance of 5° is recorded between the upper Clarno felsitic lavas east of Rowe Creek and the overlying John Day Formation and Columbia River Basalts.

As a rock-stratigraphic unit the Clarno lavas can only be assigned a Late Eocene or Early Oligocene age as part of the Clarno Formation. This is based on a potassium-argon date of 37 million years reported by Hay (7, p. 202) from pyroxene andesite near Mitchell.

Source and Mode of Deposition

Andesitic plugs which record the sites of extrusion for the lower Clarno lavas are not exposed in the area. The abundance of breccias and volcanic conglomerates suggests the lower flows were deposited on the flanks of a large strato-volcano.
The large number of associated plugs and dikes suggest that the upper Clarno lavas originated from small vents which ceased eruption before large cones were built.

**Clarno Tuffaceous Sediments**

Although uniformly fine-grained tuffaceous sediments are moderately thick and extensive west of the area south of Clarno, they constitute a minor part of the Clarno Formation in this area.

**Distribution and Topographic Expression**

These tuffaceous beds are exposed only within road cuts at the intersection of Straw Fork road and Route 19 and along the southeastern side of the spur valley which drains into the valley of Butte Creek opposite Straw Fork (Plate 1). The tuffs underlie the spur valley and cross Butte Creek as an arcuate belt which is one-fourth mile wide and is convex to the northwest. The belt extends 1 1/2 miles from the head of the spur valley to a point one-fourth mile up Straw Fork. The tuffs offer less resistance to erosion than the surrounding lavas and have permitted widening of Butte Creek valley.

**Lithology**

Interbedded siltstone and sandstone are exposed in road cuts; natural outcrops do not occur. Colors of the tuffs are commonly
shades of yellow and brown. Yellow siltstone at Straw Fork junction is poorly stratified and has a nodular structure consisting of concretions two inches in diameter. Yellowish-brown sandstones in the spur valley are thinly laminated beds of alternating coarse and fine tuff. Thin sections reveal that subrounded fragments of porphyritic and pilotaxitic lavas compose the moderately sorted sediments. The fragments average one-half mm in diameter. Dark brown tuffaceous sandstones along the southeast side of the spur valley contain considerable silicified and carbonized plant material. Coaly lenses averaging one-half inch thick are intercalated with the laminated portions of the sandstone.

**Structure and Thickness**

A dip of 70° to the southeast is considered a reliable indication of structure and conforms to the general attitude of the enclosing Clarno lavas. Other beds in the spur valley dip 23° to the southeast. At Straw Fork junction the lower beds dip 20° due north. These last two attitudes reflect slumping in the tuffs.

Because of poorly exposed contacts, thickness can only be estimated to range between 50 and 100 feet.

**Paleontology**

Plant and animal fossils are fairly abundant in exposures
along the spur valley road. Fragments of reed-like plants and carbonaceous lenses are common along bedding surfaces of thinly laminated yellow tuffs. Carbonized seeds and nuts (?) up to one-fourth inch in diameter and more reed fragments occur in the massive dark brown tuffs. Pelecypod casts clearly showing external features of the shells are abundant in the dark brown tuffs. The shells range between one and two inches in length. They exhibit no ornamentation except concentric growth lines (21, p. 381). No attempt was made to identify these fossils for purposes of correlation. The author believes these are not reliable index fossils because they are too readily affected by conditions of their local lacustrine environment. Each pond would be expected to contain its own form of generally related clams.

Stratigraphic Relations and Age

The tuffs rest disconformably on light-colored, scoriaceous flow breccias southeast of Straw Fork. Tuffs are concordantly overlain by lava flows along both sides of the spur valley. Abrupt thinning of the tuffs northward and southward along the east side of Butte Creek valley indicates that the tuffaceous sediments form a lenticular body within the Clarno lavas.

The Straw Fork tuffs cannot be more closely dated than Eocene to Early Oligocene which is the accepted age of the enclosing Clarno lavas.
Source and Mode of Deposition

The Straw Fork tuffs are composed of lithic tuff fragments transported by streams and laid down in a small lake basin. The underlying scoriaceous flow breccias weather to form the same light-colored detritus that makes up the tuffs. Ash-fall material from an unknown source composes part of the tuff. Since the low amount of hematite in these tuffs is not typical of sediments derived from the Clarno lavas, the greatest volume of tuffs originated as ash fall material low in iron-bearing minerals.
JOHN DAY FORMATION

General Statement

In 1875 O. C. Marsh (13, p. 52) referred to a thick sequence of bedded tuffs which were deposited in "John Day lake basin" during Miocene time. Merriam (14, p. 291) wrote a composite description in 1901 in order to define the stratigraphic position of mammalian fossils collected from several exposures along the John Day River. He established the name John Day Formation and on the basis of color divided it into lower red beds, middle green beds including a "rhyolite" flow near the base, and uppermost buff beds.

More recently in 1949 Coleman (4, p. 61) described a specific type section near Picture Gorge in which lithology, color, and stratigraphic position dictated a threefold division similar to that proposed by Merriam. However, Coleman recognized the "rhyolite" as a welded tuff and included within the upper member all rocks from the base of the welded tuff to the base of the overlying Columbia River Basalt.

A summary of recent work by White (27, p. 48) points out that for several type sections different criteria have resulted in only slight differences in the definition of members within the John Day Formation. Each of these schemes generally conforms to that first proposed by Merriam.
Distribution and Topographic Expression

The John Day Formation crops out over eleven square miles as irregular belts and isolated patches inside the northwestern and southeastern margins of the area. The best exposures form a belt ranging from one-fourth to one mile in width which extends from the east side of Prairie Ranch around the north end of Muleshoe Mountain, and across Service Creek (Plate 1). It then crosses Dutch Flat, and continues westward to Corral Mountain. The belt narrows between the south end of Corral Mountain and old Dedman Ranch site. Upper and lower contacts of the John Day Formation included within a strip two miles wide along the southern boundary are adopted without revision from an Oregon State University master's thesis by Bedford in 1954 (1). South of Corral Mountain the formation is exposed in a claw-shaped belt which is concave to the south. The belt averages one mile in width as it trends west and swings southward to Bull Canyon near the southern boundary, and continues southwestward six miles outside the area to the John Day River near Twickenham. Two other small strips of tuff crop out west and north of Fossil. The first semicircular band is concave to the west along the western boundary, 1 1/2 miles long, and averages one-fourth mile in width. The other exposure extends eastward from the north edge of Fossil along the 45th parallel for about three miles. Here the total outcrop
breadth is about one-half mile, but only one-fourth mile is within the northern boundary.

Two roughly tabular, isolated patches lie on the southwest and northeast sides of Lake Creek near the east-central margin of the area. They are one-half mile apart and each covers about one square mile.

Topographically, the John Day tuffs underlie a break in slope at the contact with overlying Columbia River Basalt. Generally, erosional forms developed on the tuffs reflect their local degree of induration. The more indurated deposits form laterally discontinuous cliffs usually less than 1000 feet long that conform to the strike of bedding. Outcrops along the south side of Dutch Flat and south of Bull Canyon provide the best examples. Less consolidated deposits underlie widened segments of valley floors such as those at Prairie Ranch, Dutch Flat, lower Rowe Creek, and Butte Creek west of Fossil (Figure 10). Landslide topography is exhibited west of Stone Cabin Creek and south of Corral Mountain. Isolated exposures of ash flow tuff in the vicinity of Lake Creek have a topographic expression that is not distinguishable from that of the adjacent Clarno lavas.

Lithology and Nature of Outcrop

The John Day Formation in this area consists of two rock types. Both are composed of acid to intermediate pyroclastic
FIGURE 10. John Day Formation exposed in topographic basin at Prairie Ranch.
material, but are distinguished on the basis of megascopic and thin section studies of texture, primary structure, and the nature of included fragments. First in respect to volume are tuffaceous volcanic siltstones and sandstones which are composed dominantly of reworked pyroclastic deposits and contain minor amounts of detritus from the underlying basaltic andesites of the Clarno Formation. The second rock type consists of ash flow and ash fall deposits which have a simple composition, but exhibit a wide range in their degree of induration. Although Lukanuski (12, p. 52) described rhyolite flows on Stevenson Mountain which is thirty miles to the southwest, none were discovered within the area.

**Tuffaceous Volcanic Siltstones and Sandstones**

Tuffaceous volcanic sediments are of two types which differ chiefly in the extent of their sorting and stratification.

1) The first type consists of well-stratified beds which average six inches in thickness. They are exposed along both sides of Service Creek near Dutch Flat. These yellowish-tan rocks have a greenish tint when they are moist. Rounded pumice fragments which average one mm in length compose 98 percent of the rock. The rock is friable as a result of alteration of the smaller pumice fragments to montmorillonitic clays. The resulting soil cover obscures most outcrops even along the walls of this canyon. Other constituents
include euhedral prisms of plagioclase altered to clay minerals; these appear as prominent white patches in the darker matrix. Various dark grains are visible beneath the hand lens. Heavy mineral fractionation using tetrabromoethane (sp. gr. 2.95) yielded two percent heavies from 80 grams of washed sand obtained from 100 grams of crushed tuff. The following distribution is based on a count of 300 grains:

<table>
<thead>
<tr>
<th>MINERAL</th>
<th>PERCENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>brown hornblende</td>
<td>4</td>
</tr>
<tr>
<td>pyroxene</td>
<td>5</td>
</tr>
<tr>
<td>magnetite</td>
<td>70</td>
</tr>
<tr>
<td>olivine</td>
<td>17</td>
</tr>
<tr>
<td>rock fragments</td>
<td>4</td>
</tr>
</tbody>
</table>

This assemblage of euhedral and subhedral crystals was deposited as part of the pumice fall.

2) The second type and the greatest volume of tuffaceous sediments are poorly sorted and stratified. These creamy yellow rocks also have a greenish tint when moist. Completely altered ash constitutes most of the rock. Crystals of subhedral quartz and plagioclase are sparsely distributed throughout the tuff. Its detrital nature is not always apparent from study with a hand lens. A thin section of a pebble conglomerate revealed subangular fragments of hematite-stained andesitic basalt derived from the underlying Clarno Formation. The tuffaceous matrix displays a faint granular texture,
but no relict vitroclastic texture is visible. The probable origin of these thick deposits is discussed in a later section.

**Ash Flow and Ash Fall Deposits**

Abrupt lateral and vertical variation in texture and composition is the outstanding feature of the pyroclastic deposits in this area. The following descriptions of six representative samples are given in support of this statement.

1) The first sample to be described was taken from a roadcut near the intersection of Lake Creek road and the road to Snowboard Lookout. The creamy white outcrop resembles a felsitic flow rock with some dark included rock fragments. The sawed surface resembles figure 13 shown in Professional Paper 366 (18, p. 29). Microscopically, the dark elongate fragments with frayed ends are compressed pumice. The glassy groundmass of deformed pumice shards has a refractive index less than that of balsam. Pumice is molded around large euhedral crystals of zoned sodic plagioclase. These crystals and a few subhedral crystals of quartz make up less than five percent of the rock. Angular fragments of andesitic basalt and glassy ash flow tuff constitute ten percent of this welded ash flow tuff. The remaining 85 percent consists of compressed glassy pumice shards.

2) One mile southeast of the last location pale green beds
crop out in a road cut. This dense, welded ash flow tuff is composed of laminated pumice fragments several inches long. The pumice has lost most of its primary porosity, but fragments are easily identified. Frequently one or more bands of black glass lie in the plane of lamination of the flattened pumice fragments. A few fragments of dark rock averaging two mm in cross section are included in the matrix.

3) A ridge at the head of the south fork of Lake Creek is capped by pinkish, dense rock exhibiting well-developed horizontal platy jointing. Under the hand lens it appears to be a moderately porphyritic flow rock. However, this is also an ash flow tuff. Thin section study shows euhedral crystals of quartz, zoned sodic plagioclase, and occasional tuff fragments are set in a glassy groundmass of deformed pumice shards. The shards constitute 97 percent of the rock and are molded around the included crystals and tuff fragments. The interior of the shards is replaced by parallel crystalline intergrowths which project from each shard wall and nearly meet along a center line parallel to the length of the shard. These structures are called axiolites and Ross and Smith (18, p. 36) report that by means of X-ray studies the minerals have been identified as sanidine feldspar and cristobalite. This type of devitrification is distinct from alteration of glassy welded ash flows during ordinary weathering processes. The growth of these crystalline aggregates at the expense of glass probably began immediately after welding of the shards and continued
until some minimum cooling temperature was attained.

4) Sample four was taken from the lower east-facing slope of a ridge at the C., SE 1/4, sec. 30, T. 7 S., R. 23 E. about one mile southeast of the last described sample. This sample is a dark green, dense rock with parallel brown bands spaced three mm apart. Under the hand lens it appears to be slightly weathered and devitrified. In a thin section the rock shows a moderately deformed vitroclastic texture. The glass shards are devitrified and altered to crystalline aggregates that are probably composed of sanidine feldspar and tridymite or cristobalite. Phenocrysts of zoned sodic plagioclase and some quartz make up less than two percent of the rock. This rock is a welded and devitrified ash flow tuff.

5) At the SW cor., NE 1/4, sec. 7, T. 8 S., R. 23 E., one mile northeast of Prairie Ranch, light tan rocks are exposed in three ledges each about three feet thick and extending only twenty feet along their strike before tapering into overlying slopewash alluvium (Figure 11). The rock is extremely porous and is composed of undeformed pumice fragments averaging four mm in length. Most of the large pumice fragments are light tan and retain their primary cellular structure. Some fragments are smoky gray and glassy. Crystals of subhedral quartz and broken plagioclase are not abundant. The primary vitroclastic texture of this ash fall tuff is replaced by fragile, concentrically shelled spherules probably composed of
FIGURE 11. John Day Formation; outcrop of bedded ash fall tuff at east edge of Prairie Ranch basin. View looking WSW.
tridymite and cristobalite.

6) Immediately northwest across the road from the last sample is an isolated ledge of yellow-brown, dense rock. It fractures irregularly and produces a hollow ringing sound when struck with a hammer. Megascopically, sparse prisms of plagioclase are visible, and poorly developed lamination is seen. A thin section reveals it is composed of flattened pumice shards and has a moderately deformed vitroclastic texture.

None of these units maintain their lithologic identity for more than one-fourth mile laterally or one hundred feet vertically. Poor exposures do not permit definition of individual ash flow and ash fall units.

**Thickness**

The thickness of the John Day Formation in this area ranges from 200 to 400 feet (Plate 1). In the area to the south mapped by Bedford (1), a maximum thickness of 700 feet is scaled from the map one mile south of Bull Canyon. Northward from this section the John Day Formation wedges out and the Corral Mountain section of Columbia River Basalt lies unconformably on the Clarno andesitic basalt and leucoandesite flows. The inclusion of Clarno lava fragments in the tuffs north of Fossil suggests that the anticlinal crest was a topographic high during deposition of the tuffs. Complete
removal of the John Day Formation from the center of the area supports this idea that the tuffs were originally thinner near the center of the area than along the margins. The ash flow deposits in the Lake Creek vicinity average 100 feet in thickness and were protected from complete erosion by a relatively thin covering of Columbia River Basalt and the tendency of ash flows to be thickest in low areas of pre depositional topography.

**Structure**

Lack of well-stratified exposures and the profusion of slumping hamper direct observation of structure within the formation. Immediately north and also two miles west of Fossil well-stratified, tuffaceous volcanic siltstones dip $5^\circ$ northwestward and strike approximately northeastward, turning eastward about two miles north of Butte Creek. Along the scarp bordering Dutch Flat on the south massive ash fall deposits dip $10^\circ$ southeastward and strike northeastward. This dip is greater than the $5^\circ$ recorded one mile east of Prairie Ranch. The difference is a result of gravity sliding on the Clarno red clay and local steepening along this flank of the anticline. Welded ash flows in the vicinity of Lake Creek are so poorly exposed that they afford no direct record of tectonically produced structure.
Paleontology

Although the tuff beds are well known for their vertebrate fauna elsewhere in the region, no fossils of this type were discovered in the area. A single specimen of *Metasequoia* sp., the "dawn redwood", was collected just north of the high school at Fossil. This locality is mentioned by Merriam (14, p. 290) and the flora is described by Knowlton in the 1901 report.

Stratigraphic Relations and Age

The John Day Formation displays an erosional and slight angular unconformity of $5^\circ$ at the contact with the Clarno Formation. The finger-like outcrop pattern of the Lake Creek deposits indicates that relief of several hundred feet was developed on the Clarno lavas prior to deposition of the ash flow tuffs. Thicker deposits of re-worked tuffs rest in low areas of the pre-John Day topography.

At the northern limits of Fossil, the thinly-beded tuffaceous siltstones were considered part of the Clarno Formation by Merriam and Knowlton (14, p. 290) on the basis of fossil leaves. Immediately north and west of the area, these beds rest on the eroded surface of Clarno andesitic lavas. An angular discordance of $5^\circ$ to $10^\circ$ exists between the lava flows and the sediments. The author believes that the tuffaceous siltstones immediately north of Fossil are part of the
Lower John Day Formation.

There is a moderate erosional unconformity between the John Day Formation and the overlying Columbia River Basalt. The two units are generally concordant in this area, but an angular unconformity of a few degrees probably exists between them at Corral Mountain (Plate 1).

Because correlation of individual members from the type section at Picture Gorge is uncertain, the age of the John Day Formation in this area cannot be closely defined. No important guide fossils were found in the area. According to Wood (31), the John Day Formation ranges from Late Oligocene to Early Miocene in age. Potassium-argon age determinations on pyrogenic minerals from the John Day near Mitchell yield an age of 25-31 million years which is consistent with paleontologically defined ages (7, p. 210).

Source and Mode of Deposition

The John Day Formation in this area was deposited primarily as acid to intermediate pyroclastic material. Much of the pyroclastic debris was eroded from the highland crest of the pre-Miocene anticline in the area and laid down as a thick sequence of tuffaceous fluvial and lacustrine sediments. No clear evidence within the area indicates whether the pyroclastics were supplied by local or distant sources. It is likely that both were important.
COLUMBIA RIVER BASALT

Definition and General Statement

Thick sequences of multi-layered basalts exposed along the Columbia River were referred to as "Columbia River Lavas" by Russell (20, p. 28) in 1901. The name originally included all plateau basalts covering eastern Washington, Oregon, and western Idaho. In the Picture Gorge area, Merriam (14, p. 303-309) determined a Pliocene age for Mascall tuffs resting on the basalts and an Early Miocene age for the underlying John Day tuffs. On this basis he proposed that the name Columbia River Basalt be used only for plateau basalts of Miocene age.

Basalt flows which rest on the John Day Formation in the thesis area are laterally continuous with the Columbia River Basalt elsewhere in the region.

Distribution and Topographic Expression

Outcrops of Columbia River Basalt are peripheral to the area which is a "window" of pre-Miocene volcanic rocks. The basalts crop out over 17 square miles in the southeastern corner of the area. In the northwestern quarter, two NE-trending ridges are each capped by about one-half square mile of basalt. Three outcrops of one-third square mile each occur at the center of the north boundary, in the
FIGURE 12. Columbia River Basalt cliffs of Muleshoe Mountain as viewed eastward from Rancherie Rock.
northeastern corner, and along the eastern boundary of the area (Plate 1).

The Columbia River Basalt forms high plateaus that have low relief on their surfaces, and are bounded by either a series of step-like benches and vertical cliffs, or steep, smooth slopes (Figure 12). Cliffs are better developed in the southeastern quarter of the area. Here, a typical cliff-forming situation consists of several layers of basalt with vertical columnar joints resting on several hundred feet of soft John Day tuffs. Along Service Creek sapping of the tuffs beneath the basalts has caused periodic slumping and produced cliffs as high as 1000 feet (Figure 12). Southwest of Fossil steep, smooth slopes are formed by weathering of the less resistant vesicular basalt flows and the typically resistant flows with vertical columnar jointing. Such slopes have a mantle of subangular talus boulders. The boulders form stone stripes and polygonal nets that distinguish the basalt plateaus in the field and on aerial photo-maps.

Landslide topography is typical of the Columbia River Basalt where it rests on the John Day Formation along the sides of valleys. Two miles southwest of Fossil hummocky topography is well-developed where the John Day tuffs are thick enough to permit slumping of the overlying Columbia River Basalt (Figure 13).
FIGURE 13. Columbia River Basalt slump block resting on John Day Formation west of Fossil.
Lithology

The Columbia River Basalt is noted for its lateral and vertical uniformity in composition. Examination of thin sections of three representative samples does not provide sufficient data to either support or dispute the above generalization with respect to the thesis area. The samples were chosen because of their obvious differences when observed in the field, and because their stratigraphic position made it clear that they were part of the Columbia River Basalt. The samples include a dark gray, moderately-crystalline basalt from the northeast corner of the area, a black, finely-crystalline basalt from the north-central boundary, and a dark brown, finely-crystalline, platy basalt from the northwest corner of the area. Modes are presented in Table 3 beneath numerical headings which correspond to the order of the following paragraphs.

1) Sample no. 1 is an unweathered dark gray, moderately-crystalline basalt composed chiefly of minute laths of sodic labradorite (An50- An59) and subhedral grains of clinopyroxene. The average size of all crystals is one-fourth mm. Colorless glass with dust-like inclusions, anhedral olivine grains, and interstitial masses of hematite make up the remainder of the rock. The angular forms of the hematite grains suggest that they are pseudomorphic after magnetite. The basalt has a typical intergranular texture.
2) Sample no. 2 is a black, aphanitic basalt in which pale-brown glass constitutes more than half of the rock. Calcic labradorite (An50) laths, averaging one-fourth mm in length and disseminated hematite grains make up the remainder of the rock. Again hematite is mostly pseudomorphous after magnetite.

3) Sample no. 3 is a dark brown platy basalt. Hematite stains on the joint surfaces form circular patterns several inches in diameter. In the field this basalt is similar to many Clarno lavas in respect to platy jointing and hematite stains. The platy jointing is probably the result of flow banding because it parallels the pilotaxitic arrangement of plagioclase laths in the rock. Untwinned plagioclase laths averaging one-fourth mm long make up most of the rock. Anhedral olivine grains average one-fourth mm across and occupy interstitial spaces between plagioclase laths. A trace of interstitial brown glass and disseminated hematite makes up the remainder of the rock. None of the platy Clarno lavas examined in thin sections contain olivine. This specimen is one of the "spherulitic basalt" described by Taylor (24, p. 70).

Thickness

The maximum thickness for the Columbia River Basalt in the area is 1000 feet. This thickness is scaled from the map along the west side of Muleshoe Mountain in the southeastern quarter of the
area (Plate 1). Thickness prior to erosion is unknown because no concordant younger formations overlie the basalts in this area. The basalts probably once covered the entire area, but were originally thinner across the pre-Miocene anticlinal crest described in the section on the Clarno Formation.

TABLE 3. Modes of Columbia River Basalt (%)

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<th>Sample no.</th>
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<td>Magnetite</td>
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</tr>
<tr>
<td>Hematite</td>
<td>-</td>
<td>T</td>
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</tr>
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1) Basalt capping Snowboard Ridge in SE 1/4, sec. 20, T. 7 S., R. 23 E.

2) Basalt capping hill in center, sec. 36, T. 6 S., R. 21 E.

3) Platy basalt capping slump block in NW 1/4, sec. 6, T. 7 S., R. 21 E.

T Equals trace amount less than one percent
Structure

Structural features within the basalts include columnar jointing perpendicular to flow layering, spheroidally weathered joints, one occurrence of a diamond-shaped joint pattern, and rare instances of platy jointing. Columnar joints are exposed in most cliff-forming sequences of the basalts. Spheroidal weathering is restricted to basal flows on the west side of Corral Mountain. Two sets of joints exposed on top of Corral Mountain have trends of N. 45° W. and N. 5° W. with an intersecting angle of 40°. Platy jointing is developed at two locations where basalts can be seen resting concordantly on the John Day Formation. One exposure of the platy basalts is two miles west-southwest of Fossil in cliffs immediately above the Hunt Ranch. The other is one-half mile northeast of the intersection of the Kinzua road and the 45th parallel. The platy basalts at Hunt Ranch are the "spherulitic basalt" described by Taylor (24, p. 70). The author believes they are lateral correlatives of the platy basalts near the Kinzua road and that both are part of the Columbia River Basalt.

During the Late Tertiary, the Columbia River Basalt was folded into a broad anticline parallel to pre-Miocene structural trends in the area. The basalts dip 2° to 4° southeastward in the eastern half of the area. North of Fossil the basalt flows dip 5° north-north-
eastward. West of Fossil the dip is 5° to 10° northwest. The axial trace of the anticline swings from northeast to due east (Plate 1).
The south limb of the anticline is shared by an east-trending syncline that parallel the John Day River near its junction with Service Creek (29, Figure 38). Outside the area, near Picture Gorge; Late Miocene Mascall tuffs rest with slight angular unconformity on the Columbia River Basalt. The folding in this area is probably also Late Miocene.

Slump faulting of Columbia River Basalt is common southwest of Fossil (Figure 14). The author believes that outcrops of the "spherulitic basalt" described by Taylor (24, p. 70) from the cliffs southwest of Fossil are not platy Clarno lavas, but are slumped blocks of Columbia River Basalt resting concordantly but disconformably on John Day tuffs. In the east-trending ravine bisected by the southern border of Township 6 South, the contact is exposed between a slumped block of platy basalt and an underlying cream-yellow tuff. The tuff is considered part of the massive, well-indurated tuffaceous sediments, containing both crystals and lithic fragments, which are typical of the John Day Formation in this area. If the slumping hypothesis is accepted, the "Clarno Upper Welded Tuff" described by Taylor (24, p. 112) probably does not rest on the platy basalts immediately west and outside the mapped area, but is slump faulted against them. This author believes the "Clarno Upper Welded Tuff" described west of Fossil by Taylor (24, p. 112) is part of the John
FIGURE 14. Columbia River Basalt slump blocks resting on John Day Formation west of Fossil.
Day Formation.

Stratigraphic Relations and Age

An erosional unconformity having about 100 feet of relief exists between the John Day Formation and the overlying basalts (Figure 15). No younger formations overlie the Columbia River Basalt in this area. At Picture Gorge the basalts described by Waters (27, p. 607) rest upon Oligo-Miocene tuffs in Turtle Cove and are concordantly overlain by the Middle to Late Miocene Mascall Formation. The basalts of this area are lateral correlatives of the Picture Gorge basalts and are therefore considered Middle Miocene in age.

Source and Mode of Deposition

No sources for the Columbia River Basalt were discovered in the area. This concordant sequence of laterally continuous flows piled on top of one another is typical of effusive fissure eruptions described by Rittmann (17, p. 120). If sources are present they are probably buried by flows.
FIGURE 15. Columbia River Basalt of Corral Mountain resting discordantly on Clarno leucoandesites northeast of Rowe Creek. View looking northeast. John Day tuffs wedge out below Corral Mountain.
TERTIARY INTRUSIVE ROCKS

Twelve intrusives of porphyritic basalt and andesite were identified on the basis of topographic expression, structure, and texture. On the basis of their relation to the lithology and structure of enclosing lava flows and volcanic conglomerates all these intrusives are considered part of the Clarno Formation.

The composition of plagioclase in all these rocks is transitional between andesine and labradorite. For the purpose of description the dark rocks with little amphibole are designated andesitic basalts and the light-colored rocks are called basaltic andesites after Williams (30, p. 43). Modes for selected intrusives are arranged in Table 4 in columns corresponding to the following numbered descriptions.

**Basalt and Andesitic Basalt Intrusives**

1. Jennies Peak Intrusive

Jennies Peak is a prominent fin-shaped knob which stands high above smooth-crested ridges in the C., NE 1/4, sec. 36, T. 8 S., R. 21 E., one mile west of Dry Hollow (Plate 1). The upper one-third of this NE-trending intrusive is 700 feet long, 200 feet wide, and rises 200 feet above the surrounding ridge crest. The lower part is exposed at the head of a ravine formed along the contact with
<table>
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1) Jennies Peak intrusive in C., NE 1/4, sec. 36, T. 8 S., R. 21 E.

2) Craggy Rock intrusive in SW cor., SE 1/4, sec. 23, T. 8 S., R. 21 E.

4) Basalt dike 1 1/2 miles SW of Rancherie Rock in C., S 1/2, sec. 12, T. 8 S., R. 21 E.

7) Sugarloaf Mountain intrusive in NE 1/4, sec. 35, T. 8 S., R. 21 E.

9) Rancherie Rock intrusive in NE cor., SW 1/4, sec. 6, T. 8 S., R. 22 E.
FIGURE 16. Jennies Peak intrusive in center of NE 1/4, sec. 36, T. 8 S., R. 21 E. View looking northeast at relatively broad southwest face. Dimensions in the northwest direction are relatively narrow. Craggy Rock intrusive and Corral Mountain are viewed in the background across Dry Hollow.
surrounding Clarno volcanic conglomerates (Figure 16). The principal structure within the intrusive is vertical platy jointing which parallels the overall NE-trend. Major NE-trending ribs 30 feet thick are composed of smaller platy joint layers about one inch thick. Weathering and erosion of less resistant layers forms channels between the major ribs. The platy layering resulted from rapid cooling and was formed parallel to the cooling surface according to Rittmann (17, p. 70).

Freshly broken samples are dark gray, finely-crystalline, and are readily parted into plates one-half inch thick. Hematite stains are localized along the planes of flow layering. Occasionally, phenocrysts of hornblende averaging one mm long are visible beneath the hand lens. A few phenocrysts (?) of a clear vitreous mineral were also observed in hand specimens.

Microscopically, the rock is holocrystalline and has a micro-porphyritic, pilotaxitic texture. Lamprobolite phenocrysts up to one mm long constitute only a small part of the thin section, but are probably abundant within more porphyritic segments of the intrusive. About 80 percent of the lamprobolite originally present is replaced by pseudomorphs composed of granular iron oxide. Several quartz xenocrysts up to three mm across are unusual constituents of this andesitic basalt. The quartz is clear, free of inclusions, and is not resorbed or altered along its margins. The xenocryst is optically
continuous within its boundaries and yields slightly distorted uniaxial positive interference figures. The distorted figures may reflect straining of the quartz during its transportation. Minute plagioclase laths are molded tangentially to the unaltered boundaries of the quartz. Taylor (24, p. 33) reports quartz-bearing basalt intrusives west of the area near Muddy Ranch. He believes the quartz is incorporated from the surrounding phyllites. Volcanic boulder conglomerates surrounding Jennies Peak have virtually no included quartz grains. Perhaps Cretaceous sediments at greater depths gave up quartz to the Jennies Peak intrusive. Plagioclase laths ranging from one-fourth to one-half mm in length make up most of the rock (Table 4). Large crystals show zoning, albite twinning, and have an average composition of An48. All plagioclase crystals are unaltered, but many are embayed at their ends. Hematite is common, and originates as granular pseudomorphs after resorbed lamprobolite.

The igneous body crosses vertically through stratified volcanic boulder conglomerates which dip 10° southeastward. Jennies Peak originated as magma that solidified in a fissure. This fissure probably supplied much of the upper Clarno lavas in this quarter of the area. It was probably the source of intracanyon basalt flows resting on volcanic conglomerates about two miles southwest of the peak.
2. Craggy Rock Intrusive

Craggy Rock is a small butte in the SE cor., SE 1/4, sec. 23, T. 8 S., R. 21 E. The NW-trending intrusive is 1800 feet long by 500 feet wide and is teardrop-shaped in the map view (Plate 1). It is nearly encircled by cliffs which are 300 feet high at the blunt southern end and taper into a narrow natural rampway leading from the intrusive onto the ridge of volcanic boulder conglomerate to the northwest.

The structure of Craggy Rock consists of both vertical and horizontal sets of columnar joints. Nearly vertical joint columns averaging two feet across are exposed in the lower half of the intrusive (Figure 17). Sets of horizontal joint columns cap the upper one-half of the butte. Clusters of horizontal joint columns averaging 20 feet in length are arrayed in stacks that form pillars averaging 120 feet in height and ranging from 20 to 30 feet in cross-section. Deep, narrow channels have formed between the pillars as a result of differential weathering and exfoliation. The trend of elongation of the butte parallels the NW-trending joint columns (Figure 18). The upper and lower sets of columnar joints are interpreted as a record of two separate phases of intrusion and cooling in the vent.

Megascopically, both structural units of Craggy Rock consist of dark gray, finely-crystalline rocks and exhibit no phenocrysts beneath the hand lens. The outer one-quarter inch of hand specimens
FIGURE 17. Craggy Rock intrusive. View of relatively narrow south end. Note upper and lower units of columnar structure.

is weathered dark red brown. Microscopically, the rocks consist mostly of euhedral, twinned plagioclase laths averaging one-third mm in length. The texture of the rock is pilotaxitic. Extinction angles of twinning within the largest plagioclase crystals indicate a composition of \((\text{An}_{46})\) calcic andesine. Rare prisms of yellow-brown lamprobolite are bordered by fringes of opaque iron oxide. Clusters of iron oxide grains in masses of chlorite are localized between the plagioclase laths. Chlorite occurs along cleavage and fracture planes of the plagioclase, but plagioclase itself is unaltered.

The intrusive has not strongly disturbed the attitudes of surrounding strata composed of volcanic sediments. The basalt was emplaced sub-concordantly along bedding planes and is sill-like in its relation to the sediments. Craggy Rock probably also was a site of extrusion for the surrounding upper Clarno lavas.

3. Basalt Plug West of Rowe Creek

Differential erosion of this intrusive in sec. 25, T. 8 S., R. 21 E. has formed a small hill standing 150 feet above the surrounding Clarno lavas. Bedford (1, p. 70) reports horizontal joint columns near the center of the exposed southeast face, and vertical columns near the surface of the exposed body.

The basalt is fresh-appearing, dark gray and finely-crystal-line. Weathered specimens are red-brown. No thin sections were
made, but Bedford (1, p. 71) reports a microporphryritic texture of tabular plagioclase laths and clinopyroxene phenocrysts in a holocrystalline groundmass of the same minerals. Minor olivine and magnetite inclusions are disseminated throughout the groundmass.

Whether the plug intrudes the surrounding felsitic lavas or is buried by them is not certain from the poorly exposed contacts. The unweathered aspect of the plug and the basaltic flow on the northwest flank suggest that the plug cuts the felsitic lavas. The composition is not much different from other Clarno intrusives and lavas. It may be one of the youngest plugs of the Clarno Formation in this area.

4. Basalt Dikes one and one-half miles SW of Rancherie Rock

A complex of porphyritic hornblende dikes crops out at the summit of a hill in the C., S 1/2, sec. 12, T. 8 S., R. 21 E. The structural features of the best exposed dike consist of a row of polygonal joint columns averaging four feet in cross-section. The long axes of the columns are inclined 25° to 30° N. 25 E. and the dike trends N. 65 W. Other randomly oriented joint columns are exposed along the southeast side of this hill. The dike just described is exposed along the north edge of a tabular body of basalt about one-eighth mile square and 150 feet thick (Figure 19). The entire sheet-like body has a southward dip of 20° to 30°. This attitude probably developed during folding of the enclosing Clarno lavas. The original
FIGURE 19. Second hill from left capped by basalt dikes 1 1/2 miles southwest of Rancherie Rock. View looking north with Rancherie Rock, in the background.
degree of discordance between the body and the intruded lavas is not known, but is inferred to have been slight.

Megascopically the rock is black, appears unweathered and contains euhedral amphibole phenocrysts up to two inches long and one-quarter inch wide.

Microscopically, the groundmass consists of euhedral plagioclase laths having the composition An50. The laths range from one-eighth mm to one mm in length. Those one-half mm long are most common and exhibit good polysynthetic twinning. The plagioclase is embayed at the ends, but is unaltered. Brown hornblende and one phenocryst of colorless hornblende constitute one percent of the thin section. Hornblende is pleochroic from dark brown to pale tan in prismatic sections. All hornblende crystals have reaction rims of granular iron oxide which sometimes retain the original six-sided outline of cross-sectional views. Most hornblende is replaced by oval masses of granular iron oxide and clinopyroxene. The cores of some clinopyroxene crystals are composed of dense aggregates of chloritic alteration products. Light brown glass with an index of refraction greater than balsam forms the groundmass and makes up one-third of the rock. Subhedral grains of clinopyroxene are frequently mixed with pseudomorphous iron oxide replacements of hornblende. The clinopyroxene is a deuteric alteration product of the hornblende. Chloritic alteration products derived from the
amphiboles occur in the interstitial spaces of the granular clinopyroxene and iron oxide aggregations.

5. Dike in NE cor., Sec. 16, T. 8 S., R. 21 E.

An ENE-trending ridge about 500 feet long rises 200 feet above the surrounding Clarno lavas. The only structural feature is a set of several N. 75° E. -trending fracture planes that are nearly vertical. The outcrop is considered to be an intrusive on the basis of its topographic expression and because its trend intersects the strike of the adjacent SE-dipping Clarno lavas composed of similar dark gray, aphanitic rock.

6. Plug along upper Pine Creek in the C., NE 1/4, Sec. 5, T. 8 S., R. 21 E.

A conical hill composed of basalt rises about 150 feet above the south side of Pine Creek. Vertical joint columns exposed in the north-facing cliff extend the entire height of the hill. The contact with volcanic boulder conglomerates is poorly exposed. Since no basalt is found in this outcropping of conglomerates, the basalt body is considered to be a plug. The basaltic lavas exposed immediately north across Pine Creek were probably extruded from the vent now filled by this plug.
Andesite and Basaltic Andesite Intrusives

7. Sugarloaf Mountain Intrusive

Sugarloaf Mountain is a cone-shaped butte in the NE 1/4, sec. 35, T. 8 S., R. 21 E. in the south-central half of the area. It rises 500 feet above the encircling ravine and is a quarter of a mile in diameter at the base. The present conical form of this plug results from erosion of the original shape and from exfoliation of random platy jointing to form thick talus deposits on all slopes. Platy jointing is the only internal structure exposed near the summit (Figure 20).

In outcrops and hand specimens the platy, felsitic rock is light tan on fresh exposures and is pinkish on weathered surfaces. Microscopically, the rock consists mostly of calcic andesine (An$_{46}$) laths (Table 3). This rock has a microporphyritic texture and the plagioclase laths show a pilotaxitic arrangement. Anhedral plagioclase fills interstitial spaces between the relatively smaller laths of the groundmass. Chloritic alteration products are minor constituents and occupy interstitial spaces along boundaries of anhedral groundmass plagioclase. Hematite pseudomorphs after subhedral disseminated magnetite grains constitute between one and two percent of the rock. Less than one percent brown biotite filaments one-half mm long are the only dark minerals present. This leucoandesite intrusive is very similar to a plug described by Taylor (24, p. 49) about 13 miles westward and outside the area.
FIGURE 20. Sugarloaf Mountain intrusive. Columbia River Basalt of Corral Mountain in left background rests discordantly on Clarno leucoandesites.
The Sugarloaf Mountain intrusive cuts across the stratification of adjacent Clarno volcanic conglomerates and the andesitic basalt flows which rest with erosional unconformity upon the conglomerates. The intruded conglomerates dip 13° southeast, the same as those in Dry Hollow. The rocks that were shifted during emplacement of the leucoandesite body have been eroded completely. This intrusive marks the probable source of leucocratic andesite flows which form steeply dipping, irregular contacts with and lap onto andesitic basalts one mile north-northeast. The west-facing erosional scarp along the east side of Rowe Creek valley is composed of leucocratic andesite flows (Figure 20). These flows dip 10° southeastward and are overlain by Columbia River Basalt which dips 2° to 5° southeastward.

The John Day Formation tuffs wedge out against the leucoandesites and either were never deposited or, more likely, were eroded prior to deposition of the Corral Mountain sequence of Columbia River Basalt. From the foregoing stratigraphic relations the Sugarloaf Mountain intrusive and associated leucoandesite flows are considered to be uppermost Clarno or Early Oligocene in age (7, p. 202).

8. Basaltic Andesite Plug of Sec. 19, T. 8 S., R. 21 E.

On the western border near the southwestern corner of this area a bench mark at 3907 feet is located on a conical, round-topped plug of basaltic andesite (Plate 1). The hill rises 100 feet above
surrounding outward dipping flows and flow breccias of basaltic andesite. Taylor (24, p. 46) describes this same intrusive (Figure 21).

Megascopically, the rock is classed as a basaltic andesite on the basis of its light gray color. Small red spots are composed of hematite which is disseminated throughout the rock. Phenocrysts of red-stained plagioclase are up to five mm in length. A sample was collected from a ledge on the west side and about 50 feet below the summit. Microscopically, it differs from the thin section described by Taylor in three respects: 1) heulandite is not present as an alteration product of plagioclase phenocrysts or groundmass laths; 2) both fresh and some uralitized clinopyroxene compose four percent of the groundmass crystals; 3) pseudomorphous hematite forms elongate ovals, but no hornblende outlines are preserved. Plagioclase phenocrysts are calcic andesine and are rarely zoned. Polysynthetic twinning occurs in about half the phenocrysts. Corrosion is common about the margins of phenocrysts and yields poikilitic textures. Corrosion pits occupied by kaolinite accentuate the bands of zoning. Clinopyroxene is subhedral and conforms to the pilotaxitic texture of the groundmass plagioclase. Blood-red hematite infiltrates fractures within the plagioclase phenocrysts. Chlorite occurs with uralite as an alteration of clinopyroxene.

This plug probably represents one source of lower Clarno andesitic lavas and flow breccias. This same rock type is a major
constituent of the volcanic conglomerates.

9. Rancherie Rock Intrusive

Rancherie Rock is an isolated knob rising 500 feet above a broad SE-dipping cuesta which forms a bench on all sides except the steep south slope. The plug is about 1500 feet long and one-half as wide. It trends west-northwest and is located at the NE cor., SW 1/4, sec. 6, T. 7 S., R. 22 E. Pentagonal and hexagonal joint columns which have their long axes trending northward are the dominant structures. Individual columns do not extend the full width of the body. Columns are nearly horizontal on the end of Rancherie, but dip from 30° to vertical along the northeast face (Figures 22 and 23). Platy jointing is well developed at the summit and represents a different cooling history than that for the columnar joints. At the south edge of the summit, horizontal joint columns exhibit internal platy jointing which is inclined at various angles to a plane at right angles to the long axes of the joint columns.

Megascopically, the intrusive is composed of two rock types. One is the light green platy hornblende andesite. The other is the black, less porphyritic basaltic hornblende andesite. Microscopically, the only difference between the two is crystal size. The thin sections are mostly calcic andesine (Table 3). In both the porphyritic and darker microporphyritic rocks the calcic cores of plagioclase
FIGURE 22. Rancherie Rock intrusive showing columnar jointing on the east end.

FIGURE 23. Rancherie Rock intrusive showing columnar jointing on the north face.
phenocrysts are altered to kaolinite. Unaltered cores of lamprobolite inside rims of pseudomorphous hematite constitute three percent of the rock. Another two percent consists of pseudomorphous granular hematite. An additional one percent is disseminated hematite alteration of primary magnetite. The remainder of the rock is ten percent kaolinite and two percent chlorite. The kaolinite occurs as exceptional radial aggregates of bladed crystals up to one-fourth mm long. The larger crystals grow in fractures and in the cores of plagioclase phenocrysts. Gray, dust-like alteration products on plagioclase are probably kaolinite and sodium mica. Chloritic alteration fills some interstitial spaces in the groundmass and is derived from deuteric clinopyroxene associated with corroded hornblende.

The Rancherie Rock intrusive has the form of a short, thick dike which probably supplied the low-dipping flows to the north. The absence of surrounding outward dipping flows suggests Rancherie Rock is the site of a fissure type extrusion. Rancherie Rock has a lithologic similarity to the dike complex described in section four of this chapter. A conical hill immediately northwest of the dikes and 1 1/2 miles southwest of Rancherie is made of the same type of platy, light green andesite. The two intrusives are probably closely related in respect to time of emplacement and type of source magma.
10. Andesite Intrusive in NW cor., SE 1/4, sec. 17, T. 8 S., R. 21 E.

This conical hill has a summit elevation of 4142 feet and rises 500 feet above the smooth-topped, narrow ridge which extends eastward (Plate 1). Because the structure of this hill is not exposed, it is not positively identified as an intrusive. The topographic form, porphyritic texture and the distribution of tabular flow units around the base suggest that the body is a plug dome (Figure 24). The sample from this hill has been described with the lower Clarno lavas in column D of Table 2.

11. Dikes West of Rowe Creek

Several hornblende andesite dikes penetrate the Clarno volcanic conglomerate west of Rowe Creek in sec. 36, T. 8 S., R. 21 E. The dikes do not cut through the upper Clarno andesitic basalts one-half mile to the east.

12. Dike in the W. 1/2, sec. 25, T. 7 S., R. 21 E.

An ENE-trending ridge of light green porphyritic andesite crops out near the head of Lone Pine Creek and is surrounded by flow breccias of the same composition. The summit and slopes are covered by subangular talus blocks averaging two feet along the edges. The blocks probably are derived from columnar jointing within the outcrop.
The ridge is probably underlain by a major dike following the ENE-trend of other Clarno intrusives and the areal trend of jointing.
QUATERNARY ALLUVIUM

Quaternary alluvium includes landslide, fluvial, and terrace deposits. Thin slopewash deposits are widespread, but were not mapped because the intent of this report is to show the distribution of underlying consolidated rocks.

Landslide Deposits

Extensive hummocky landslide deposits are formed below cliffs and steep slopes of Columbia River Basalt resting on John Day tuffs. These deposits are composed mostly of basalt debris ranging in size from blocks a quarter of a mile square to small, subangular boulders. Montmorillonitic John Day tuffs compose less than one-half of the deposits and act as a lubricant beneath the slumped basalt masses. One large block near the northwestern outskirts of Fossil is an erosional outlier resting one mile from the source cliffs of Columbia River Basalt to the north. This block has the appearance of a dike because of its tilted columnar joints. Another block about 500 feet square is exposed along the north side of Route 19 about one-half mile east of Fossil. In the northwestern corner of the area about half a square mile of hummocky landslide deposits lie along the northwest side of Stone Cabin Creek. Here, boulders of basalt form a mantle on the underlying hummocks of tuff. Similar deposits occur
one mile north-northwest of the old Butte Creek school site and extend southward nearly to Route 19. Landslide deposits composed mostly of John Day tuffs cover two square miles south of Corral Mountain and west of Service Creek in the vicinity of Dutch Flat. Small outliers of basalt lie west of the old Prairie Ranch (Plate 1).

**Fluvial Deposits**

Fluvial deposits are present in all stream valleys, but are not of great extent or thickness in any of them. Flood-plain sand and gravel deposits are thickest where valleys widen downstream from a relatively narrow segment of their course. These deposits are not more than 20 feet in thickness and the channel deposits are usually less than ten feet thick. Fluvial sediments in the area are composed mostly of detritus from the underlying Clarno Formation and partly of Columbia River Basalt.

In addition to gravels derived from the older rocks, thin layers of white ash lie at the heads and along the courses of most valleys and ravines. The ash is as much as ten feet thick in the southern branch of Club Hollow, upper Dry Hollow, and in a small basin in the center of sec. 36, T. 7 S., R. 21 E. about one mile north of Rancherie Rock. The occurrence of this white ash in the area is typical of similar deposits throughout the Mitchell Quadrangle. Hand lens study shows the ash is composed of about 90
percent silt-sized pumice fragments. Less than ten percent of the ash consists of euhedral plagioclase crystals of fine sand size. A minor amount of hornblende and biotite make up the remainder of the deposit. According to Calkins (3, p. 169) chemical analyses show that the ash is andesitic in composition.

The sources of the ash were probably distant volcanoes west of the area. The wind blown ash was laid down over the entire area and was washed into valleys shortly after deposition. The origin of these deposits is indicated by the intertonguing relation between relatively pure ash beds and typical fluvial deposits composed of detritus from underlying lava flows.

Terrace Deposits

Terrace deposits are exposed in only two valleys within the area. The deposits in secs. 25 and 36, T. 7 S., R. 22 E. are probably the older of the two. These older deposits crop out along the sides and at the head of a ravine which opens southward into the Prairie Ranch basin (Plate 1). They are well-stratified, cream-yellow tuffaceous sandstones which rest unconformably on the margin of a partly dissected plateau of Clarno lavas. The beds are nearly flat lying and range from 4000 to 4200 feet elevation at the basal contact with Clarno lavas. Channel conglomerates are composed of detritus from all older rocks within the area and intertongue with the
stratified deposits. These deposits were probably laid down in Pleistocene or Recent time by a stream shifting its bed southward along the southward dipping contact surface between Clarno lavas and overlying John Day tuffs.

The other terrace deposits are along the northwest side of the Kinzua road one mile from its junction with Route 19. These semi-consolidated sands and gravels contain rocks from all three formations in the area. The matrix is mostly tuffaceous. These light green beds are mostly flat-lying, but local slumps have produced random tilting. A broad-topped ridge southeastward across the valley is about the same elevation (3300 feet) as the base of these beds and is probably a stream-cut platform of the same age.
STRUCTURAL GEOLOGY

Principal features of structural geology in the area include a broad NE-trending anticlinal fold, minor tectonic faults, slump faults, and a persistent joint pattern.

Folds

The principal structure in the area is a broad anticline. The trace of the anticlinal axis crosses the western boundary of the area at Pine Creek and trends northeastward to a point near the old Cottonwood school site. Here, the axial trace swings east-northeast and continues eastward from Straw Fork to the eastern boundary (Plate 1). The fold plunges eastward at a low angle and dies out beneath the Columbia River Basalt. Rocks of the Clarno Formation dip 20° northwestward on the northwestern limb. Dips of 10° to 15° southeastward are recorded for Clarno rocks along the southeast limb. The youngest rocks exposed on the anticline are Columbia River Basalts which have dips of 5° or less along both flanks. The angular unconformity between Clarno rocks and overlying John Day tuffs and Columbia River Basalt indicates that the anticline developed during Eocene-Oligocene time and its growth was renewed during post-Middle-Miocene time. In the eastern half of the area, the south limb of the anticline becomes the north limb of a syncline having its east-trending axis
along the John Day River in Spray quadrangle.

Faults

Because persistent horizons are lacking and lithologic variations are normally abrupt, few faults are shown on the map. Faults that have been traced in the field have three features in common. 1) Displacement is less than 200 feet and is vertical. 2) The trace generally trends within 10° of due east and; 3) the trace extends less than 1 1/2 miles.

All three mapped faults are recognizable as prominent lineations on the aerial photographs and as brecciated zones on the ground. The two cutting the Clarno Formation consist of one near the head of Robinson Canyon and one parallel to upper Service Creek valley. Vertical displacement on the Robinson Canyon fault is about 100 feet. Clarno lavas are down-faulted on the south against Clarno volcanic conglomerates on the north. Displacement along the Service Creek fault cannot be determined, but the sense of movement in the vertical plane is slightly northwards from vertical, according to the orientation of slickensides exposed on a surface 150 feet square. The third fault has about 200 feet of displacement according to Bedford (1, p. 83) and drops Columbia River Basalt on the south against an upthrown block of John Day tuffs on the north.
Joints

Throughout the Clarno lavas the dominant trend of vertical joint planes is eastward. This trend is not repeated in the overlying Columbia River Basalts.

Two prominent lineations on the aerial photographs cross Route 19 between Butte Creek pass and Bear Hollow. The lineations trend northeast and cross the highway at NE cor., SE 1/4, sec. 32, and NE cor., SE 1/4, sec. 29, T. 7 S., R. 22 E. These are minor joints in the Clarno lavas and extend for only one mile each way from the road. Diamond-shaped joint patterns exposed on Corral Mountain have previously been described in the chapter on Columbia River Basalt.
HISTORICAL GEOLOGY

Extrusion of porphyritic andesite is the earliest event recorded in this area. During Early Eocene time at least one great volcanic pile of these andesite flows and autobreccias accumulated near the center of the western half of the area. These rocks were deeply weathered under the influence of a moist, subtropical climate with heavy seasonal rains. As the breccias shed great volumes of talus, the mass became unstable and was flushed onto the surrounding lowlands as water-soaked mudflows. As the mudflows passed farther from their source, they became rudely stratified and cross-stratified. Deposits several hundred feet thick were laid down within a short time. Streams reworked the surface material and coal swamps developed in some depressions. This sequence was repeated several times and the stratigraphic relations between flows and volcanic sediments became very complex. The area probably underwent slight uplifting and an erosional surface having several hundred feet of relief formed.

Later in Eocene time a different type of volcanic activity was initiated. Thinly-layered lava flows poured from numerous small vents. Some pyroclastic layers were intercalated with these platy andesitic flows. At Straw Fork, small, fresh-water clams lived in a lake formed on the earlier flows. The clams were preserved in
waterlaid tuffs along with plant seeds, and reedlike plant fragments. After the andesitic basalts were deposited, the Sugarloaf Mountain leucoandesite intrusive was emplaced. Felsitic flow rocks were extruded from near Sugarloaf Mountain onto a moderately eroded andesitic basalt surface of the north. The last eruptions of basaltic material deposited scoriaceous layers of lava and some pyroclastic material. Sometime after the volcanic activity ceased, the rocks were folded into a NE-trending anticline which tended to swing eastward across the north-central part of the area. Deep weathering of scoriaceous flows and isolated patches of pyroclastic material produced a red clay soil atop the Clarno lavas. This period of little volcanic activity probably continued well into Oligocene time.

From Upper Oligocene to Lower Miocene time, the tuffs of the John Day Formation were deposited upon the weathered and moderately eroded Clarno lava surface. Some of the Clarno red soils were reworked by streams and incorporated into the basal tuffs. The general absence of older rock debris in the John Day sediments indicates that the ash falls were rapidly built up to several hundred feet in thickness. Possibly the volcanoes of the Cascade Range were a source of this pyroclastic material.

When the tuffaceous sediments attained a thickness of about 500 feet south of Corral Mountain, an ash flow tuff was laid over most of the area. The ash flows were partly eroded from the old
anticlinal crest in the same way as the earlier ash falls. A surface of moderate relief developed on the tuffs prior to deposition of the Columbia River Basalts.

In Middle-Miocene time, flood basalts covered the entire area. These continuous flows were probably extruded from fissure-type vents. Following the close of this extrusive phase, the rocks of the area were gently folded along the pre-existing Early Tertiary anticlinal trend.

Rocks from Upper Miocene to Recent were eroded or never extensively deposited in this area.

Consequent streams stripped the Miocene lavas from the anticlinal crest. West of Prairie Ranch the John Day ash flows supplied detritus for tuffaceous sandstones which were laid down by streams eroding channels along the Clarno-John Day contact surface.

As Butte Creek cut into the John Day tuffs west of Fossil, landsliding occurred on a large scale. Downcutting of the creek was interrupted and terraces developed.

White volcanic ash was intercalated with Recent alluvium throughout the area. Its source is unknown, but volcanoes of the Cascade Range are considered the most likely sources.

Presently, erosion by intermittent streams is the dominant geologic process.
ECONOMIC GEOLOGY

No mineral or mineral fuel deposits of economic value have been discovered in the thesis area. However, the scenic beauty of the area results from geologic features and attracts a small number of tourists to the vicinity of Fossil.


