PRELIMINARY REPORT ON THE RECONNAISSANCE GEOLOGY OF THE UPPER CLACKAMAS AND NORTH SANTIAM RIVERS AREA, CASCADE RANGE, OREGON

by

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July 1976

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SUMMARY OF MAIN GEOLOGIC FINDINGS

The upper Clackamas and North Santiam River area, covering about 635 square miles (1645 sq. km.) lies in the northwestern part of the Cascade Range, just west of Mount Jefferson. The area is underlain by over 20,000 feet (6100 m.) of volcanic strata of the probable upper part of the Western Cascade Volcanic Group. The upper Western Cascade Group is subdivided into 10 mappable formations, five of which are newly named and defined in this report. The formations proposed by Thayer (1936, 1937, 1939) are valid stratigraphic units; they have been redefined and incorporated in this report. The formations of Peck and others (1964) are thick complex stratigraphic units which have been subdivided and renamed in the course of this study; Peck's names are therefore not used.

The most diagnostic formation is the Breitenbush Tuff, composed of several ignimbrites, which extend beyond the project area. Because it is easily recognized and extensive, the formation serves as a stratigraphic marker unit and its top surface as a structural datum plane in the northern Oregon Cascade Range. It divides the Western Cascade Group into its lower and upper parts. The

Breitenbush Tuff is immediately overlain by a conformable sequence of characteristically platy pyroxene andesite porphyry, lava flows, assigned to the newly named Nohorn Formation.

Previous studies (Thayer, 1936, 1937, 1939; Peck and others, 1964) included the Outerson Volcanics in the High Cascade Group but this formation is found to be deformed and questionably underlying the Rhododendron Formation. It is assigned to the Western Cascade Group. The Outerson and Rhododendron Formations fill broad valleys which were eroded into older Western Cascade volcanic strata.

A distinctive but less extensive ignimbrite containing black pumice is found in a new unit, named herein the Cub Point Formation. It may prove to be a valuable marker unit in the Western Cascade Strata southward from the project area. This formation is, in turn, overlain by a section of diverse lithologies, principally basalt and andesite flows, newly called the Gordan Peak Formation, which can be traced well south of the project area at least as far as the McKenzie River.

The Columbia River Basalt is part of the stratigraphic section, intercalated in the upper part of the Western Cascade Group, contrary to the arching-over interpretation of Wheeler and Mallory (1970). It is a "foreign" rock unit, being of a different source, origin, and composition from the bulk of the indigenous Cascade volcanic rocks (Wright, Grolier, and Swanson, 1973; Waters, 1973). The formation occurs in the Clackamas River drainge, thinning out to the south.

The Cheat Creek and Scar Mountain beds, informally named, occupy approximately the same stratigraphic positions. Although they are composed of different lithologies, the units may be indicative of the same depositional processes then on-going within the Cascade Range province that produced the Troutdale and The Dalles Formations bordering the ancestral course of the Columbia River.

Two isolated lava flows are recognized. They are assigned to the Western Cascade Group but may be representative of the earliest High Cascade volcanic activity. One is the vitrophyric andesite of Coopers and Boulder Ridges. Locally it is extensively altered. Its distribution is suggestive of a broad intravalley lava flow before the North Santiam River was incised. The second is the vitrophyric basalt of Lost Creek, a tributary of Blowout Creek. The flow nearly fills the present valley.

The Western Cascade Group are complexly warped into an irregular north-trending anticline, the Breitenbush anticline of Thayer (1936, 1937, 1939) which is cut by a series of northwest-trending faults in the southern part, and north-trending faults, as a probable extension of the Brothers-Portland Hills lineation (Lawrence, 1976) in the northern part of the area.

Superimposed on these complex internal structures is the north-south axis of uplift of the Cascade Range. Another order of magnitude of structure, between the complex folding and faulting and the Cascade Range arch, comes to light in the course of this project and investigations in the southern Washington Cascade Range (Hammond and others, 1976). A broad depression, called the Mount Hood structural basin, underlies the northern Oregon Cascade Range and southern Washington Cascade Range. It is outlined by the extent of Columbia River Basalt and underlying Eagle Creek Formation and its probable equivalent, the Bull Creek beds. The structural low is centered west of Mount Hood. And another structure, nearly east-west structural high, a "ridge", normal to the Cascade axis, terminates the southern margin of the Mount Hood structural low. It is the Mount Jefferson structural high.

Subsequent to complex folding, the area was intruded by a series of plutons, of which five main groups are recognized: (1) northwest-trending narrow dikes and small plugs of basalt, probably related to deposition of the Outerson Formation; (2) the Bull of the Woods complex of dikes, plugs and small stocks of porphyritic hornblende, grading into pyroxene andesite, which extends from the Halls Creek pluton at Detroit Lake northeastward through Battle Ax to the promontory of its namesake; (3) non-porphyritic pyroxene andesite which forms a number of scattered plutons, most prominent of which are the Austin Point pluton and intrusions along the Clackamas River near Austin Hot Springs; (4) a few east-west-trending dikes and stocks of pyroxene diorite, most of which are associated with the Battle Ax intrusive complex; and (5) isolated basalt dikes and plugs, some of which are the cores of eroded older High Cascade volcanoes.

The Breitenbush anticline is bowed eastward in passing around the margin of the Halls Creek pluton and Bull of the Woods intrusive complex. The fold was probably displaced laterally by the emplacement of the intrusions. To the north and south of the bow, the anticline plunges in opposite directions. The northwest-trending faults, displacing the anticline, are possibly related to the intrusive emplacement. The faults are possibly wrench faults, almost normal to the trend of the Cascade Range, along which left-lateral separation has occurred. The northern offset segments of the Breitenbush anticline, called separately the Hawkins and Cub Creek anticlines respectively, may be truncated by similar yet presently unidentified faults with right-lateral separation.

Northwest-trending to east-west faulting post-dates folding; it truncates the folds but pre-dates north-trending faulting, which may be presently active. These faults are concentrated in the Clackamas River area and serve as conduits for Quaternary volcanism north of Mount Jefferson. Austin Hot Springs is located on one of these faults. Breitenbush Hot Springs may be located on a north-south fault zone which is yet unidentified.

High Cascade basaltic volcanism began about 6 million years ago. Pliocene High Cascade volcanism was concentrated at centers just east of the Breitenbush anticlinal axis. Such centers are now recognized as, from south to north, Coffin Mountain, Triangulation Peak, Bald Butte, Battle Ax, Oak Grove Butte, and Mount Mitchell. Quaternary High Cascade volcanism built broad low shield volcanoes whose lavas coalesced to form a plateau along the crest of the range. Centers of these shield volcanoes, lying east of the Pliocene centers, occur at the western edge of Hanks Cove, Marion, Grizzly, and Turpentine Peaks, and Park Butte. Streams were forced westward by the younger volcanism against the base of the older volcanoes. By integrating and lengthening their courses, these streams cut broad valleys between the two chains of High Cascade basaltic volcanism. These valleys are recognized as the Upper Clackamas and North Santiam Rivers, which are part of the distinctive north-south topographic trend bordering the High Cascade volcanic plateau.

No prominent north-south fault, postulated by Thayer (1936) or fault zone separates the High Cascade and Western Cascade Groups. No graben or volcano-tectonic depression (Allen, 1966) containing High Cascade volcanic rocks, extends along this part of the crest of the Cascade Range. Strata of the Western Cascade Group form a homocline which dips about 15^{o} eastward from the Breitenbush anticlinal axis beneath the crestal axis of the Cascade Range. The strata probably form an extensive synclinal trough with undulating plunges, underlying the crest of the range.

Arching of the Cascade Range began possibly as long as 6 million years ago, with 1 to 2 km. of uplift occurring.

Latest High Cascade volcanism, which began probably no longer than .7 million years ago (McBirney, 1968, p. 101) formed the High Cascade composite andesite volcanoes of which Mount Jefferson, along the border of the project area, is an example. All total andesitic volcanic products probably represent less than one-tenth of the volume of High Cascade volcanism.

Two stages of glaciation are recognized; the older, of probable Jack Creek Drift (Scott, 1974) or Hayden Creek Drift of Salmon Springs (Crandell and Miller, 1974) was more extensive, covering interfluve upland areas. The more easily recognized younger glacial deposits are probably Suttle Lake Drift (Scott, 1974) or Evans Creek Drift of early Fraser Glaciation (Crandell and Miller, 1974).

Landslides are extensively developed within the area, especially in oversteepened glaciated terrain underlain by less indurated but deformed strata of the Western Cascade Group. Landslides are presently active, presenting a hazard to roads. Landsliding is the dominant mass wasting process in the area and probably in the entire Cascade Range. About 10 percent of the area is mantled by landslide debris.

The hot springs - Austin, Bagby, and Breitenbush - are not located along a major north-south fault. Austin Hot Springs is located on a north-trending fault of limited extent. Bagby Hot Springs is believed to lie along a northwest-trending fault. The structural setting of Breitenbush Hot Springs is unclear but is supposedly located on another north-south fault yet to be delineated.

PRELIMINARY EVALUATION OF HOT SPRINGS FOR GEOTHERMAL RESOURCE

Reconnaissance geologic mapping has not revealed a unique geologic setting for the hot springs - Austin, Bagby, and Breitenbush - in this part of the Cascade Range (Pl. 1). Further detailed may not reveal the structural or stratigraphic control of the hot springs outlet, primarily because of the surficial cover in the area - in fact, all of the Western Cascades. The lower or western springs at Breitenbush arise along the contact of a north-trending basalt dike with Breitenbush Tuff (Clayton, 1976, p. 70-71). The springs upstream arise through alluvium and glacial outwash deposits. Similarly Austin Hot Springs arises through alluvium and possible landslide deposits. In this setting the water may arise from a structure directly below, migrate atop the bedrock surface beneath the surficial cover, or migrate laterally through the surficial deposits to the outlet. Bagby Hot Springs arise from a glacially scoured bedrock surface about 20 feet (6 m.) above the level of the Hot Springs Fork. The waters bubble from fractures in either a pyroxene andesite porphyry lava flow of the Nohorn Formation or a small intrusion, along a fault trending N. 80° W. (Dyhrman, 1975, p. 65-66).

The hot springs appear not to be located along major fault zones of preferred orientation, displacement, or age. Nor are they located along specific fold axes. Apparently the convective flow of thermal waters, of which the hot springs are leaks, are related to deeper structures and are possibly greatly influenced by hydrologic flow patterns. Neither the deep structures nor the hydrologic flow is known in the Cascade Range. They require investigations of the thermal water resource is to be evaluated.

INTRODUCTION

This preliminary report is a partial summary of the geology in the upper Clackamas and North Santiam Rivers area, Cascade Range, Oregon. The area was mapped reconnaissantly during April-December 1974 and June-July 1975. Several major stratigraphic and structural problems have not yet been resolved, preventing a complete interpretation of the geology, especially the structure, of the area. These problems will be mentioned in the course of this report.

The project area covers about 635 square miles (1645 sq. km.) in the northwestern Cascade Range of Oregon extending across parts of six 15-minute topographic quadrangles. Parts of the area were mapped in greater detail as theses by:

Dyhrman, Richard F., 1975, Geology of the Bagby Hot Springs area, Clackamas and Marion Counties, Oregon: MS, Oregon St. Univ.; 78 p. covers 55 sq. mi. (142 sq. km.).

Clayton, C. Michael, 1976, Geology of the Breitenbush Hot Springs area, Cascade Range, Oregon: MS, Portland St. Univ., 80 p.; covers 45 sq. mi. (117 sq. km.).

Rollins, Anthony, in progress, Geology of the Bachelor Mountain area, Marion County, Oregon: Oregon St. Univ.; covers about 90 sq. mi. (233 sq. km.).

Objectives

Primary objectives of the study are:

(1) To develop a geologic framework in this part of the Cascade Range as a basis for follow-up detailed geologic, geophysical, and geochemical investigations in order to evaluate the potential for geothermal resources.

(2) To define the major geologic units, their lithology, and stratigraphic position, and to delineate the geologic structures in order to extend similar studies into adjacent parts of the Range.

(3) To determine the nature of the contact between the Western and High Cascade volcanic rocks.

(4) To delineate the geologic controls for the apparently north-south alignment of hot springs.

Only part of these objectives were attained. About 10 to 15 more field days are necessary in critical roadless areas to trace out stratigraphic contacts. To resolve the complexities in the paleomagnetic stratigraphy, about 500 of the total 1,000 oriented specimens collected need to be rechecked. Also, because of the lithologic similarity of some volcanic units, all samples of these units must be visually compared. Some petrographic examination is warranted in order to separate these units with confidence. Without definition of these stratigraphic relations, some contacts are not located on the map and the geologic cross-sections for the project area can not be completed. It is estimated that about 30 office days, in addition to the 10 field days, will be needed to complete these studies, and about 10 days to incorporate the results in a finalized report.

Accessibility

The area is easily accessible from State Highways 22 and 224 (U.S. Forest Service S-46). The former follows the North Santiam River; the latter follows the Clackamas River south of Estacada over Breitenbush Saddle, elevation 3569 feet, and the Breitenbush River, joining Highway 22 at Detroit. A great number of graded logging roads provide additional access to most parts of the project area.

Method of Mapping

Mapping was conducted by traversing nearly all roads and some trails. Readings were made with aid of a Brunton compass and a Gisco Model 70 flux-gate magnetometer. Field stations, geologic data, and contacts were plotted on scale 1:24,000 topographic base maps and transferred by hand to the scale 1:62,500 topographic quadrangle maps (Pl. 1). Aerial photographs (U.S. Forest Service, 1972) scale 1:15,680, were utilized as reference in more detailed mapping about Austin, Bagby, and Breitenbush Hot Springs and the Bachelor Mountain area. Robert Lawrence and James Carter, Department of Geology, Oregon State University, provided a lineation map of the area, scale 1:250,000, plotted on photographs of enlarged ERTS imagery.

Thicknesses of stratigraphic units were measured in the field by pacing. In addition, thick units were scaled from the topographic base maps. All thicknesses over 25 feet are rounded off to the nearest 5 feet, likewise for all metric equivalents over 25 feet (7.6 m.).

Remnant paleomagnetic polarity determinations should be considered pre-liminary until they can be verified by resampling and spot checking with a spinner magnetometer. Oxidation state, stratigraphic position within a lava flow or ash flow, weathering, contact metamorphism, and lightning strikes are all factors which can cause anomalous field flux-gate magnetometer readings. Incorrect readings can not be detected without resampling at different locations within the same stratigraphic unit, a time-consuming but necessary procedure to insure exactness.

The ages of the formations, based upon million years, correspond to the Cenozoic time scale of Berggren (1972).

Previous reports on at least parts of the area have been completed by Barnes and Butler (1930), Callaghan (1933), Thayer (1936, 1937, 1939), Williams (1957), Peck and others (1964), Walker, Greene, and Pattee (1966), Jan (1967), Greene (1968), Pungrassami (1969), Wheeler and Mallory (1970), Sutton (1974), and McBirney and Sutter (1974). Their work will be referred to in the course of this report.

Rock Nomenclature

All rock names are applied on basis of hand specimen examination.

Basalts range from light gray to very dark gray, are holocrystalline and fine-grained. Light-colored basalts form the majority of the Quaternary lavas. In these basalts olivine is common as phenocrysts in phyric varieties or in the groundmass. Plagioclase forms stubby to lath-like prisms and microlites and occurs as phenocrysts and in the groundmass. Pyroxene, similar to hypersthene, occurs less commonly, generally in the groundmass. The light-colored basalts tend to have an inflated texture. Medium to dark-colored basalts with similar mineralogical composition and texture to the light-colored basalts are common in the Outerson Formation and the lavas of Three Pyramids. Dark-colored aphyric basalts, common in the Columbia River lavas and narrow intrusions, are dense, merocrystalline, and fine-grained. Plagioclase as lath-like prisms or microlites are the only recognizable minerals. All basalts have a blocky jointing; they are rarely platy to slabby jointed. In addition, the basaltic lavas are scoriaceous to vesicular along their margins.

Andesites range from very light gray to very dark gray to blackish brown, are merocrystalline to very finely crystalline (aphanitic). Phenocrysts are almost always present, commonly as stubby to lath-like prisms of plagioclase, less commonly as pyroxene. Both brown to black hypersthene and very dark green to black augite are recognized. Olivine occurs rarely. If olivine is present, the rock is a basaltic andesite. Andesites are typically platy to angular blocky jointed and non-vesicular.

Other flow rocks are recognized on the basis of quartz phenocrysts content and color. No potassium feldspars are observed in the flow rocks. Some light-gray to very pale brown, dense, very fine-grained (aphanitic) rocks without observable ferromagnesian minerals are called silicic lavas if they are flow layered, or felsite if a sugary texture is detectable and the rock has a massive structure.

Fragmental (volcaniclastic) volcanic rocks are classified and named according to the size and abundance of various fragments (Fig. 2).

ROCK UNITS

Introduction

Rock units within the project area are subdivided into four groups, in approximate order of decreasing age: Western Cascade Group, of deformed, stratified volcanic units; intrusive hypabyssal rocks; High Cascade Group, of mainly flat-lying lavas capping the range; and surficial deposits. They are described in this order.

Western Cascade Group

The older, structurally deformed, and moderately altered volcanic strata underlying the western part of the Cascade Range were assigned to the Western Cascade volcanic series [Volcanic Group] (Callaghan, 1933; Williams, 1957). Thayer (1936, 1937, 1939) subdivided this series into an older Breitenbush Tuffs, of about 7500 feet (2285 m.) thickness, and a younger Sardine Series, of predominantly lavas, about 6000 feet (1830 m.) thick. Peck and others (1964) renamed the Breitenbush Tuffs, the Little Butte Volcanic Series, and the Sardine Series, the Sardine Formation (Table I).

In the course of this mapping project, several volcanic stratigraphic units have been recognized and traced. The Breitenbush Tuffs of Thayer (1936, 1937, 1939) have been restricted to a sequence of ash flow tuffs (ignimbrites) interbedded volcanic sedimentary rocks and a few lava flows exposed just west of Breitenbush Hot Springs. The strata underlying the Breitenbush Tuff are referred informally in this report to the beds at Detroit. Units recognized overlying the Breitenbush Tuff, in stratigraphic order, are the Nohorn Formation (newly described herein); Bull Creek Beds (Barns and Butler, 1930) possibly correlative with the Eagle Creek Formation of the Columbia River Gorge; Outerson Formation, formerly the Outerson Volcanics of Thayer (1939); Cub Point Formation (newly described herein); Gordon Peak Formation (newly described herein); Columbia River Basalt; Cheat Creek beds (informally described herein); Scar Mountain beds (also informally described herein); and the Rhododendron Formation (Barnes and Butler, 1930). The Bull Creek beds are largely confined to the Clackamas River area. To the south, similar lithologies are found in the Outerson, Cub Point and Gordon Peak Formations. Because these formations occupy about the same stratigraphic position, they are considered as possible correlatives of the Bull Creek beds.

The distinctive and widespread Breitenbush Tuff separates the thick Western Cascade Group into a lower and upper group. The formations listed above form the upper group; the beds at Detroit, and restricted Sardine Formation, among others not yet recognized, form the lower group.

The Western Cascade Group also includes three isolated lava complexes - the basalt at Lost Creek in the Blowout Creek drainage and the fresh to extensively altered vitrophyric flows atop Boulder Ridge and Coopers Ridge bordering the North Santiam River. The lavas are undeformed and are clearly younger than the underlying strata.

The Columbia River Basalt is interstratified between formations of the Western Cascade Group. Because it originates outside the province (Peck and others, 1964), it is not considered as an inherent stratigraphic unit of the group. It is, however, a marker stratigraphic unit in the northern Cascade Range and for that reason it is discussed in stratigraphic order with the formations of the group.

The Outerson Formation had been previously (Thayer, 1936, 1937, 1939; Peck and others, 1964) included in the High Cascade Group. But in this study, strata of this formation are found to be deformed and questionably underlying the Rhododendron Formation, and consequently are grouped with the Western Cascades.

No formation newly described is found to be entirely correlative with either Sardine of Thayer (1936, 1937, 1939) or Peck and others (1964). The Breitenbush Tuff, restricted herein, overlies strata shown as Sardine Series by Thayer (1936, 1937, 1939). Further mapping will probably show that the Sardine Formation is restricted to or below the beds at Detroit described herein. Strata assigned to the Sardine Formation by Peck and others (1964) are found to both underlie and overlie the Breitenbush Tuff. Therefore, the name Sardine is not included in this report in preference to the now better defined stratigraphic units. For the latter reason, the name Little Butte Volcanics is also not included. These units are briefly described in stratigraphic order, as shown in Table II. The thickness of the Western Cascade Group in the map area ranges from 19,495 to 26,515 feet (5940 to 8080m.).

A longitudinal section (Fig. 3) shows diagrammatically the stratigraphic relationships of the units of the Western and High Cascade Groups.

The formations are described separately, starting with the oldest strata.

Beds at Detroit (Td)

A thick section, over 8125 feet (2475 m.) of mixed well-bedded and highly indurated volcanic stratigraphic units forms the oldest rock within the project area. They occur along the lower part of the Breitenbush River Valley between Detroit Lake and Breitenbush Hot Springs, in the upper part of the Collawash River between Rhododendron Ridge and Janus Butte, and in the Middle Stretch of Blowout Creek southeast of Detroit Lake. The true extent of the beds in the upper Collawash River - Elk Lake Creek and Blowout Creek areas will be determined after the basal contact of the Breitenbush Tuff is traced. Structural complications superimposed upon an irregular stratigraphic contact have so far precluded easy tracing of the formational contacts in these areas. The distribution of these strata about Detroit Lake outline a structural high enclosing the complex andesite and diorite intrusive zone (the Halls Diorite Porphyry of Thayer, 1939) at West Detroit Lake (Peck and others, 1964; Pungrassami, 1969).

Strata are composed of drab-colored volcanic sedimentary rocks, mostly coarse-grained volcanic sandstone, lithic-pumice vitric tuff, laharic breccias of lithic lapilli-tuff, and a lesser percentage of andesite and basalt lava flows. Proportion of lava rock increases to the west. All strata are moderately altered, zeolitized and argillized, and replaced with chalcedony, calcite, hematite, and clay minerals.

The bedding is the best developed on all formations in the project area. It can be readily traced across valleys and on aerial photographs. The strata are well jointed, broken locally by small-scale faulting. Rocks are competent, probably due to extensive zeolitization, especially in comparison with the overlying landslide-prone Breitenbush Tuff and Bull Creek beds.

The strata are well exposed in logging road cuts along Tom Creek, south-west of Idanha; along Hoover Ridge, east of Detroit; along the Byars and Humbug Creeks north of Breitenbush River; and the western slope of Rhododendron

Ridge. Partial sections of the beds along the Byars Creek Road (U.S. Forest Service # S-80E) are described below. This section lies possibly as much as 2000 feet (610 m.) stratigraphically below the contact with the unconformably overlying Breitenbush Tuff. The best exposed section lies along the Breitenbush River at Detroit upstream from French Creek. It will be measured and designated as the type or reference section.

Andesite lava flows form a greater proportion of the formation where it is exposed north of Detroit Lake, along French Creek and Hall Ridge (Pungrassami, 1969). Silicified vitrophyric lavas are exposed in Blowout Creek Valley between Cliff and Hawkins Creeks.

The base of sequence referred to as the beds at Detroit is not exposed in the project area, so the basal stratigraphic relations of this unit are unknown. The beds are overlain unconformably by the Breitenbush Tuff, the next stratigraphically overlying unit, in the Breitenbush River and Blowout Creek areas. In the upper Collawash River the beds are overlain unconformably on the east by the Rhododendron Formation. As much as 2000 feet (610 m.) of relief occurs atop the formation where it is buried by Breitenbush Tuff.

Too little is known presently of the lateral extent of the beds to suggest their correlation. Detailed stratigraphic mapping is necessary west of Detroit Lake to determine their westward distribution. This mapping will probably indicate that the Sardine Series of Thayer (1936, 1937, 1939) consists of strata underlying the Breitenbush Tuff, described and restricted herein, and that the beds at Detroit are an upper part of this formation.

On the assumption that the strata extending westward and underlying Hall Ridge, north of Detroit Lake, are stratigraphically a part of the beds at Detroit, radiogenic age dates (Table IV) from these rocks provide a basis upon which to date the beds. A date of 15.5 million years from the upper part and intrusive rock dates of 15.9 and 25 $\pm$ 10 million years are, of course, discordant but suggest that the beds are no younger than Early Miocene and may be as old as Oligocene.

Breitenbush Tuff (Tbt)

The Breitenbush Tuffs of Thayer (1939) are restricted to about the 2600 foot (790 m.) section sporadically exposed along the Breitenbush River valley near Breitenbush Hot Springs (Clayton, 1976, p. 16). The section consists principally of pale green, light gray to olive, purple to pale red, crystal-vitric tuff, characterized by pyroxene, quartz, plagioclase, and locally abundant pumice and lithic fragments. The tuffs are poorly to moderately welded and represent a series of widespread ash flow sheets (ignimbrites). They are separated locally by thin beds of volcanic sedimentary rocks and a few lava flows. Clayton (1976, p. 22) describes briefly a 15-foot (4.6 m.) thick basalt lava flow, about 300 feet (90 m.) below the top of the formation.

The Blister Creek Tuff and its associated lava flows, the Pegleg Falls dacite and Rock Creek felsite (Dyhrman, 1975, p. 8-18) are possibly interstratified units in the lowest part of the Nohorn Formation or may represent the top of the Breitenbush Tuff. The occurrences of Blister Creek Tuff in upper Hot Springs Fork Valley, south of Bagby Hot Springs, and in Pansy Creek Valley, are tuff-breccia interbeds in the Nohorn Formation. They resemble neither the Blister Creek Tuff along Nohorn Creek (Table VI) nor Breitenbush Tuff.

The formation unconformably overlies the beds at Detroit and is overlain conformably by the Nohorn Formation. Where the Nohorn has been deeply eroded the Breitenbush Tuff is overlain unconformably by the Bull Creek beds, the Outerson Formation, the Cub Point Formation, and the Rhododendron Formation (Fig. 3).

The Breitenbush Tuff ranges from about 1900 to 3000 feet (580-915 m.) thick. Along the Breitenbush River it is 2600 feet (790 m.) thick and in the Collawash River valley it is 2400 feet (730 m.) thick. Additional stratigraphic thickness are south of Elk Lake, about 3000 feet (914 m.) and in upper Blowout Creek valley, 1900 feet (580 m.).

The Breitenbush Tuff is the most diagnostic formation of the Western Cascade Group. Because of the great thicknesses of Western Cascade strata, both overlying and underlying the formation, the Breitenbush Tuff separates the group into a lower and upper part. The tuff is traceable north and south throughout the map area and undoubtedly will be delineated in other areas of the Cascade Range. The Breitenbush Tuff is possibly correlative with the basal tuff of the Little Butte Volcanic Series (Peck and others, 1964) and the Stevens Ridge Formation of the southern Washington Cascade Range (Fiske, Hopson, and Waters, 1963; Hammond, 1974). Because the tuff is extensive and easily recognized, it serves as a stratigraphic marker bed and structural datum plane in the northern Oregon Cascade Range.

The Breitenbush Tuff is present in the lower elevations of most major valleys in the map area. Only the top of the formation and a partial section is exposed along Trout and Rod Creeks in the Battle Ax and Fish Creek Mountain quadrangles respectively, and along Pyramid Creek in the Detroit quadrangle. An excellent section is exposed in the upper Collawash River Valley between Blitzen and Happy Creeks. Very good sections are exposed along Blowout Creek, the North Santiam River Valley, and at Boulder Ridge (Clayton, 1976) separating the Breitenbush and North Santiam Rivers. The formation has yet to be mapped in the area of the upper Collawash River and north of Gold Butte in order to tie together the stratigraphy and structure in the map area. The distribution of the formation between the Collawash and North Santiam Rivers within the map area outlines a major structural high in the Cascade Range. This high exposes possibly the greatest stratigraphic section of the Western Cascade Group immediately adjacent to a major High Cascade volcano, Mount Jefferson.

A stratigraphic section of the Breitenbush Tuff along the Breitenbush River, designated herein as the type section, is described in Table V. The characteristic lithology can be noted in the description. Rock from an upper ash-flow unit of the formation, exposed along Highway 22 east of Idanha, the same as listed in Table IV, was analyzed by Peck and others (1964, p. 45, no. 18). It contains 70.5 percent silica.

The top of the stratigraphic section corresponds to the Cleator Bend unit of Breitenbush Tuff (Clayton, 1976, p. 17-19) but the Cleator Bend member, informally designated and described in the stratigraphic section (Table V), compares favorably and can be traced with reasonable certainty into the thick columnarly jointed ash-flow unit, resembling the sculptured maol statues of Easter Island, exposed to the south atop Boulder Ridge, part of the Boulder Ridge unit (Clayton, 1976, p. 19-21). The stratigraphic section is, therefore, missing the upper Gale Hill unit (Clayton, 1976, p. 21-22) about 500 feet (152 m.) thick and the lower 150 feet (46 m.).

Uppermost exposed ash-flow unit exposed along Highway 22 and in the upper Blowout Creek Valley, both listed in Table IV, are tentatively considered as equivalent to the Cleator Bend member and the "maol" unit atop Boulder Ridge. The unit has not yet been traced into the Collawash River area.

K-Ar radiometric age dates (Table IV) of three samples of the Breitenbush Tuff reveal that the middle part of the formation is 12 to 13 million years old. The Breitenbush Tuff is Middle to possibly Early Miocene in age.

Nohorn Formation (new formation; Tnh)

About 2000 feet (610 m.) of predominantly brown-weathering, dark gray platy jointed pyroxene andesite porphyry lava flows and associated breccia and minor volcanic sedimentary interbeds of tuffaceous sandstone, lapilli tuff and laharic breccia overlie conformably the Breitenbush Tuff. This section is named herein the Nohorn Formation after the drainage basin in the Battle Ax 15-minute quadrangle in which the strata are extensively exposed. The brown-weathering lavas are the characteristic lithology of this formation and, where underlain by the Breitenbush Tuff, serve to distinguish it from other sequences of lavas.

Two members are recognized in the lower part of the formation, the Blister Creek Tuff member (Dhyrman, 1975, p. 8-15) and the Hugh Creek member of one or more thick glassy pyroxene andesite porphyry lava flows (Table VI). The Blister Creek Tuff member was originally considered as top of the Breitenbush Tuff but an aphanitic pyroxene andesite porphyry flow underlies the tuff. So the tuff could be the top tuff unit of the Breitenbush or an interbed near the bottom of the Nohorn Formation. The Hugh Creek member was formerly considered as the Nohorn Creek basaltic andesite of Dyrhman (1975, p. 24-28). The formation also includes the Silver King andesite and Hugh Creek basaltic andesite of Dyrhman (1975, p. 21-24, 28-32).

In addition to the Nohorn Creek and Hot Springs Fork areas, the formation is fairly well exposed in the divide between Blowout and Pyramid Creeks in the slopes of Scar Mountain. Narrow exposures of the formation also occur along lower Oak Grove Fork and the Clackamas River east of the Collawash River and atop Coopers Ridge. Elsewhere the formation has been deeply eroded and extensively removed from large parts of the map area, which it once probably covered continuously. The formation is overlain unconformably by the Bull Creek beds, Cub Point Formation, Columbia River Basalt, Rhododendron Formation, vitrophyric lava of Coopers Ridge, and High Cascade lava flows.

The maximum thickness of the Nohorn Formation ranges from 2000 to 2400 feet (610-730 m.). Dyrhman (1975, p. 21) estimated the formation to be about 1000 feet (305 m.) thick in the Hot Springs Fork area. It is about 2400 feet (730 m.) thick between Lost Creek and the northwest ridge of Scar Mountain, in the Blowout Creek area, where the formation is unconformably overlain by the Cub Point Formation. It is at least 2000 feet (610 m.) thick on the north side of the Hot Springs Fork, where the formation is unconformably overlain by the Rhododendron Formation.

Extensive stratigraphic sequences of the formation are rare or very poorly exposed. A partial stratigraphic section, designated herein as the type section, was measured and described (Table VI) in the lower part of the formation along Nohorn Creek west of Bagby Hot Springs. The section contains only part of the lithology; the few thick breccias common to the upper part of the formation, making it difficult to separate from the overlying Bull Creek beds, are not present. Furthermore, the measured section is cut by at least two faults and one large dike of similar composition, causing alteration of some units. The stratigraphic position of the measured section within the Nohorn Formation is not known. It presumably lies near the base, but the stratigraphic interval between the base of the section and the true base of the formation. If future work determines that the Blister Creek Tuff member is the top unit of the underlying Breitenbush Tuff, then the flow atop the member can be designated as the base.

All lithologic types common to the formation are exposed in cuts along U.S. Forest Service # S-738 and # S-741, making a loop in the area between Nohorn Creek and the Hot Springs Fork.

A reference stratigraphic section will be measured in the upper Blowout Creek area.

Petrographic descriptions of the lava flows are furnished by Dyhrman (1975, p. 21-32). His chemical analyses indicate that the lavas range from 54 to 70 percent silica.

The base of the Nohorn Formation can readily be recognized by the presence of the underlying Breitenbush Tuff. The top can generally be recognized by overlying diagnostic units, the volcanic sedimentary rocks of the Cub Point Formation, Columbia River Basalt, light-colored lithic breccia and coarsely porphyritic lavas of the Rhododendron Formation, and the vitrophyric lava of Coopers Ridge. Contact with the overlying beds of Bull Creek is uncertain, especially in the Hot Springs Fork area, because of the varied lithology and the tendency of the younger formation to landslide.

The Nohorn Formation is Middle to Late Miocene age. One flow along Hugh Creek was K-Ar dated at 13 to 16.5 million years (Table IV). It is underlain conformably by the Breitenbush Tuff at 12 to 13 million years.

Bull Creek Beds (Tbc)

A 1000-foot (305 m.) thick unconformity bound sequence of high varied deposits of predominantly fine to conglomeratic volcanic sedimentary rocks occurs within the Clackamas River drainage basin. These strata were originally named informally as the Bull Creek sediments (Barnes and Butler, 1930, p. 101-107). The strata are incompetent and prone to landslide. The formation overlies the Breitenbush Tuff and Nohorn Formation and is overlain unconformably by Columbia River Basalt, Rhododendron Formation, and locally by High Cascade lavas. The formation is probably confined to the Clackamas River drainage. Dyhrman (1975) did not separate Bull Creek beds from Nohorn Formation. However, somewhat similar volcanic sedimentary deposits occur in the Cub Point Formation to the south. Also thin sequences of basalt lava flows in the Bull Creek beds are similar to the basalt lava flows and breccia of the Gordan Peak and Outerson Formations. Because of their close stratigraphic positions and similar lithologies, the Outerson, Cub Point, and Gordan Peak Formations are tentatively considered as possible correlatives, at least in part, with the Bull Creek beds (Table 1, Fig. 3).

The Bull Creek beds represent the filling of a large structural basin, now uplifted to form part of the northern Oregon Cascade Range. This basin is informally named the Mount Hood structural low. It contains the overlying Columbia River Basalt. Similar strata extend well north of the map area and are called the Eagle Creek Formation in the Columbia River Gorge (Barnes and Butler, 1930; Allen, 1957; and Waters, 1973). The formation extends farther northward in the southern Washington Cascade Range (Wise, 1970; Hammond and others, 1976).

The maximum thickness of the Bull Creek beds ranges from 1600 to 1800 feet (490-550 m.). The formation is about 1600 feet (490 m.) thick between Austin Hot Springs on the Clackamas River to Oak Grove Butte to the north. Lava flows of the Nohorn Formation are exposed in the valley bottom and the beds are overlain unconformably by lavas of the High Cascades at Oak Grove Butte. About 1800 feet (550 m.) is exposed between Happy Creek, at approximately the top of the Breitenbush Tuff, to the base of the Rhododendron Formation below Granite Peaks, between the Clackamas River and northern Rhododendron Ridge, in the Battle Ax quadrangle. A maximum exposed thickness of about 1200 feet (365 m.)

lies along Sandstone Creek, between the Clackamas River and the base of the overlying Columbia River Basalt, in the Fish Creek Mountain quadrangle.

The first but very short stratigraphic section of the Bull Creek beds was given by Barnes and Butler (1930, p. 103). It is reproduced in Table VII. The section provides a brief description of the sedimentary beds. Strata are folded and range in attitudes from 10° to 90°. Bedding is disrupted, caused probably by extensive landsliding in the area. J.E. Allen (1966, written communication) considered that the Bull Creek beds underlay volcanic conglomerate and breccia of the Eagle Creek Formation. But the lithologies are common, as exposed in the many outcrops in the area and not readily separable in mapping; all are included in the beds of Bull Creek. Allen noted that the conglomerate beds contain clasts up to 3 inches (7.5 cm.) in diameter, consisting of 90 percent porphyritic andesite; 3 percent rhyolite, some banded; 2 percent basalt; and a few of quartz, diorite, jasper and chert.

No specific lithology or sequence of beds was or could be traced in the Bull Creek beds. No evidence of a black pumice tuff, diagnostic of the Cub Point Formation to the south, was noted.

A profound unconformity lies beneath the beds of Bull Creek, indicating that a major erosive event occurred prior to their deposition. Large sections of the Nohorn Formation were entirely eroded during this period. The beds possibly fill broad valleys and bury low hills of older strata, making the basal contact difficult to trace and identify with certainty. In contrast, the upper surface is more uniform. Columbia River Basalt may be a series of intracanyon lavas filling a broad valley in the Bull Creek beds. The younger basalt flows overlap the older. Furthermore, the lower interbed above the basal Columbia River Basalt flow (Table IX) and also exposed in the NW¼ SE¼ sec. 16, T. 5 S., R. 6 E., along the Clackamas River highway (U.S. Forest Service # S-46, County 224), about 1 mile (1.6 km.) north of Three Lynx, north of the map area, contains identical Bull Creek beds lithology, indicating on-going depositional patterns during outpouring of Columbia River Basalt flows. In addition, the basal surface of the Rhododendron Formation slopes northward in elevation in agreement with the regional structure from 3600 feet near Hawk Mountain along the west side of Rhododendron Ridge to 3200 feet at Granite Peaks, to 2800 feet atop Columbia River Basalt near Three Lynx.

The age of the Bull Creek beds is bracketed by the enclosing formations. It is underlain by strata ranging in age from 12 to 16 million years. It is overlain by Columbia River Basalt, whose maximum age is about 16 million years (D.A. Swanson, oral communication, April 3, 1976). The stratigraphic position of the basalt flows in the map area (Fish Creek Mountain quadrangle) have not yet been ascertained; they are possibly younger than the 16 million year date. As best estimate, the age of Bull Creek beds is Middle to Late Miocene.

Outerson Formation (To)

The Outerson volcanics (Thayer, 1936, 1937, 1939) are restricted in this report to the interstratified very dark-colored phyric olivine basalt lava flows, scoriaceous breccia and minor amounts of basaltic derived volcanic sedimentary rocks exposed continuously about Outerson Mountain in the Breitenbush and North Santiam River area. They are herein renamed the Outerson Formation. The formation overlies unconformably the Breitenbush Tuff, and probably beds at Detroit in the area north of Breitenbush Hot Springs. It is in turn overlain conformably by the Gordan Peak Formation, at northern Mount Bruno, and probably the Cub Point Formation (the latter conformably underlies the former) unconformably by the Cheat Creek beds, and is unconformably overlain by the Rhododendron Formation; however, with some uncertainty, and lava flows of the High Cascade Group.

Clayton (1976, p. 25-39) has made the best stratigraphic description to date. He recognizes a thick basal basalt lava flow, lying between Outerson Mountain and Eagle Rock, the Leone Lake sediments near the base of the formation west of Outerson Mountain, and a tuff unit with sedimentary interbeds outcropping north of the Breitenbush River, all apparently interstratified with typical dark-colored olivine basalt lava and scoriaceous breccia. The Leone Lake sediments (Tos) and tuff (Tot) are shown separately on the map (Pl. 1).

Similar strata extend southward from Outerson Mountain in the North Santiam River Valley but are designated as part of the Gordan Peak Formation in this report. The underlying Cub Point and Gordan Peak Formations are considered to be in part correlative with the Outerson Formation. To the north, in the Clackamas River drainage, the Outerson Formation is considered also to be partly contemporaneous with the Bull Creek beds.

Best exposures of the Outerson Formation occur (1) along U.S. Forest Service road #1071, along Skunk Creek, where a type section will be measured and designated; (2) along U.S. Forest Service road # S-94, the Devils Creek road; and (3) along the North Santiam River, along U.S. Forest Service road # 1069 and along Highway 22 near the Pamelia Creek bridge.

In its type area, the Outerson Formation is the erosional remains of a large shield lava complex derived from a series of basalt dikes and plugs concentrated northeast and southeast of Breitenbush Hot Springs. The shield volcano complex had occupied a broad valley where it initially impounded the local drainage to form the basin for the Leone Lake sediments until the growing volcano diverted the drainage elsewhere. Subsequently deformation in the Cascade Range has tilted the volcano complex to the east (see discussion on Structures).

The maximum thickness of the Outerson Formation is estimated to be 1800 feet (550 m.) in the area just north of Outerson Mountain. No stratigraphic section has so far been measured.

The basal basalt flow (Clayton, 1976, p. 28-29), up to 400 feet (120 m.) thick, with brickbat jointing, is aphanitic, glassy (15 percent) and contains a few fine-grained plagioclase laths. It is poorly altered to chalcedony and celadonite. These characteristics differ from the overlying typical Outerson Basalt and suggest the possibility of remnant lava flows of the Nohorn Formation occurring in the area. Outerson Basalt are brownish black to olivine black, weathering grayish red purple, holocrystalline, fine-grained, vesicular to amygdaloidal, containing also fine-grained plagioclase, about 5 percent, and olivine, poorly altered to iddingsite, about 5 percent. The intervening scoriaceous breccias are oxidized, locally altered, and variegated, commonly vividly colored.

The sedimentary interbeds occur at different stratigraphic levels within the formation, except for the thick basal beds near Leone Lake. They are composed of fluvially deposited palagonitic sandstone and lithic-pumice breccia.

The Leone Lake sediments (Tos; Clayton, 1976, p. 33-36) can probably be designated as a member when the formation is formally named. They consist of interstratified volcanic sandstone, mudstone, and air fall tuff, of fluvial and lacustrine origin, interlensing with basal lava and breccia. They are about 1000 feet (305 m.) thick and are best exposed along U.S. Forest Service road # S-916A in NW¼ SE¼ sec 31, T. 9 S., R. 7 E.

The tuff unit (Tot) along Rapidan trail, as mapped within the Outerson Formation by Clayton (1976, p. 36-39) is an enigma. No similar tuff has been found elsewhere in the Outerson Formation. It ranges from 10 to about 600 feet (3-185 m.) thick, and consists of interstratified pale gray to pinkish gray sedimentary tuffs, thin lava flows, one of which is a dark gray porphyritic hypersthene-plagioclse basalt, and one pinkish gray to pale yellow brown partially welded crystal-vitric tuff, all of which closely resemble the Upper Gale Hill unit of Breitenbush Tuff (Clayton, 1976, p. 21-22). The tuff unit is in vertical fault contact with Outerson Formation on the east and Clayton's map shows the unit to be underlain by Outerson. This relationship is conjectural and should be carefully checked. Topographic features and the few discontinuous stratigraphic contacts so far traced in the Breitenbush Hot Springs area suggest the presence of several north-south trending faults. These relationships are important if extensive faulting should be influencing the flow of geothermal water. If the tuff unit along Rapidan trail is found to be underlain by undeniable Breitenbush Tuff, then the unit could lie within an uplifted fault block of Breitenbush. This enigma is one example of the several stratigraphic problems that should be resolved before the map is finalized.

Another enigma is the stratigraphic relationship between the Outerson and Rhododendron Formations. The Rhododendron Formation is determined as unconformably overlying the Outerson Formation based on very poor exposures in the uppermost Collawash River basin between Cachebox Creek and Mansfield Mountain, in the Breitenbush Hot Springs quadrangle. The fault possibilities discussed above may be complicating the stratigraphic relations here. No Rhododendron or Outerson lithology types have been found atop the opposite formation to confirm the stratigraphic interpretation. Except one 300-foot (91 m.) wide vertical dike of Outerson-like basalt intruding Rhododendron Formation is noted just northeast of Hawk Mountain in the southern part of Rhododendron Ridge. If Outerson Formation is found to overlie Rhododendron Formation, then this report is subject to considerable revision. The area between Breitenbush Hot Springs and the upper Collawash River is indeed critical and warrants careful checking!

K-Ar dating (Table IV) of a few rocks in the north Outerson Mountain area bracket, with a degree of uncertainty, the age of the Outerson Formation. One sample dated at 11.23 ± 0.17 million years was taken supposedly from the Outerson Basalt, after Thayer's (1939) map. The approximate location of the sample places it within the middle to upper part of the formation. The formation is in turn overlain unconformably by lavas 3.5 to 5 million years old and is underlain by Breitenbush Tuff, 12 to 13 million years old. As presently known, the age of the Outerson Formation can range from 5 to 13 million years, possibly Middle to Late Miocene. In spite of the 11 million year date, McBirney, Sutter and others (1974) stated that the Outerson Formation is 3.4 to 5.7 million years old, about Early Pliocene. Clayton (1976, p. 38-39) considered the Formation to be Early to Late Pliocene.

Cub Point Formation (new formation; Tcp)

The Cub Point Formation is a distinctive section of interstratified light-colored tuffs, conglomeratic volcanic sandstone, and a gray lithic-black pumice vitric tuff. The formation is named for Cub Point near where it is best exposed. It forms a diagnostic stratigraphic marker in the upper Western Cascade Group, although it is possibly limited laterally (Fig. 3). The formation unconformably overlies Nohorn Formation, Breitenbush Tuff, and probably beds at Detroit. It is overlain conformably by Gordan Peak Formation, possibly by the Outerson Formation, and unconformably by the lavas of Coffin Mountain at Cub Point and the vitrophyric lavas of Coopers and Boulder Ridges.

The formation extends discontinuously from Pinnacle Peak northeastward through the drainage basin of Blowout Creek to Coopers Ridge in the Detroit quadrangle (Pl. 1). Isolated occurrences lie at east Boulder Ridge and along the south side of Pamelia Creek Valley. The formation ranges in thickness from about 800 feet (245 m.) at Cub Point to about 1800 feet (550 m.) in the area between Pinnacle Peak and Scar Mountain.

The characteristic lithology is described in two stratigraphic sections (Tables VII and VIII) of the Cub Point Formation. The lithic-black pumice vitric tuff, unit no. 30 (Table VII) and unit no. 6 (Table VIII) are considered correlative. This distinctive unit is also present at east Boulder Ridge in the SE¼ SW¼ sec. 36, T. 9 S., R. 6 E. along U.S. Forest Service road # 2-916E, where more than 60 feet (18 m.) is exposed. It is overlain unconformably by the hypersthene vitrophyric lava flow of Boulder Ridge. Although its base is not exposed, it presumably rests upon Breitenbush Tuff. Clayton (1976, p. 21) included the black pumice tuff in his middle Boulder Ridge unit and the vitrophyric lava in his upper Gale Hill unit, both of the Breitenbush Tuff. Similar black pumice tuff, about 5 feet (1.5 m.) thick, crops out in the SW¼ SE¼ sec. 36, T. 10 S., R 7 E., at the end of the Pamelia Creek road (U.S. Forest Service #109). The tuff overlies a platy iron-stained pyroxene andesite lava flow of possible Nohorn Formation.

The extent of the formation atop Coopers Ridge is based on sporadic roadcuts of variegated tuffs similar to those described in the stratigraphic sections. No black pumice tuff was noted here.

Contact relations with enclosing formations are exposed between Pinnacle Peak and Scar Mountain. These relations are stated in stratigraphic section, no. 1 (Table VII). Northward the exposures are poor because of the extensive landsliding and contacts are inferred. The relationships near Cub Point are stated in stratigraphic section no. 2 (Table VIII). The Outerson Formation and the black pumice tuff unit are not in contact at east Boulder Ridge. Consequently the stratigraphic relations between these two formations is unknown. The base of the Outerson Formation, here the beds of Leone Lake, line at lower elevations on the north side of Boulder Ridge than the black pumice tuff on the south side. These paleotopographic relations might suggest that the Cub Point is younger than the lower part of the Outerson Formation. Because the conformably overlying Gordan Peak Formation is lithologically similar and in part equivalent to the upper Outerson Formation, the Cub Point Formation is tentatively considered about the same age as the Outerson Formation.

The strata of these two formations are, however, not equivalent as indicated by their lithologic differences. The Cub Point Formation is bracketed by a maximum age of 12 to 13 million years for the Breitenbush Tuff and 11.23 $\pm$ 0.17 million years (Table IV) for the middle to upper part of the Outerson Formation. Therefore the age of the Cub Point Formation is 11 to 12 million years, corresponding to Middle Miocene.

Gordan Peak Formation (new formation; Tgp)

The Gordan Peak Formation consists of predominantly phyric olivine basalt, porphyritic and non-porphyritic pyroxene andesite lava and breccia, and a small amount of interbedded venticular volcaniclastic deposits. The formation ranges from about 330 to 1600 feet (100-490 m.) thick. It is named after Gordan Peak on whose northern slope the lavas are exposed in logging roadcuts and where its stratigraphic position is defined. The formation conformably overlies the Cub Point Formation and unconformably underlies the sedimentary beds of Scar Mountain (Fig. 3).

The formation is traceable from Mount Bruno, where it includes the Nan Creek Volcanics of Anthony Rollins (oral communication, Aug. 15, 1975), southward along the North Santiam River Valley and east of Blowout Creek in the Detroit and Mount Jefferson quadrangles (Pl. 1). It extends southward beyond the map area and is recognized between Smith River and McKenzie River in the Echo Mountain quadrangle, there described briefly by Taylor (1968, p. 10-12).

A stratigraphic section of the formation has not yet been measured, nor has a type section been designated. Best exposures of the formation occur in U.S. Forest Service logging roadcuts, along # 1177M between Gordan Peak and Scar Mountain, along # 1234 on the north and west sides and along # 1349T on the southeast sides respectively of Three Pyramids, along # 111 and # 111A between Tule Lake, Trappers Butte and Scar Mountain, and along Straight Creek along # 1155 along Bugaboo Creek, along # 1166 along Parkett Creek, along # 124R west of the North Santiam River and south of Lynx Creek, and sporadically along State Highway 22 parallelling the North Santiam River south of Riverside campground.

From Gordan Peak the formation thickens northeastward. It is about 330 feet (100 m.) thick between Gordan Peak and Scar Mountain; about 1200 feet (365 m.) thick between Cub Point and the Quaternary lavas capping Coffin

Mountain; and about 1600 feet (490 m.) thick at Mount Bruno between the underlying Outerson Formation and overlying Cheat Creek beds and Quaternary lavas.

The phyric olivine basalt lava flows are very similar to the flows of the Outerson Formation. Flows are 10 to 15 feet (3-5 m.) thick, separated by 2 to 6 feet (½-2 m.) thick oxidized opalized and zeolitized breccia. The compact lava is blocky to platy jointed, locally flow layered, and consists of hematitic olivine and randomly altered pyroxene with plagioclase laths in a vesicular to dense fine-grained matrix. The rock is dark gray to olive black, weathering brownish gray. Thin, less than 1 m., of gray to brown tuffaceous, probably palagonitic sandstone separate some flows. A rare glomeroporphyritic olivine basalt flow, up to 20 feet (6 m.) thick is dark gray and contains coarse-grained plagioclase laths and prisms with olivine in a dense very fine-grained groundmass.

Basalt flows form sequences of several lavas. Pyroxene andesite lavas commonly occur separately, within sequences of 100 feet (30 m.) thick lithic breccia of similar composition, and interbedded volcaniclastic strata of tuffaceous siltstone, cobble-boulder conglomerate, and laharic breccia. The compact lava is blocky to platy jointed, dark gray, weathering brown, and contains altered pyroxene and plagioclase prisms in a dense fine-grained groundmass. Both pyroxene and plagioclase crystals are variable in size and abundance. The lavas are 35 to 100 feet (10-30 m.) thick and enclosed in massive altered breccia 65 to 100 feet (20-30 m.) thick.

Along the North Santiam River Valley and along Straight Creek are exposed several volcaniclastic beds, 10 to 20 feet (3-6 m.) thick. Strata consist of interstratified moderate brown, gray, olive gray, pale greenish yellow to dusky yellow lithic-pumice crystal (plagioclase-quartz) vitric tuff (ash flow ?) massive to cross-bedded, soft tuffaceous and palagonitic sandstone, tuffaceous claystone, and rounded tuffaceous conglomerate. Bedding is thin, laminar, to thick, locally lenticular. Lava flows with oxidized breccia zones are commonly interbedded. Several "ribs" of these light-colored volcaniclastic beds can be seen in the upper eastern slopes of Mount Bruno. These beds dip southward and intersect the river valley south of Marion Forks. The 20-foot (6 m.) thick lithic-pumice crystal tuff bed along Straight Creek in the NW¼ SE¼ sec. 36, T. 11 S., R. 6 E. is very similar lithologically to the tuff bed exposed along the North Santiam River in the SW¼ NE¼ sec. 10, T. 11 S., R. 7 E., north of Marion Forks. The beds could be equivalent.

Basalt lavas are common in the lower part of the formation; andesite lava flows and volcaniclastic beds are more abundant in the upper part.

The base of the Gordan Peak Formation can be traced atop the distinctive Cub Point Formation from Scar Mountain northeastward to Cub Point. Northward the Cub Point Formation is not traceable (although isolated exposures occur at east Boulder Ridge and Pamelia Creek Valley; see discussion of Cub Point Formation) and contacts with underlying Outerson and Nohorn Formations are uncertain. Southward between Three Pyramids and Trappers Butte the Cub Point Formation is not identified and the Gordan Peak Formation rests upon questionably vitrophyric lavas of the Nohorn Formation. The top of the formation can be readily defined by the unconformably overlying beds of Scar Mountain and Cheat Creek, the latter at Mount Bruno, and Quaternary basalt lavas at Buck Mountain, Coffin Mountain, Bachelor Mountain, Mount Bruno, and along the east side of the North Santiam River Valley.

Because the basalt lavas are very similar to the characteristic olivine basalt lavas of the Outerson Formation where the underlying Cub Point Formation is missing or not identified, particularly at Mount Bruno and Woodpecker Ridge, the contact between the Gordan Peak and Outerson Formations is uncertain (Fig. 3). The Gordan Peak and possibly the Outerson Formations overlie the Cub Point Formation, although north of the North Santiam River, the extent of the Cub Point Formation is uncertain. As mentioned previously, the Cub Point Formation is tentatively considered equivalent at least to the upper part of the Outerson Formation. Although the Outerson Formation is restricted to its source area, the Gordan Peak Formation is more widespread and, because of its diverse lithology, is derived from several sources, none of which was identified in this study.

K-Ar age dates (Table IV) suggest that the Gordan Peak Formation could range in age from about 11 to 5 million years, about Late Miocene. McBirney obtained a sample of middle to upper part of the Outerson Formation, dated at 11.23 $\pm$ 0.17 million years and a sample of the unconformably overlying lavas, dated at 4.72 $\pm$ 0.19 million years. The Gordan Peak Formation lies approximately within this stratigraphic interval.

Columbia River Basalt (Tcr)

As mentioned previously, the distinctive dark-colored layer-upon-layer lava flows of the Columbia River Basalt are not a part of the group. The formation is briefly described here in order of its stratigraphic position. In the northern Cascade Range of Oregon, the flows serve as an important stratigraphic marker unit in the upper part of the group, contrary to the arguments of Wheeler and Mallory (1970) that the Columbia River Basalt arches over the range.

The formation is present only in the northern part of the map area, in the drainage area of the Clackamas River, where they were identified by Barnes and Butler (1930) and more extensively mapped by Peck and others (1964).

The Columbia River Basalt unconformably overlies the Bull Creek beds and the Nohorn Formation, the latter exposed along Oak Grove Fork. The formation is overlain unconformably by the Rhododendron Formation and lavas of the High Cascade Group.

The formation has a maximum thickness of about 1000 feet (305 m.), as exposed along Cripple Creek just southeast of Three Lynx. The formation thins out to the south over a distance of about 4½ miles (7.2 km.) as shown in the eastern side of Fish Creek Divide. The last remnant flow, about 80 feet (24 m.) thick, occurs in secs. 25 and 36, T. 6 S., R. 6 E., just above Austin Hot Springs, about 7½ miles (12 km.) south of Cripple Creek. The formation is over 500 feet (152 m.) thick in the slopes above Ripplebrook where a partial stratigraphic section is exposed (Table IX).

The lithology is briefly described in the stratigraphic section.

The flow rock is commonly dark gray, fine-grained, dense to porphyritic, plagioclase being the common phenocryst. Individual lava flows are uniformly thick, ranging from 20 to over 80 feet (6-25 m.). A columnar to blocky jointed interior zone, defining a colonade or entablature is also distinctive. Individual flows commonly make good rims which can be followed for a considerable distance through the tree-clad slopes. This characteristic most readily serves to distinguish Columbia River Basalt lava flows from other flows.

The basal flow and overlying sedimentary interbed (units #1 and #2 in the stratigraphic section, Table IX) are probably correlative with the basal flow and overlying sedimentary beds exposed at Dinner Creek along Highway 224 north of Three Lynx, about 1 mile (1.6 km.) north of the map area.

This study of the Columbia River Basalt in the Clackamas River area is preliminary to a much more intensive investigation by M.H. Beeson and students at Portland State University, involving flow-by-flow mapping, sampling, and correlating by remnant magnetic polarity and trace element composition.

The Columbia River Basalts range in age from about 8 to 16 million years (D.A. Swanson, written communication, April 3, 1976). Although the exact stratigraphic position of the lava flows in the Clackamas River area within the group is not yet unknown, pending further investigation by Beeson and others, it is supposed the local flows are lower in the section and closer to 16 million years. However, K-Ar dates (Table IV) reveal that units underlying Columbia River Basalt by as much as 4500 feet (1370 m.) are as young as the basalt. Either (a) the ages of the underlying units are too young, (b) the Columbia River Basalts are not as old as presently considered, (c) K-Ar dating can not resolve the ages of closely spaced volcanic events 10 to 25 million years ago and considerable volcanic deposition has occurred within only a short geologic time in the Cascade Range. At present the Columbia River Basalt in the Clackamas River area is estimated to be Late Miocene in age.

Rhododendron Formation (Tr)

The uppermost major extensive stratigraphic unit of the Western Cascade Group is mapped as the Rhododendron Formation. The strata consist predominantly of brown to gray colored coarsely phyric pyroxene andesite porphyry lava flows, with platy to blocky jointing, a lesser amount of light-gray-colored thick-bedded lithic breccia, and minor amounts of volcanic sedimentary rocks. The rock is very similar to the strata described at Zigzag Mountain by Barnes and Butler (1930). In contrast to Barnes'and Butler's description, the Rhododendron Formation in the map area consists of abundant lava flows, as especially well exposed along the upper western face of Rhododendron Ridge. The formation occurs only in the northern part of the map area.

A profound unconformity underlies the Rhododendron Formation. It overlies beds at Detroit, Breitenbush Tuff, Bull Creek beds, questionable Outerson Formation, and Columbia River Basalt. The Rhododendron Formation is in turn overlain unconformably by the lavas of the High Cascade Group.

The formation ranges in thickness from 550 to 3500 feet (170-1065 m.). It is 550 feet (170 m.) thick above Columbia River at Cripple Creek east of

Three Lynx; 900 feet (275 m.) thick west of Graham Pass and 1850 feet (565 m.) at Granite Peaks, at the middle and northern ends, respectively, of Rhododendron Ridge; and 3500 feet (1065 m.) thick southeast of Fish Creek Mountain, where it may fill a former valley eroded into Bull Creek beds. However the trends of thickness suggest a possible source area west of the northern part of the map area.

No stratigraphic section has been measured and described in the map area. The formation does contain some distinctive units and lithologies. The units mapped as Dutch Creek tuff, Thunder Mountain andesite, Whetstone Mountain volcaniclastic rocks and Hugh Creek ignimbrite (Dyhrman, 1975) do comprise the Rhododendron Formation.

The Dutch Creek tuff rests unconformably on Silver King andesite (Dyhrman, 1975, p. 32-35), included here in the Nohorn Formation. The Dutch Creek unit consists of yellowish gray, weathering pale brown, lithic-pumice tuff-breccia, containing 10 percent dark gray lithic fragments of pyroxene andesite porphyry and 20 percent very light gray pumice lapilli in tuff matrix with coarse-grained euhedral crystals of plagioclase, hornblende, and quartz. The lump pumice consists of 72.9 percent silica (Dyhrman, 1975, p. 35, 76). The unit is exposed in secs. 1 and 2, T. 7 S., R. 5 E., east of Thunder Mountain, in the Battle Ax quadrangle. It is a discontinuous deposit, has a maximum thickness of 200 feet (61 m.) and is overlain unconformably by the Thumder Mountain andesite.

Similar lithology has been noted in basal Rhododendron strata in the SW¼ NW¼ sec. 8, T. 6 S., R. 6 E., southeastern slope of Fish Creek Mountain, where the lithic fragments are more common and larger in size. It has also been noted extending along the western slope of Rhododendron Ridge between Mount Lowe southward to Hawk Mountain in the Breitenbush Hot Springs quadrangle, where it ranges from 20 to 50 feet (6-15 m.) thick.

Thunder Mountain andesite (Dyhrman, 1976, p. 35-38) includes the bulk of the interstratified lava flows and breccias of the Rhododendron Formation. It is a gray-colored pyroxene andesite porphyry, containing up to 50 percent fine- to coarse-grained phenocrysts of hypersthene, augite, plagioclase, and a few olivine, in a partly glassy, very fine-grained groundmass. Selected samples yielded 54.0 to 59.8 percent silica (Dyhrman, 1975, p. 38, 76). Lavas are platy to blocky jointed, with the latter predominating. Flows range from 20 to over 100 feet (6-30 m.) thick. This rock is the common lithic fragment in the light gray-colored breccias, containing a matrix of probably quite similar composition.

The Whetstone Mountain volcaniclastic rocks (Dyhrman, 1975, p. 38-41) overlie the Thunder Mountain andesite. They occur at Whetstone Mountain and extend eastward to Silver King Mountain, in the Battle Ax quadrangle. Similar lavas to Thunder Mountain andesite overlie the volcaniclastic rocks just west of Silver King Mountain, so the unit may be a lens within the lower part of the Rhododendron Formation. They consist of a part of light olive-gray thick bedded, lithic-pumice tuff breccia grading into boulder conglomerate and an upper part of light greenish gray, thin-bedded pumiceous crystal (quartz-plagioclase) vitric tuff. Together they are 150 feet (46 m.) thick.

The Hugh Creek ignimbrite (Dyhrman, 1975, p. 41-46) consisting mostly of brown partially welded pumice lapilli crystal (hornblende-augite-quartz-plagioclase) vitric tuff, is a distinctive unit within the Rhododendron Formation. It is not associated with the other units of the Rhododendron Formation but rests separately and unconformably on the Nohorn Formation. Its stratigraphic position in the formation is indefinite; it probably represents a discontinuous basal unit. It occurs discontinuously in the Battle Ax quadrangle, northwest of Whetstone Mountain, at North Dickey Peak, and near Byars Peak, to the south. The maximum thickness is 400 feet (122 m.). In addition to its characteristic pumice lapilli and hornblende crystals, the tuff contains a few lithic inclusions of granite. Chemical analysis indicates that the tuff contains 55.8 percent silica (Dyhrman, 1975, p. 45, 76).

Together the Whetstone Mountain volcaniclastic rocks and the Hugh Creek ignimbrite could be eastward correlatives of Thayer's (1939) Fern Ridge Tuffs.

The Rhododendron Formation is underlain by the ~~immediately underlying~~ Columbia River Basalt, of 8 to 16 million years, and overlain by 5 million year lavas of the High Cascade Group. Wise (1969, p. 977) reports a K-Ar date of 7 $\pm$ 2 million years for Rhododendron Formation as Late Miocene in age.

Cheat Creek Beds (Tcc)

Cheat Creek beds is the informally named (Anthony Rollins, written communication, Nov. 15, 1974; Clayton, 1976, p. 39-41) sequence of volcaniclastic rocks, tuffs and lava flows about 800 feet (245 m.) thick, unconformably overlying the Outerson Formation, and unconformably underlying the lavas of the High Cascade Group. They are exposed on the southern slopes of Triangulation Peak and Outerson Mountain above Cheat Creek on the upper northern slopes of Woodpecker Ridge, and at the northern slope of Mount Bruno. The beds are confined to this area, in a once shallow basin about 5 to 6 miles (9-14.4 km.) across, as ascertained by Rollins. These beds have the same stratigraphic relationship, at the top of the Western Cascade Group and below the High Cascade Group, as the Scar Mountain beds. Except the beds are not similar lithologically and the Cheat Creek beds are inclined about 10^{o} eastward in response to late Tertiary tectonic uplift.

The type area of the Cheat Creek beds is designated herein as the southern slope of Outerson Mountain. The type section (Table XI) is exposed in the cuts of U.S. Forest Service road # 1071. The lithology is described in the stratigraphic section. The bedded sequence overlaps and buries, at its base, a small cinder cone, located in the NW¼ sec. 13, T. 10 S., R. 7 E. (Anthony Rollins, oral communication, July 12, 1974).

The Cheat Creek beds are stratified between formations which have been dated at 11 and 5 million years (Table IV). The beds are Late Miocene in age.

The Cheat Creek beds and the next unit to be described, the Scar Mountain beds, occupy approximately the same stratigraphic position. Although they are composed of different lithologies, the stratigraphic units may be indicative of the same depositional processes then on-going within the Cascade Range province that produced the Troutdale and The Dalles Formations bordering the ancestral course of the Columbia River.

Scar Mountain Beds (Tsm)

Scar Mountain beds is the informal name given to the distinctive, yet restricted flat-lying lithologic unit over 300 feet (90 m.) well exposed at Scar Mountain, 5022 feet elevation, in the south part of the Detroit quadrangle. On the south slope of the mountain the beds are devoid of vegetation, producing a light-colored streak beneath the prominent summit, hence probably its name. The beds unconformably overlie the dipping lava flows of the Gordan Peak Formation and are conformably overlain by basalt lava flows of the High Cascade Group. The maximum thickness of the beds is estimated to be 560 feet (170 m.).

A partial stratigraphic section (Table X) was measured on the south slope. Additional good exposures can be found in cuts along U.S. Forest Service road # 111 at the east end of Scar Mountain. The characteristic lithology is described in the section.

Inclined fore-set bedding indicates that the beds were deposited by westward flowing streams, undoubtedly before uplift of the Cascade Range. The beds, situated over the axial portion of a broad anticline, suffered no deformation in the possibly last deformation of the anticline.

Because the beds lie between formations considered to be 11 million years or older and 5 million years or younger, the age of the Scar Mountain beds is estimated to be Late Miocene in age.

Miscellaneous lava flows

Two groups of miscellaneous lava flows are recognized in the map area. They are the vitrophyric andesite of Coopers and Boulder Ridges, and the vitrophyric basalt of Lost Creek. Both overlie all bedrock units in their areas. They may be part of the latest Western Cascade Group, such as the Rhododendron Formation, or part of the earliest High Cascade Group. The vitrophyric andesite of Coopers and Boulder Ridges will be discussed first. It appears to be the older.

Vitrophyric andesite of Coopers and Boulder Ridges (Tcbr). The vitrophyric andesite of Coopers and Boulder Ridges underlies the top flattish surfaces of the ridges, at elevations of about 3500 to 4000 feet. The rocks are very similar. Consequently they may be parts of once extensive flow or several flows covering formerly a broad valley, which subsequently has been encised by the North Santiam River.

The lava atop Boulder Ridge is exposed in cuts along U.S. Forest Service roads # S-916A and S-916E in the N½ sec. 36, T. 9 S., R. 6 E., and NW¼ sec. 1, T. 10 S., R. 6 E., in the Battle Ax and Detroit quadrangles, respectively. The rock is dark gray, porphyritic with abundant fine to coarse-grained phenocrysts of hornblende and plagioclase in a glassy groundmass. Clayton (1976, p. 21) included the flow in the upper Gale Hill unit of Breitenbush Tuff. But the restricted extent of the flow here, its glassy state, topographic position confined to the ridge crest, and similarity to vitrophyric lava atop Coopers Ridge, suggest that the flow is younger than Breitenbush Tuff. Its thickness at Boulder Ridge is about 30 feet (9 m.). It has normal remnant magnetic polarity.

The vitrophyric andesite of Coopers Ridge covers a wider extent. It is exposed in cuts along U.S. Forest Service roads # S-1068D and # 1159 in secs. 28, 29, and 33, T. 10 S., R. 6 E., in the Detroit quadrangle. The lava is very similar lithologically to the vitrophyre flow atop Boulder Ridge, but here has contorted flow layering and is intensely altered locally. Alteration has produced a variety of bright colors; the rock is argillized and silicified, either hydrothermally or fumarolically. It differs also from the Boulder Ridge flow by having reversed remnant magnetic polarity, indicating different ages of outpouring. The flow atop Coopers Ridge has a maximum thickness of about 60 feet (18 m.).

Vitrophyric basalt of Lost Creek (Tlc). The vitrophyric basalt of Lost Creek is scattered in a number of occurrences west of Blowout Creek in the Detroit quadrangle. It is exposed in cuts along U.S. Forest Service road # 1156 in the NE¼ SW¼ sec. 18, T. 11 S., R. 6 E.; # 1156 in the SW¼ SW¼ sec. 30, T. 11 S., R. 6 E.; in quarry in SE¼ sec. 25, T. 11 S., R. 5 E.; and along # 103 in Lost Creek in the S½ sec. 20, T. 11 S., R. 6 E. They occur on the flanks of Pinnacle Peak, suggesting a common source at or near the peak, possibly from a series of west-trending dikes exposed on its eastern slope. The rock is grayish black, has fine-grained phenocrysts of pyroxene and plagioclase, and possible olivine, in a glassy groundmass. Columnar jointing is very well developed. Where exposed in the quarry and in Lost Creek, it is 130 feet (40 m.) thick. The flow has normal remnant magnetic polarity.

The ages of these flows are considered Late Miocene to possibly Early Pliocene.

Intrusive Rocks

The intrusions are briefly described here together. They consist of hypabyssal dikes, sills, plugs and small stocks, less than 2 square miles (5 sq. km.) in outcrop area, consisting mostly of vitrophyre (dacite ?) basalt, hornblende, and pyroxene andesite, and pyroxene diorite. All are irregular in shape; many appear to be complexly intruded. For that reason, minimal time was spent in mapping their extent. The complex of hornblende andesite and pyroxene diorite dikes of probable small stocks extending from Battle Ax to Bull of the Woods, herein called the Bull of the Woods dike complex, probably the northeast extent of the Hall Ridge diorite at Detroit Lake, warrant a separate mapping project to delineate the shape and extent of intrusions, their composition, sequence of emplacement, and relationship to the base metal mineralization in the Little North Santiam River Valley, of which the intrusives appear to be intimately associated (Callaghan and Buddington, 1938, p. 82-99). They are named either after their one main occurrence or, if the rock occurs at several locations, after the rock type. They are described in approximate order of age, from oldest to youngest. The ages of their emplacement probably differ considerably; most are pre-High Cascade Group in age.

Trout Creek Vitrophyre (Titc)

The Trout Creek vitrophyre is an irregular mushroom-shaped (wider at the top) intrusion of primarily flow-layered vitrophyre located at Trout Creek opposite the mouth of the Collawash River. The rock is a brownish black to light brownish black, iron-stained, very fine-grained, containing about 10 percent plagioclase prisms. It intrudes Breitenbush Tuff and probable Nohorn Formation and Bull Creek beds. The intrusion covers about 3/4 square mile (2 sq. km.). Similar flow-layered lava occurs atop the Breitenbush Tuff in the E½ sec. 18, T. 6 S., R. 6 E., west of the intrusion. Also, the Pegleg Falls dacite flow (Dyhrman, 1975, p. 15-16) interstratified with the Breitenbush Tuff near its stratigraphic top, in the E½ sec. 14, T. 7 S., R. 5 E., is similar. The Pegleg Falls dacite flow is about 40 feet (12 m.) thick, and contains about 12 percent plagioclase and 3 percent pyroxene phenocrysts. The rock contains 68.6 percent silica. It is very similar chemically to the Breitenbush Tuff, east of Idanha, analyzed in Peck and others (1964, p. 45, no. 18). These relationships suggest a genetic association between the Breitenbush Tuff and the Trout Creek intrusion, that one or more ash flows may have been derived from the source vent now occupied by the intrusion, and that after eruption of the last sheet, a more viscous-mass was deposited as a platy, vitrophyric lava flow. The Trout Creek intrusion would, therefore, be about Middle Miocene in age. Selected samples give normal remnant magnetic polarity.

Basalt Dikes and Plugs (Tib)

A series of lithologically similar dark-colored phyric olivine basalt dikes occur in the map area. They are too numerous to specifically locate, but do occur in two clusters. The larger occurs in the area between Outerson Mountain, Mansfield Mountain, and East Humbug Creek. All are similar lithologically to Outerson basalt lava flows and probably served as feeders to the flows. The dikes trend from about N. 30° W. to N. 30° E. They range in width from 3 to 75 feet (1-23 m.), the wider trending more westerly. Clayton (1976, p. 41-43) recognized two episodes of emplacement of the dikes, one feeding the early basal Outerson flow, the other feeding the main volcanic complex. The concentration of dikes northeast of Breitenbush Hot Springs suggested to him that another major volcanic center existed there, similar to the remnant volcano at north Outerson Mountain. The third concentration of dikes at East

Humbug Creek may be related to yet another volcanic center. These dikes intrude beds at Detroit, Breitenbush Tuff; in fact, the Breitenbush Hot Springs percolate along the contacts of the northerly trending dikes with the tuff, and also the Outerson Formation. The first cluster of dikes is considered to be Middle to Late Miocene in age.

The second cluster of dikes occurs from Pinnacle Peak eastward through Scar Mountain and along Straight Creek. An isolated dike is exposed west of Coffin Mountain in the NW¼ NW¼ sec. 15, T. 11 S., R. 6 E. These dikes trend westward to northward, are very fine grained to vitrophyric, range from 10 to 50 feet (3-15 m.) wide, and are altered or coarser grained in the center. These dikes intrude Breitenbush Tuff, Nohorn, Cub Point, and Gordan Peak Formations, and Scar Mountain beds. They appear to be feeders to the vitrophyric basalt of Lost Creek and possibly the older High Cascade lavas capping Scar Mountain and Coffin Mountain. This cluster is probably younger than the first, Late Miocene to Pliocene in age.

Hornblende Andesite (Tiha)

A number of dikes and probably small stocks of brownish black, dark to greenish to light gray porphyritic hornblende-bearing andesite, gradational into pyroxene-bearing andesite, occur throughout the map area. The greatest concentration occurs in the area from Beachie Saddle, near Battle Ax, to Bull of the Woods in the Battle Ax quadrangle. It is called herein the Bull of the Woods intrusive complex. Enough outcrops of the rock occur along the ridge crest between Battle Ax and Silver King Mountain to suggest that the entire ridge is underlain by intrusive rocks, mostly parallel dikes trending about N. 50° W. Bull of the Woods also appears to be wholly composed of intrusive rocks. Lighter colored intrusions along the west side of Rhododendron Ridge and at Whale Mountain, the latter in the Fish Creek Mountain quadrangle are possible feeders to the Rhododendron Formation. A saussuritized glomeroporphyritic hornblende andesite intrusion occurs along the Clackamas River east of Austin Hot Springs. Plugs of pyroxene andesite porphyry bordered by landslide terrain rise prominently in the Collawash River valley at its confluence with Hot Springs Fork. Intrusions of similar pyroxene andesite porphyry occur north of Whetstone Mountain, along the Hot Springs Fork east of Bagby Hot Springs, the latter called Silver Lake andesite, both in the Battle Ax quadrangle (Dyhrman, 1975, p. 50-52). Each has 59.3 and 59.9 percent silica respectively (Dyhrman, 1975, p. 51-52, 77). A northwest-trending dike of similar rock occurs northwest of the confluence of the Hot Springs and Collawash Rivers. A porphyritic hornblende andesite plug is located between Breitenbush Hot Springs and Gale Hill (Clayton, 1976, p. 42). A similar appearing, although pyroxene bearing andesite porphyryr, containing 59.6 percent silica (Rollins, personal communication, Aug. 15, 1975) occurs in the SW¼ NE¼ sec. 3, T. 11 S., R. 6 E., Detroit quadrangle. The last noteworthy occurrence of this rock type occurs near Pinnacle Peak. A west-trending dike occurs along Lost Creek and a small stock underlies the hill to the southwest in sec. 30, T. 11 S., R. 6 E. The latter contains biotite in addition to the hornblende.

These intrusions cut all stratigraphic units up through the Rhododendron Formation. They are probably Miocene in age. They have both normal and reverse remnant magnetic polarity.

Pyroxene Andesite (Tipa)

The pyroxene andesite intrusions differ from the hornblende andesite, previously discussed, by being generally light colored, less porphyritic and a more equigranular texture, and gradational into fine-grained pyroxene diorite. The intrusions are less widespread than hornblende-bearing andesite.

The largest intrusion, the Austin Point pluton, is composed of this rock. It forms the inner canyon walls of the Collawash River between its confluence with the Clackamas and Hot Springs Rivers. Another large mass lies to the north along the Clackamas River. The total outcrop area is about 3 square miles (7.8 sq. km.). Very likely the intrusions are connected at depth. Along the Collawash River the pluton is surrounded by landslides so the total area of outcrop is probably larger.

The rock is dark, medium to greenish gray, phyric, fine to medium grained, with coarse crystals of clinopyroxene and plagioclase laths in dense finer grained matrix. The rock is more typically diorite, that is, uniformly medium grained along its western margin. Along the western margin of the Clackamas River occurrence, the intrusion forms a sill extending over pyroxene andesite porphyry lava flows of the Nohorn Formation. It forms a narrow, less than 5 foot (1.5 m.) contact metamorphic zone.

A possible outlier of the Austin Point intrusion is a highly altered-argillized and silicified-andesite porphyry exposed along the Clackamas River east of Austin Hot Springs, in the NW¼ sec. 26, T. 6 S., R. 7 E., in the High Rock quadrangle. The rock is medium light gray to pinkish gray and contains a few fine to medium-grained phenocrysts of entirely altered plagioclase and iron oxide stained ferromagnesian crystals, probably pyroxene, in a similarly altered very fine-grained groundmass. This rock is the most altered noted in the map area.

Two other small intrusions of similar rock occur to the south. One, a probable sill in Breitenbush Tuff, occurs along Highway 22, east of Idanha, in the NE¼ SW¼ sec. 19, T. 10 S., R. 7 E. The other forms a small plug, intruding lavas of Gordan Peak Formation, in the SE¼ SE¼ sec. 36, T. 11 S., R. 5 E., between Gordan Peak and Pinnacle Peak in the Detroit quadrangle. It, like the sill on the Clackamas River, has a narrow contact metamorphic aurede.

The Austin Point pluton intrudes Breitenbush Tuff, Nohorn Formation and Bull Creek beds. Host rocks to the two southern intrusions are mentioned above.

All have normal remnant magnetic polarity. Possibly they are of the same age, estimated to be Miocene.

Pyroxene Diorite (Tipd)

Medium to coarse-grained intrusions of pyroxene diorite are associated with the Bull of the Woods dike complex and probably represent the youngest emplacement stage of the complex. The rock is medium to dark greenish gray to greenish black. The texture is transitional; with an increase in percentage of phenocrystic plagioclase, the darker colored pyroxene andesite grades into diorite. The rock consists of chloritized pyroxene and epidotized plagioclase prisms in an altered finer grained matrix. The northern intrusion of the complex is the Pasola Mountain andesite porphyry which forms a 6 mile wide dike along the Bagby Hot Springs fault (Dyhrman, 1975, p. 53-55, 77). It has 62.8 percent silica. A similar, although quartz-bearing, pluton, also containing hornblende, called the Pin Creek andesite (Dyhrman, 1975, p. 46-50) occurs along the Hot Springs Fork east of Bagby Hot Springs. This rock contains 63.9 percent silica (Dyhrman, 1975, p. 50, 77). It has normal remnant magnetic polarity.

Isolated intrusions of this rock type occur southeast of Idahna in the SW¼ SE¼ sec. 35, T. 10 S., R. 6 E., and in the NE¼ NE¼ sec. 3, T. 11 S., R. 6 E., and west of Coffin Mountain, between Hawkins and Blowout Creeks in the NE¼ sec. 17, T. 11 S., R. 6 E. Exposures are limited but their trend indicate possible east-west dikes. The second one dips 70° S.

These intrusions cut most stratigraphic units, the youngest being Cut Point Formation and Bull Creek beds. They have normal and reversed remnant magnetic polarity. These are estimated to be Miocene in age.

Possible Quaternary Intrusions (Qi)

Several intrusions of possible Quaternary age occur in the map area. They are all phyric olivine basalts, ranging from light, medium, dark to olive gray in color, and occur in the eroded summits of High Cascade basalt volcanoes. Most form north-trending dikes, up to 5 miles wide, or irregular-shaped plugs. Spire Rock, composed of glassy porphyritic basalt with plagioclase phenocrysts, is the largest of five plugs on Triangulation Peak (Clayton, 1976, p. 45). A basalt dike, about 75 feet (23 m.) wide trending east-west, is believed to be the feeder to the High Cascade lava flows atop Coffin Mountain (Rollins, written communication, Nov. 15, 1974). Additional dikes are exposed atop Turpentine Peak, Marion Peak, Bingham Ridge, and reportedly atop Sisi Butte (John Hook, personal communication, Sept. 11, 1974). Additional dikes were observed east of the map area at Park Butte, Grizzly Peak, and above Hanks Lake, all in the Mount Jefferson quadrangle. Many have normal remnant magnetic polarity, indicating the possibility of some being younger than 690,000 years old.

High Cascade Group

The less deformed, commonly flat-lying and unaltered young volcanic rocks capping the crest of the Cascade Range were assigned to the High Cascade volcanic series [Volcanic Group] (Callaghan, 1933; Williams, 1957). Unlike the underlying Western Cascade Group, the volcanic strata of the High Cascade Group underlie constructional landforms and in spite of deep glaciation and stream erosion, can be commonly traced to their source centers. On the eastern slope of the Cascade Range these strata merge with the lavas of the High Lava Plains. As yet no clear distinction has been mapped, separating the volcanic rocks arising from sources within the Cascade Range from those to the east.

Thayer (1936, 1937, 1939) subdivided the group into five volcanic units in chronological order - the Outerson Volcanics, Minto Lavas, Battle Ax Lavas, Olallie Lavas, and Santiam Basalts. The volcanic deposits of Mount Jefferson were included in the Olallie Lavas. He recognized as much as 4000 feet (1200 m.) of strata. Peck and others (1964) preferred to regroup these strata as the volcanic rocks of the High Cascade Range, their thickness ranging from 2000 to more than 3000 feet (600-900 m.).

As stated previously, the Outerson Volcanics are renamed Outerson Formation and assigned in this report to the Western Cascade Group. The strata are deformed and underlie the Rhododendron Formation, and probably the stratigraphic level of the Columbia River Basalt. The rock of the High Cascade Group is very similar petrographically. It consists overwhelmingly of gray-colored, blocky jointed phyric olivine basalt, with and without pyroxene and/or plagioclase phenocrysts. They are fine grained, generally holocrystalline, and range from dense to open textured (diktytaxitic). Platy jointed, dense lavas resembling andesite are much less common. All these rocks form abundant lava flows which radiate from shield volcanoes surmounted by cinder cones. Lava flows, 1 to 10 miles, commonly less than 5 miles, are pahoehoe to aa and are separated by thin breccia or scoria zones. They are interstratified locally with glacial and fluvial deposits.

The High Cascade volcanic deposits are commonly flat-lying, as previously stated, but where they are traced to their source vents the bedding steepens perceptibly. Near the volcanic summits the dips range from 15° to 35°; for example, 35° on the summit of Turpentine Mountain, 25° on Battle Ax. Dips over

35^{o} suggest Quaternary deformation such as in the interstratified lavas and sediments at the eastern base of Rhododendron Ridge. Clayton (1976, p. 46-48) observed a reversal in dip in the strata underlying Collawash Mountain, from 3 to 4^{o} E. near the base to 3 to 4^{o} W. upsection, suggesting (1) uplift on the east during volcanic build-up, or (2) derivation of the strata from another source. No additional evidence was found in support of either possibility.

The lavas compose close to 90 percent of the volume of young volcanic rocks capping the range. The remaining rocks are assigned herein to the volcanic deposits of Mount Jefferson, easily distinguishable because of their freshness, their constructional form, and topographic and geographic position peripheral to Mount Jefferson. They consist principally of debris avalanche and laharic (mud flow) deposits and subordinate lava flows. For this reason they are separated from the Olallie lavas of Thayer (1936, 1937, 1939). No dacite or rhyolites, of the types described by Greene (1968) and Thayer (1936, 1937, and 1939) were observed in the map area, primarily because no traverse was run across the rhyolite locality of Thayer's, lying between Sentinel Hills and the South Fork of the Breitenbush River. But Anthony Rollins (oral communication, Aug. 15, 1975) reports finding no rhyolites in Thayer's second locality at the north base of Minto Mountain.

In this study the High Cascade volcanic rocks are assigned to older High Cascade (QtB), younger high Cascade (Qb) and deposits of Mount Jefferson (Qi) The units are discussed in order, from oldest to youngest, by geographic location. They are distinguished on the basis of (1) their stratigraphic superposition, (2) their topographic position and expression, and (3) their remnant magnetic polarity. The approximate stratigraphic positions of the volcanic rocks are summarized in Table XII.

Estimated maximum thickness for the High Cascade Volcanic Group ranges from 1000 to 3600 feet (305-1100 m.) thick. The older High Cascade rocks are 600 to 2000 feet (185-610 m.) thick; the younger are 400 to 1600 feet (122-490 m.) thick.

A second erosional interval occurred after construction of the Park Butte shield volcano complex, north of Mount Jefferson. The volcanic deposits of Mount Jefferson are banked against 400 to 600 feet (122-183 m.) canyon walls cut into the older levas. Part of this sculpturing is possibly attributable to Late Pleistocene glaciation.

The positions of the volcanic centers offer an explanation to the north-south drainage paths bordering the High Cascade volcanic rocks. Examination of the map (Pl. 1) reveals that the older High Cascade volcanic rocks are concentrated along the western margin of the High Cascade Group. The source vents for these lavas also lie within this western margin, supporting the possibility that these lavas form a north-south belt, ranging from 10 to 20 miles (16-32 km.) wide. The belt is widest where source vents lie close to the edge - for example, Battle Ax on the west and Bald Butte on the east. The eastern edge of this belt is not delineated because, of course, it is overlapped by the younger High Cascade volcanic rocks. The younger High Cascade volcanic rocks form a parallel belt to the east, which defines the crest of the range. Within this second belt lie the composite High Cascade andesite volcanoes, a relationship which extends the length of the Oregon Cascade Range.

The average elevations, about 4000 feet, at the base of the younger High Cascade volcanic rocks indicate a lower topography in existence prior to their outpourings in comparison to the topographic levels in the western belt, which range from 4400 to 4800 feet. This relationship suggests, furthermore, the absence of older volcanic rocks to the east.

These geographic relations suggest a shift in zones of volcanism, from a western zone active about 2½ to 5 million years ago, to a volcanically active eastern zone, beginning about 1 million years ago. This line of volcanoes may have been the former drainage divide for the range. With development of the present crestal volcanic belt, the drainage was diverted to the west against the older volcanic edifices. As a consequence, streams developed, draining northward, or southward (the Smith River tributary of the McKenzie River south of the project area) in seeking outlets around the older volcanoes.

Older High Cascade Volcanic Rocks (Qtb)

Older High Cascade volcanic rocks occur as erosional remnants capping flat-topped mountains and ridges and as extensive sheets underlying upland surfaces. Erosion has more extensively dissected the older rocks south of the Clackamas drainage area, caused by (1) earlier outpourings of the lavas in the southern part of the area, or (2) greater uplift in the area adjacent to Mount Jefferson. Flat top cappings are remnants of a few thick intracanyon flows or former volcanic centers. Ridges exposing thick sections of lavas are remnants of fillings of deep valleys eroded into the Western Cascade Group.

Two K-Ar dates (Table IV) of probable older High Cascade lavas indicate that the lavas are as old as 4.5 million years, or Early Pliocene age. One date is believed to be of the lower Outerson Mountain - Woodpecker Hill - Triangulation Peak group of lavas (Table XII). The dated lavas have reversed magnetic polarity and, therefore, are of the Gilbert Reversed Polarity Epoch (Cox, 1969). The overlying normally magnetized lavas at the same locations are possibly of the Gaus Normal Polarity Epoch, 2.43 to 3.32 million years ago. These rocks are in turn overlain by the lava flows of Firecamp

Lakes - Sentinel Ridge - Woodpecker Ridge, which are derived from Park Butte north of Mount Jefferson and east of the map area. However, the lower flows at Firecamp Lakes are dated at 3.6 million years (Table IV) and are normally magnetized. The age date places these lavas likewise within the Gilbert Reversed Polarity Epoch, specifically during the Cochiti Event 3.7 to 3.92 million years ago. These relations create major problems. Either (1) the stratigraphic positions of the High Cascade volcanic rocks are out of order, (2) the remnant magnetic polarity is incorrectly determined, (3) the K-Ar age dates are incorrect, or (4) the dated rocks are assigned to the wrong formation. The Firecamp Lakes - Sentinel Ridge - Woodpecker Ridge lavas overlie two groups of older High Cascade lavas and represent the culmination of High Cascade basaltic volcanism in the map area; only minor amounts of succeeding lavas are present. It seems highly unlikely, in comparison with other areas of the Cascade Range, that only minor volcanism has occurred in the area during the last 3.7 million years.

The first consideration in solving this problem should be to review the formational assignment of the dated rocks, a procedure requiring a map or description giving specific locations to the samples. If the samples are found to represent the underlying Outerson Formation, then this formation has a much greater time span than stated previously in this report. These problems warrant further investigation, especially in attempting to delineate young volcanic centers or zones for potential geothermal resources but is beyond the scope of the present investigation.

Sampling and K-Ar age dating (Wise, 1969; McBirney and Sutter, 1974; Armstrong and others, 1975) of oldest High Cascade volcanic rocks indicate that these rocks began about 6 million years ago.

Flat-top cappings, and their thicknesses, occur from south to north (Table XII) at Three Pyramids, 1200 feet (365 m.); Trappers Butte, 500 feet (165 m.); Coffin Mountain, 570 feet (175 m.); Bachelor Mountain, 950 feet (290 m.); and Mount Bruno, 400 feet (135 m.). Cappings along ridges occur at Woodpecker Hill, 300 feet (100 m.); Outerson Mountain - Triangulation Peak, 800 feet (245 m.); Timber Butte - Gale Hill, 600 feet (185 m.); Collawash and Mansfield Mountains, 600 feet (185 m.); and Battle Ax, 800 feet (245 m.). Remnants of a deep valley filling is preserved in the sides of the North Fork of the Breitenbush River at Bald Butte and Breitenbush Mountain, 2000 feet (610 m.). The extensive sheets to the north are less thick, ranging from 300 to 600 feet (90-185 m.). The 2200 foot (670 m.) section at Mount Mitchell, along the Oake Grove Fork of the Clackamas River, represents a major older High Cascade volcanic center.

Remnant paleomagnetic polarity was determined for most of the lava flows of the Older High Cascade Group. The group has both normal and reversed polarity. These determinations are summarized in Table XII. Several lava successions have magnetic reversals within their sections, yet show no erosional stratigraphic break between lavas of different polarity. For example, the basal Battle Ax basalt lavas are reversed; dikes cutting these lavas are normal, and the upper lavas are normal.

The Older High Cascade Group includes some of the Outerson volcanics, most of the Minto lavas, and all of the Battle Ax lavas of Thayer (1936, 1937, 1939). It also includes the Triangulation Peak volcanics and Coffin Mountain flows of Rollins (written communication, Nov. 15, 1974) and the Triangulation Peak and Collawash volcanics of Clayton (1976, p. 43-48). However, the age relationship for Clayton's units are reversed in this report; the Triangulation Peak lavas are considered younger than the Collawash because the former cap on upland surface and have normal remnant magnetic polarity. The Devils Peak ridge occurrence of Collawash volcanics (Clayton, 1976) is included in this report in the Outerson Formation. They are lithologically more similar to Outerson basalt than High Cascade basalt.

Younger High Cascade Volcanic Rocks (Qb)

Younger High Cascade volcanic rocks form a continuous sheet of deposits capping the crest of the range. Most are a series of coalescing lavas from a number of broad low-profile but voluminous shield volcanoes. Some lavas form cappings atop long ridges extending westward from the crest. A few form thick intracanyon lava flows. The major deposits and their volcanic centers are listed by age, geographic and approximate stratigraphic position, in Table XII. Volcanic centers, and their approximate thickness of deposits, from south to north, are: Turpentine Peak, 800 feet (245 m.); Marion Peak, over 500 feet (152 m.); Minto Mountain - Bingham Ridge, 1200 to 1500 feet (365-455 m.); ridge at Firecamp Lakes - Sentinel Ridge - Woodpecker Ridge, 900 to 1600 feet

(275-490 m.); Sisi Butte, about 2000 feet (610 m.); and Peavine Mountain, 800 feet (245 m.). Intracanyon lava flows, and their thicknesses, are: Marion Creek Basalt, 200 to 400 feet (61-122 m.) in the valley of the same name; Santiam Basalt (Thayer, 1936, 1937, and 1939) 400 to 1000 feet (122-305 m.) in the valley of the North Santiam River; and an unnamed remnant, about 200 feet (61 m.) originating probably from Sisi Butte, in the Clackamas River valley east of Austin Hot Springs.

The oldest younger High Cascade lava flow, of light-gray, platy, aphyric, fine-grained andesite, underlies Pine Ridge northwest of Turpentine Mountain. It forms a prominent rim 150 feet (46 m.) overlooking the North Santiam River and Marion Creek valleys. Its source is unknown, presumably to the east, beneath Turpentine and Marion Peaks or the Cascade crest.

Most of the occurrences mentioned above were included on Thayer's (1936, 1937, 1939) maps as Minto basalts. His Olallie Basalt is preferably restricted to the young High Cascade volcanic rocks occurring at Olallie Butte itself, which lies outside the project area. Rollins (oral communication, Aug. 15, 1975) mapped the occurrences at Bingham Ridge and Minto Mountain and Woodpecker Ridge as Minto Basalt. He considered the lava flows at Sentinel Ridge and the intra-canyon Santiam Basalt as the same; like Thayer (1939, p. 18) he believes that the lavas entered the North Santiam valley at Whitewater Creek and spread both down and up the valley. The top of the lava decreases from 3600 feet elevation near the confluence of Whitewater Creek and the Santiam River to 2300 feet at Idanha. Elevations atop the remnant lava extending up from Whitewater Creek range nonuniformily from 2800 to 3400 feet. Inasmuch as the Santiam Basalt varies in lithology, the basalt could have come from several sources, from the Marion Creek valley as well as from Park Butte volcano, north of Mount Jefferson, via Sentinel and Woodpecker Ridges.

All younger High Cascade lava flows and their source areas in the map area are extensively glaciated by the last glaciation, probably equivalent to the Suttle Lake advance (Scott, 1974) and Evans Creek stade of Fraser glaciation between about 12,500 and 20,000 years ago (Crandell and Miller, 1974). Thin lava flows in the upper Clackamas River valley, between Sisi Butte and Cub Creek, are interstratified with fresh till and may be the youngest High Cascade volcanic rocks in the area, having been derived from the numerous volcanic centers west of Olallie Butte.

Mount Jefferson Volcanic Deposits (Qj)

At least two post-glacial (younger than about 12,500 years) deposits from Mount Jefferson extend into the map area. The larger consists of an avalanche deposit which fills the central encised channel of Whitewater River, fans out across the North Santiam River valley and into the narrow constriction downstream from the confluence with Whitewater Creek. Over 80 feet (24 m.) is exposed in the banks of the North Santiam River. A small quarry in the NW¼ NE¼ SW¼ sec. 28, T. 10 S., R. 7 E., off U.S. Forest Service road # 1044 (Woodpecker Ridge road) exposes the following section:

3. Brownish gray silt		1-2 ft. (0.3-0.6 m.)
2. Yellowish gray granule-conglomeratic silt. .		3 ft. (0.9 m.)
1. Medium light gray volcanic breccia; subangular to angular lithic clasts; texture with very little fines; base not exposed.	Over	20 ft. (6 m.)
Thickness measured.	Over	25 ft. (7.5 m.)

The deposit shows faint stratification. All lithic clasts are from Mount Jefferson. Most are fresh; many are iron-stained, deeply altered vitrophyre. The deposit laps against boulder till on the south. It is a probable avalanche deposit.

The second deposit consists of a mudflow which descended the channel of Milk Creek to Grizzly Creek. It blocked Pamelia Creek to form Pamelia Lake. The lake is drained by several springs a short distance downstream. The deposit, as exposed in the banks of Pamelia Creek, consists of crudely stratified debris with a light gray sandy matrix. Its thickness is estimated at less than 100 feet (30 m.).

Surficial Deposits

Surficial deposits, consisting of glacial drift, landslides, talus, and alluvium, are shown separately on the map (Pl. 1) and described briefly in this order. All slopes are mantled by a thin cover of colluvium, consisting of mixed talus, soil, and glacial deposits.

Glacial Deposits (Qjt, Qjo, Qst, Qso)

An attempt has been made to recognize and map separately older and younger glacial deposits. The older deposits, consisting of both till (Qjt) and outwash gravels (Qjo) are recognized by an overlying "smoothed" topography and an upper oxidation zone over 5 feet (1.5 m.) deep containing clasts with thin weathering rinds near the surface. They are not recognized extensively or have been inadvertently mapped with younger deposits. Till is questionably recognized on the upland surface on the divide between Oak Grove Fork and the Clackamas River in the High Rock quadrangle. A small moraine is preserved at Sand Creek on the Hot Springs Branch in the Battle Ax quadrangle. Outwash gravels lie at a higher topographic level beyond the terminal moraine in Humbug Creek in the Battle Ax quadrangle. These deposits are probably equivalent to the Jack Creek

Drift (Scott, 1974) or Hayden Creek Drift of Salmon Springs Glaciation, more than 35,000 years ago (Crandell and Miller, 1974).

Younger deposits (Qst, Qso), till and outwash respectively, occur extensively. They mantle all valley floors and the north-facing slopes of ridges and mountains. The deposits underlie hummocky terrain, commonly mantled by boulders and/or loess. Roadcuts and stream banks expose fresh gravels or till. The younger deposits are probably Suttle Lake Drift (Scott, 1974) or Evans Creek Drift, of early Fraser Glaciation, between 12,500 and 20,000 years ago (Crandell and Miller, 1974).

Crest lines of moraines were plotted on field maps but not transferred to the final map (Pl. 1). Terminal moraines were recognized at Pot Creek on the Oak Grove Fork and at Pot Creek in the upper Clackamas River valley, High Rock quadrangle; at Thunder Creek in the Hot Springs Fork, and possibly at Russ Creek in the upper Collawash River valley, and East and West Humbug Creeks, Battle Ax quadrangle; at Cleator Bend on the Breitenbush River, Breitenbush Hot Springs quadrangle; the junction of Divide Creek in the Blowout Creek valley, Detroit quadrangle; and at the confluences of Marion, Minto, Pamelia and Whitewater Creeks with the North Santiam River, Mount Jefferson quadrangle. An extensive series of outwash terrace deposits lies downstream from the moraines in the Breitenbush and North Santiam River valleys.

Thicknesses of the glacial deposits are unknown. Estimations, based on heights of deposits exposed in cuts, range from 20 to more than 100 feet (6-30 m.). They cover 5 to 25 percent of the surface area, the greater amount atop High Cascade volcanic rocks.

Landslides (Qls)

Landslides cover extensive areas within the map area, ranging from 5 to 25 percent. They are most numerous in areas underlain by the Western Cascade Group, especially the Bull Creek beds and Breitenbush Tuff. Slides over 1 square mile (2.6 km.) are common. Several were active (1974) in the Clackamas-Collawash River and Outlaw Creek areas. Data on the thickness of landslide debris was not obtained, but is estimated to be up to and probably over 100 feet (30 m.) in the large slides.

Talus (Qta)

Talus deposits are locally extensive, especially where glaciation has steepened valley walls of well jointed rock - for example, the Columbia River Basalt. The most extensive talus deposits occur beneath outcrops of the basalt along the slope west of Mount Mitchell overlooking Oak Grove Fork.

Alluvium (Qal)

All valley bottoms are covered by a variable thickness, from a few feet to locally over 100 feet (30 m.) of fluvially deposited gravels, sand and silt. Much alluvium consists of reworked glacial outwash. Several high level stream-cut terrace deposits of alluvium occur, especially along the Clackamas River upstream from where it has been blocked by landslides in the Fish Creek Mountain quadrangle.

STRUCTURE

Introduction

With some major stratigraphic contacts yet to be resolved, the complete structural picture of the project area remains unclear. Several broad fold axes and discontinuous faults are shown in the map (Pl. 1). Folds will be briefly described first, then faults, lineations, and lastly some general observations.

Folds

A complex fold pattern in Western Cascade strata extends approximately north-south through the area. The principal fold is the Breitenbush anticline, recognized by Thayer (1936). It is a broad asymmetrical open fold; the east flank dips 10° to 30° E, the average being 15°. The west flank dips 20° to 70° W., averaging 25°. Its trend northward into the Collawash River is undelineated; the plunge is estimated to be 10° N.

Southward the fold passes through Boulder Ridge into the North Santiam River valley. At Boulder Ridge it is offset by the north-south Boulder Creek fault. To the south it plunges about 10° S., 15° W., passing into the Blowout

Creek valley, where it appears to be truncated by a N. 70° W. trending fault zone. From there the same fold may continue S. 40° E. as the Hawkins Creek anticline, swinging southward to about S. 10° W., plunging about 10° beneath Scar Mountain - Trappers Butte into the Pyramid Creek area.

The Breitenbush anticline culminates at Boulder Ridge, where it lies immediately east of the center of the Hall Ridge pluton (Thayer, 1939). The arcuate trend and reverse plunge of the fold is possibly due to the upward and lateral displacement of Western Cascade strata by the pluton and associated Bull of the Woods intrusive complex. The last deformation of the fold is marked by the uplift and slight eastward tilting of the Outerson Formation. All strata, which formed are large shield volcano complex, were tilted eastward. The volcanic rocks of the High Cascade Group overlie the eastern homoclinal flank of the fold. The strata of the Western Cascade Group continue to dip eastward beneath the crest of the Cascade Range.

The north-south fold trend is recognized in the Collawash River area. There the two main folds plunge about 10-15° N., 45-60° W. The Blitzen Creek anticline exposes beds of Detroit in its core, along the east side of upper

Collawash River. This fold is approximately symmetrical; the southwest flank dips 15-30°, the north flank 20-45°. The fold plunges about 15° N., 60° W., but either flattens abruptly or is terminated by a yet unrecognized fault because it is not traceable in the valley of the Hot Springs Fork of the Collawash River.

To the north the Rod Creek anticline lies between Fish Creek Mountain and the Collawash River. This fold exposes Breitenbush Tuff. Its axis is truncated by the Austin Point pluton and vitrophyre of Trout Creek. The fold plunges 10° N., 45° W. The northeast flank dips 15-50° NE., the southwest 15-40°, making an open symmetrical fold. However, the syncline separating the two anticlines is located close to the axis of the Rod Creek fold, suggesting that the fold is asymmetric with a steeper southwestern flank. All these folds can be traced southeastward into Rhododendron Ridge, precluding the existence of a possible fault running the length of the Collawash River valley.

The minor folds, Gold Butte anticline and Pansy Basin syncline, on the western flank of the Breitenbush anticline, separating it from the trough of the Sardine syncline (Thayer, 1936), appear to continue northward into the area of the Hot Springs Fork. Lack of traceable stratigraphic units and bedding attitudes in the area preclude an accurate structural interpretation.

Faults

Some faults are delineated by displacement of stratigraphic contacts. Others are suspected and should be checked. Very likely a number of significant faults have not so far been detected. Not all faults shown on the maps of Dyhrman (1975) and Clayton (1976) are shown in the map (Pl. 1).

Inasmuch as all Western Cascade strata cut by faults are warped, folding clearly preceded faulting; although the two probably occurred concomitantly in the final stages of deformation which appears to have culminated between deposition of the Outerson Formation and Columbia River Basalt.

Two stages of faulting are recognized, an earlier trending northwestward and a younger trending north-south. A fault zone trending N. 60° W. lies parallel to lower Blowout Creek. Outcrops are sparse and landslides are abundant in the area so the relationships are not clearly evident. The zone is about 2 miles (3.6 km.) wide and consists of an uplifted block of beds of Detroit. Breitenbush Tuff has been eroded from the east end of the block and Detroit beds are overlain by Cub Point Formation, a relationship indicating that faulting occurred prior to deposition of Cub Point Formation. Beds of Detroit were probably rotated by left lateral strike-slip displacement of about 5 miles (8 km.) within the fault zone; the Breitenbush anticline was displaced to the east and continues southward as the Hawkins Creek anticline. The fault zone passes southeastward beneath Coffin Mountain and is not recognized in the North Santiam River valley. The fault probably continues northwestward of the project area to Detroit Lake. It is suspected that the fault zone may be a structural weakness into which the Hall Ridge pluton was emplaced, or the zone was created in response to emplacement of the pluton.

A parallel fault zone probably exists in the North Santiam River valley between Detroit Lake and Mount Bruno. The zone is an uplifted block or horst, bringing beds of Detroit into juxtaposition with Breitenbush Tuff. The axis of the Breitenbush anticline is not displaced; no strike-slip movement is apparent. Yet this zone is likewise probably related to plutonic emplacement west of Detroit Lake.

To the north, several northwest to east-west trending faults have been mapped by Dyhrman (1975, p. 58-59) in the area of the Hot Springs Fork. He notes three small faults of minor displacement trending N. 40° W. between Hugh Creek and Hot Springs Fork. Two larger approximately east-west faults are traceable 3 to 4 miles (4.8-6.4 km); yet evidence for these faults is unequivocal. The northern or Bagby Hot Springs fault cuts Nohorn Formation; its displacement is estimated to be 330 feet (100 m.). The southern Pansy Creek fault cuts Nohorn Formation. Its displacement is estimated to be 500 feet (150 m.).

North-trending faults were formed in association with High Cascade volcanism because many basalt volcano centers are aligned northward on the faults, as readily apparent in the Olallie Butte area just east of the map. The faults served as conduits for the volcanoes. Several north to N. 20° W. trending faults have been delineated in the northeastern part of the area where High Cascade basalt lies in juxtaposition with Rhododendron Formation and Columbia River Basalt. The faults extend about 10 miles (16 km.) and have alternate downthrown sides; no uniform sense of displacement is evident.

The faults are listed below, from west to east, with sense and estimated amount of displacement:

Fault	Sense of Displacement	Amount (ft./m.)
Austin Hot Springs	E. side up	400/122
Granite Creek.	E. side down	400/122
Sam Creek.	E. side down	200/61
Kink Creek	E. side down	200/61
Devils Springs	E. side up	600/183
Cabin Creek.	E. side down	300/91
Peavine Mountain	E. side up	800/244

Boulder Ridge fault zone is a major north-south structure lying west of the High Cascades. It extends from the North Santiam River near Idanha across Boulder Ridge, along Cultus Creek, across the Breitenbush River and probably northward into Humbu Creek, a distance of about 6 miles (9.7 km.). In crossing Boulder Ridge, it subparallels the axis of the Breitenbush anticline. The east side has been down-dropped about 1000 feet (305 m.) and displaced southward about 2500 feet (760 m.). The anticline has been offset to the east.

Clayton (1976, p. 55-59) has mapped several north-trending faults in the Breitenbush Hot Springs area. The west side of the faults is generally down-dropped. The Scorpion Creek fault, contrarily, has down-dropped Breitenbush Tuff, on the east, into juxtaposition with beds of Detroit. The displacement is about 250 feet (75 m.).

The complex stratigraphic relationships just north of Breitenbush Hot Springs may be attributed to north-south faults. The bedrock is extensively covered by glacial deposits and landslides, precluding their determination. One suspected fault lies just east of the area mapped as Outerson tuff (Clayton, 1976, p. 36-39); see previous discussion in this report on Breitenbush Tuff).

Lineations

A lineation map, scale 1:250,000, of the northern Oregon Cascade Range was prepared from enlarged ERTS imagery by Robert Lawrence and James Carter, Department of Geology, Oregon State University. Most of the lineations appear to be ridges or straight stream courses. The ridges are parallel to strike of the warped strata (for example, Rhododendron Ridge), straight stream courses parallel to long joint sets (for example, Hot Springs Fork and Dickey Creek). A few north-south lineations are aligned High Cascade volcanic centers. One lineation in the project area does coincide with the north-south Boulder Ridge fault. None of the few short, less than 2 km., lineations plotted by Clayton (1976) coincide with those plotted on the ERTS imagery. Unfortunately, the lineation map has not supplied answers to the interpretations of structures in the project area.

Some General Observations

High Cascade Graben or Volcano-Tectonic Depression. The lack of a through-going north-south normal fault or series of parallel to en echelon faults, with down-faulted east sides, in the map area (Pl. 1) is evidence for the lack of a continuous crestal High Cascade graben or volcano-tectonic depression. A Cascade fault, so named by Thayer (1936, p. 708-711) was postulated to trend N. 10^{o} E. from between the North Santiam River and Minto Mountain to between Collawash Mountain and Bald Butte. It had a supposed throw of at least 2000 feet (610 m.). On subsequent maps (Thayer, 1937, 1939) the fault is not plotted; Thayer apparently had second thoughts on the existence of the fault.

The idea of a crestal graben or volcano-tectonic depression was proposed by Allen (1966) based on comparison with other Cenozoic volcanic chains and the possible existence of a Hood River graben. The depression was believed to contain most of the High Cascade volcanic rocks. But no fault has been detected in the location of the hypothetized Cascade fault during the course of this mapping project. Furthermore, the Western Cascade strata can be traced uninterruptedly eastward into the deep glaciated valleys just west of Mount Jefferson, indicating that the Western Cascade Group pass beneath the High Cascade Group and the crest of the range.

A series of normal north-trending faults do exist in the northern part of the area but none is traceable southward beyond the Clackamas River valley. Here the faults separate alternate down-dropped blocks. Rather than border the High Cascade volcano-tectonic depression, the faults may mark the zone of the Portland Hills - Brothers fracture zone lineament (Lawrence, 1976). In crossing the Cascade Range, the lineament is a zone of small scale en echelon tensional faulting. The range is spreading apart, perhaps as much as 1 km., along a northwest-trending zone of right-lateral displacement. The faults are the locii for Quaternary basaltic volcanism and Austin Hot Springs.

Arching of the Cascade Range. Based on Peck and others' (1964) map, Wheeler and Mallory (1970) have attempted to show that Peck and associates mismapped Columbia River Basalt, that remnants of the basalt have been included in Peck's Sardine Formation or High Cascade volcanic rocks, that it originally extended across the region of now the northern Oregon Cascade Range, and lastly, that the basalt was arched during uplift of the Cascade Range in Late Cenozoic.

This mapping project indicates that Peck and others (1964) were accurate in their delineation of Columbia River Basalt, and as expressed previously in this report, the basalt is a stratigraphic marker unit in the upper Western Cascade Group. It does not extend south of the Clackamas River area along the crestal portion of the range.

Evidence has been found to suggest strongly that the Cascade Range was a site of almost continuous volcanic accumulations during the Middle Cenozoic, possibly even longer in time, from Early Cenozoic. The High Cascade volcanism perhaps marks a major reversal to this process with uplift occurring on the order of 1 to 2 km. at the Cascade crest within the last 6 million years. This amount of uplift is a small part of the more than 6 km. of depression, shown in the accumulation of volcanic strata by Late Miocene. In this sense, Wheeler and Mallory are correct.

But the internal structures of the Cascade Range are a good deal more complex than simple downwarping and succeeding arching. This mapping project, because of its emphasis on stratigraphy, is just beginning to show the complexities of its internal structure and, also an important consideration, the varied paleogeomorphic surfaces. Major structures superimposed by the north-south axis of the Cascade Range uplift, are now evident. One is a large structural basin which extends from the Clackamas-Breitenbush Rivers divide northward beneath Mount Hood and the Columbia River to about the Lewis-Cispies Rivers divide in the southern Washington Cascade Range. The extent of Columbia River Basalt in the Cascade Range, underlain by Eagle Creek Formation, and its probable Bull Creek beds equivalent, outlines this basin. The structural low is postulated as centered west of Mount Hood at about Bull Run. It is tentatively named the Mount Hood structural basin. The structural high at the south border of the basin is transverse to the Cascade axis, running from Mount Jefferson to Detroit Lake and beyond. South of this structural "ridge" folds plunge southward. This "ridge" is tentatively named the Mount Jefferson structural high. After more stratigraphic control is obtained, various stratigraphic horizons can be contoured to determine the time of existence and amount of closure on this structural feature. Eventually they will be further defined by gravity surveying.

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