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GEOLOGICAL SURVEY PROFESSIONAL PAPER 449

Prepared in cooperation with the State of Oregon, Department of Geology and Mineral Industries

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By DALLAS L. PECK, ALLAN B. GRIGGS, HERBERT G. SCHLICKER,
FRANCIS G. WELLS, *and* HOLLIS M. DOLE

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By Dallas L. Peck, Allan B. Griggs, Herbert G. Schlicker, Francis G. Wells, and Hollis M. Dole

ABSTRACT

This report presents a description of the stratigraphy, structure, and petrology of the volcanic rocks of the central and northern parts of the Western Cascade Range of Oregon. The study is a part of a long-range cooperative program between the U.S. Geological Survey and the Oregon State Department of Geology and Mineral Industries to prepare a geologic map of Oregon. The map area, about 7,500 square miles, lies in the densely forested western slope of the Cascade Range. It is bounded approximately by lat 43° N. and lat 45°30′ N. on the south and north, the crest of the range on the east, and long 123° W. and the edge of the Willamette Valley on the west. The geology, which was mapped by reconnaissance methods, is chiefly based on examination of rock exposures along roads.

The Cascade Range in Oregon comprises two physiographic divisions: the Western Cascade Range, which includes a wide, deeply dissected belt of volcanic formations making up the western slope of the range, and the High Cascade Range, which includes chiefly younger cones and lava flows forming the nearly undissected crest of the range. The volcanic rocks of the Western Cascade Range are deformed and partially altered flows and pyroclastic rocks that range in age from late Eocene to late Miocene, as determined chiefly from fossil plants from more than 50 localities. These volcanic rocks overlie or interfinger westward with marine sedimentary rocks, and in the southwestern part of the map area they overlie pre-Tertiary plutonic and metamorphic rocks of the Klamath Mountains.

Rocks of Eocene age are exposed along the foothills of the Cascade Range south of Eugene. They include the marine Umpqua, Tyee, and Spencer Formations, which consist of sandstone, mudstone, conglomerate, and interbedded basaltic flows and pyroclastic rocks, and the overlying Colestin Formation of late Eocene age, which consists chiefly of pyroclastic rocks and flows of basaltic andesite and pyroxene andesite that total as much as 3,000 feet. The overlying Little Butte Volcanic Series of Oligocene and early Miocene age, which has an average thickness of 5,000 to 10,000 feet, consists of (1) massive beds of vitric andesitic and dacitic lapilli tuff, (2) less abundant flows and breccia of basalt and andesite, (3) welded tuff, domes, and flows of dacite and rhyodacite, and (4) rhyodacitic tuff. The basalt and andesite typically contain phenocrysts of altered olivine and diopsidic pyroxene in a fine-grained groundmass containing little glass. Along the foothills north of Dorena dam, strata of the Little Butte interfinger with marine sandstone and tuff of middle Oligocene age, and still farther north with strata of late Oligocene and early Miocene age. Middle Miocene Columbia River Basalt, which unconformably overlies these strata in northern Oregon, consists of as much as 1,500 feet of dark gray columnar-jointed flows of distinctive, very fine grained basalt that contains abundant glass, plagioclase, augitic pyroxene, and chlorophaeite, but little or no olivine. The overlying Sardine Formation of middle and late Miocene age, which averages 3,000 feet thick, consists chiefly of flows and tuff breccia of andesite that contains abundant phenocrysts of plagioclase and hypersthene in a dark aphanitic groundmass. Between Molalla and Troutdale the Sardine Formation is overlain unconformably by more than 1,000 feet of fluviatile conglomerate, sandstone, and siltstone of the Pliocene Troutdale Formation. The overlying Boring Lava and volcanic rocks of the High Cascade Range, of Pliocene and Quaternary age, consist mostly of unaltered and undeformed flows of porous-textured nonporphyritic gray basaltic andesite and olivine basalt.

The volcanic rocks of the Western Cascade Range are cut by small intrusive bodies of fine- to medium-grained rocks that range in composition from rhyodacite to basalt. The medium-grained intrusive bodies are bordered by contact metamorphic aureoles of dark flinty hornfels and are surrounded by more extensive areas of propylitically altered rocks. Medium-grained intrusives, areas of propylitic alteration, and metalliferous deposits are mostly limited to a narrow northward trending belt. Throughout most of the Western Cascade Range, pyroclastic rocks are devitrified to fine-grained aggregates consisting chiefly of zeolite (clinoptilolite or mordenite) and montmorillonitic clay or celadonite.

The volcanic rocks of the Cascade Range fill a broad northward-trending downwarp. In the central and northern parts of the Western Cascade Range in Oregon, the structure is dominated by several northeast-trending folds—the en echelon Mehama and Clackamas anticlines, the Sardine syncline, and the Breitenbush anticline. Farther south, in the drainage basins of the Middle Fork of the Willamette River and the North Umpqua River, the rocks dip mostly to the east, and northwest-trending faults are the major structural feature.

The calc-alkalic volcanic rocks of the Western Cascade Range in Oregon have a total volume of about 25,000 cubic miles and an average composition of silicic andesite or dacite. Andesite that has a silica content of about 56 percent is the most abundant rock type; rocks containing 63 to 68 percent silica are sparse, and rocks containing about 70 percent silica are moderately abundant. Most of the volcanic activity in the Cascade Range was apparently concentrated in northward-trending belts, which in general shifted progressively eastward during the Cenozoic.

Most of the volcanic rocks are thought to be formed by crystal fractionation of four or five successive magmas (or groups of similar magmas) which ranged in composition from basalt to dacite.

INTRODUCTION

SCOPE OF INVESTIGATION

A geologic reconnaissance of the Western Cascade Range in Oregon was made during the summer months of 1954, 1955, 1956, and 1957 by geologists of the U.S. Geological Survey and of the Oregon State Department of Geology and Mineral Industries, as part of a continuing cooperative project to prepare a geologic map of the State of Oregon. Emphasis was placed on determining the gross aspects of the volcanic stratigraphy, the geologic structure, and the distribution of major geologic units.

LOCATION, ACCESSIBILITY, AND CULTURE

The area studied covers most of the central and northern parts of the western slope of the Cascade Range in western Oregon (fig. 1). The area includes about 7,500 square miles in Multnomah, Clackamas, Marion, Linn, Lane, and Douglas Counties, and is bounded approximately by the crest of the Cascade Range on the east, long 123° and the border of the Willamette Valley on the west, lat 43° on the south, and lat 45°30′ on the north. Topographic quadrangle maps are available for all of the area, and almost all of the area is covered by modern maps at a scale of 1 : 62,500.

The area is traversed from west to east by a rail line of the Southern Pacific Co. and the following paved roads: U.S. Highways 126, 20, and 26; Oregon State Routes 58 and 22; and by unnumbered roads along the North Umpqua and Clackamas Rivers. Additional access is provided by a network of county, U.S. Forest Service, and private roads. The intensive logging activity during the last 20 years has so increased the

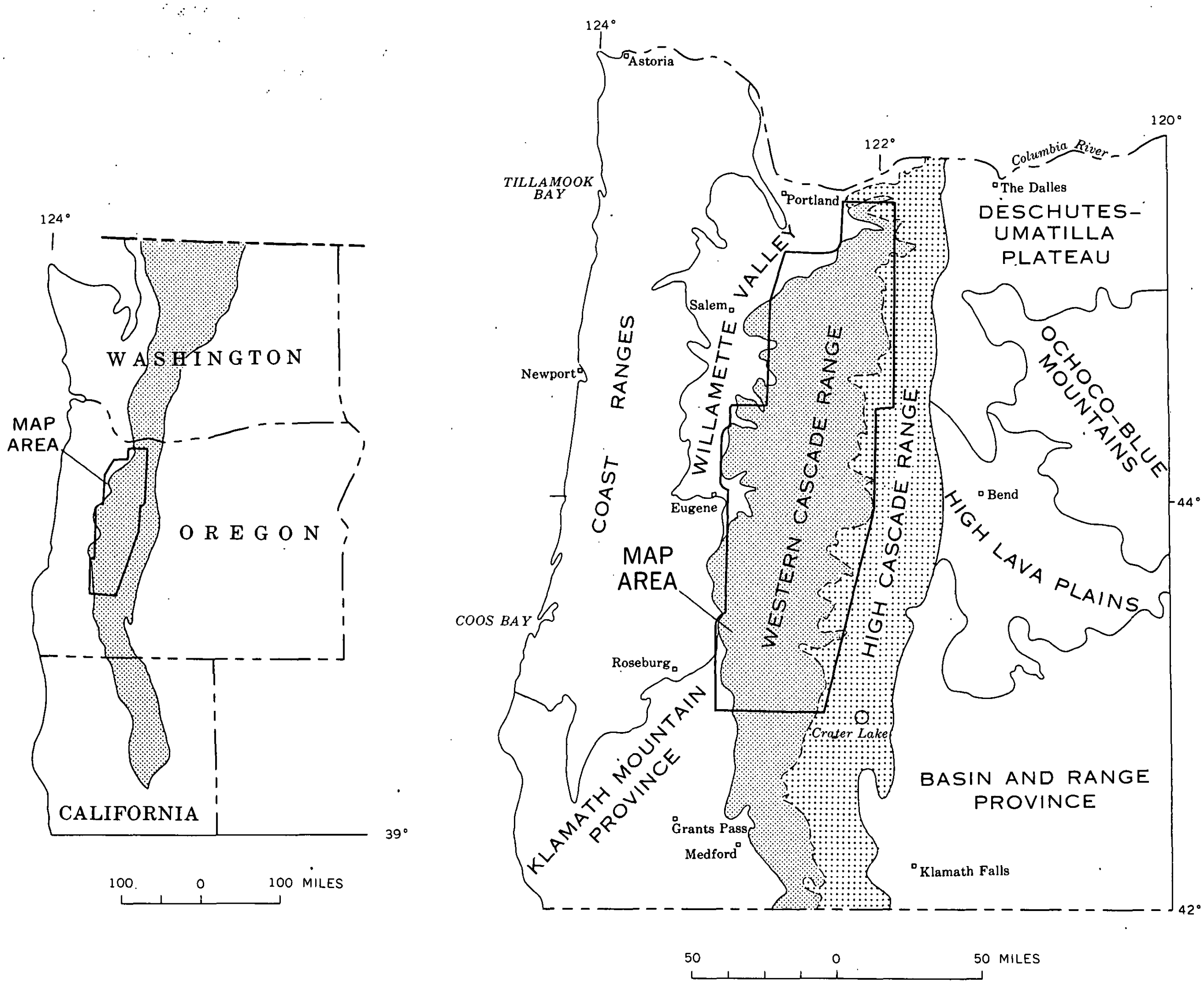

FIGURE 1.—Index maps. Left, location of Cascade Range and map area in the Pacific Northwest. Right, physical divisions of central and western Oregon.

accessibility that few points in the area are more than 6 miles from a road.

The Western Cascade Range in Oregon is sparsely settled. The population is concentrated along the major stream valleys and in the lower foothills. Springfield, a city of 16,000 contains about one-third of the total population. Towns of more than 1,000 population are Sweet Home, Mill City, Molalla, Brownsville, and Oakridge. Logging and processing of timber are the chief industries; diversified farming is practiced along the major stream valleys.

PHYSICAL FEATURES

The Cascade Range extends almost due north from northern California to British Columbia (fig. 1). The segment of the range in Oregon is 250 miles long and 30 to 70 miles wide. It is crossed by only one stream, the Columbia River. The range is unsymmetrical in cross section: the long western slope descends irregularly to the north-trending Willamette Valley and to several smaller valleys near Roseburg and Medford; the range merges with the Coast Ranges and the Klamath Mountains in several areas between Cottage Grove and Medford. The short eastern slope descends smoothly to the Deschutes plateau, the Klamath basin, and the intervening high lava plains.

The area along the crest, called the High Cascade Range, is characterized by gentle constructional volcanic slopes. The Western Cascade Range, which forms most of the western slope, is in contrast maturely dissected, as shown in figure 2.

In the Western Cascade Range a dendritic drainage is developed on the slightly folded and partially altered Tertiary volcanic rocks. Narrow stream valleys at altitudes of 500 to 2,000 feet are separated by long acute ridges, the crests of which are at altitudes of 3,000 to 5,000 feet. Slopes of 10° to 20° are common. In the foothills adjacent to the Willamette Valley the

FIGURE 2.—Oblique aerial photograph of a part of the crest and western slope of the Cascade Range in northern Oregon. View looking southeast. Quaternary volcanic peaks that project above the smooth crest of the High Cascade Range along the skyline are from left to right Olallie Butte, Mount Jefferson (center), Three Fingered Jack, and the Three Sisters. In the foreground are the deeply dissected, heavily forested slopes of the Western Cascade Range. The headwaters of the South Fork of the Clackamas River are in the lower left corner. Photograph by Delano Studios.

ridges are rounded and the valleys wider. The upper parts of most of the major stream valleys are glaciated, and glacial cirques are common on the peaks above 3,000 feet in the northern part of the range and above 5,000 feet in the southern part. A few partially dissected volcanoes of Pliocene and Quaternary age cap some of the drainage divides. Lavas from these volcanoes and from volcanoes in the High Cascade Range have flowed part way down some of the valleys; the partially dissected remnants of these lavas form benches and mesas along the valleys.

The High Cascade Range consists of a plateau of basalt and andesite capped by overlapping shield volcanoes, strato-volcanoes, cinder cones, and other volcanic forms, all in various stages of dissection. The drainage is mostly consequent on the constructional volcanic surfaces. In general, the relief is less than in the Western Cascade Range, and slopes of 5° and less are common. Glaciers have modified many of the peaks and have deepened and widened some of the major stream valleys. Intracanyon lava flows fill most of the valleys and have erased much of the former high relief.

CLIMATE AND VEGETATION

The climate of the western slope of the Cascade Range is characterized by warm dry summers and cold wet winters. In most of the area, normal annual precipitation ranges from 40 to 50 inches, and normal annual temperature ranges from 42° to 52° F (Wells, 1936). Much of the precipitation is in the form of snow in the higher parts of the range, and small glaciers are present on several of the peaks.

Dense stands of Douglas-fir and hemlock, which are actively being logged, cloak most of the western slope of the Cascade Range; these trees reach up from a luxuriant undergrowth of ferns, salal, Oregon grape, and other plants (fig. 2). The remaining areas are covered by brush and cultivated fields. Natural rock exposures make up less than 1 percent of the Western Cascade Range and are chiefly limited to ridge crests, stream canyons, and the few small areas above timber line. The rocks are locally well exposed in roadcuts along the highways and logging roads.

FIELDWORK AND RELIABILITY OF THE GEOLOGIC MAP

The mapping technique of this investigation was road reconnaissance that in general consisted of examining roadcuts at intervals averaging ¼–½ mile. A few supplementary foot traverses were also made. All lines of traverse are shown on plate 1. An average of 100 square miles of country were mapped each week in the field by each geologist. The geology was plotted by inspection on 1 mile to an inch and 2 miles to an inch U.S. Geological Survey topographic quadrangle maps; these maps were supplemented by planimetric maps prepared by the U.S. Forest Service, county protective associations, and private companies. The geologic map (pl. 1) is adapted in part from earlier maps, the outlines and authors of which are shown in the accompanying index map.

A total of 18 man-months was spent in the field by D. L. Peck, A. B. Griggs, F. G. Wells, and R. D. Brown, Jr., of the U.S. Geological Survey, and by H. G. Schlicker and H. M. Dole, of the Oregon State Department of Geology and Mineral Industries. During the summer of 1954, Wells and Peck mapped the Red Butte and Mace Mountain quadrangles, and Dole mapped parts of the Marcola, Leaburg, and Lowell 30-minute quadrangles. In the summer of 1955, Griggs and Peck mapped the area north of lat 44°15′. During the summer of 1956, Schlicker and Peck completed the mapping of the Marcola, Leaburg, and Lowell quadrangles, and Peck finished mapping the rest of the area south of lat 44°15′. R. D. Brown, Jr., mapped part of the Glide quadrangle. In the summer of 1957, Peck field-checked part of the area and collected samples.

During the periods from January 1958 to May 1959, November 1959 to May 1960, and February to April 1962, Peck transferred the mapping with the help of Esther McDermott to a base prepared by enlargement of Army Map Service topographic sheets, studied the rock samples and field notes, and prepared this report.

The reliability of the geologic map (pl. 1) varies from place to place and depends on the distinctiveness of the geologic units, the abundance of rock exposures, and the access. The most distinctive units are the Columbia River Basalt, the volcanic rocks of the High Cascade Range, and the basal rhyodacitic welded tuff member of the Little Butte Volcanic Series. Except for the basal welded tuff, the lower part of the Little Butte Volcanic Series is very similar lithologically to the Colestin Formation. The Little Butte and the Sardine Formation are distinguished only on the basis of broad lithologic differences; as a result, the reconnaissance mapping, which was done without close petrographic control, did not yield precise contacts between these two units in most of the area. Natural rock exposures become increasingly abundant from north to south in the Western Cascade Range in Oregon. Within the map area, natural exposures are most abundant in the drainage basins of the North and South Umpqua Rivers. During this fieldwork, artificial rock exposures in road cuts were used far more than natural exposures. As a result, the geologic map is much less reliable in those areas where access was limited by lack of roads. The areas most inaccessible in the period 1954 to 1957 were as follows: the divide between the North Umpqua, Rogue, and South Umpqua Rivers; the divide between the Middle Fork of the Willamette River and the North Umpqua River east of Steamboat Creek; the Wilderness area east of the South Fork of the McKenzie River; and parts of the basins of the Middle Santiam River, the Collawash River, the Salmon River, and the Bull Run River.

ACKNOWLEDGMENTS

The late Roland W. Brown assiduously collected most of the fossil floras. His paleontological conclusions helped immeasurably in determining the stratigraphy of the volcanic rocks. Jack A. Wolfe collected and identified several fossil floras and prepared the lists of fossil plants. Mrs. Eleanor Gordon of Salem told us of several critical fossil-plant localities and helped collect from them. Private logging companies, the U.S. Forest Service, the Eastern Lane Forest Protective Association, and the Douglas County Forest Protective Association gave assistance in the fieldwork. We were accompanied in the field many days by Earl Lillard and Fred Sandoz, of the Booth-Kelly Co., and by Jake Smith, of the Eastern Lane Forest Protective Association. We received helpful suggestions from geologists who are actively concerned with the geology of Oregon, such as Parke D. Snavely, Jr., Donald E. Trimble, Aaron C. Waters, Howel Williams, Ewart M. Baldwin, and Richard J. Lutton, and from geologists who toured the map area with us including Marland P. Billings, James B. Thompson, Charles A. Anderson, Robert L. Smith, and Howard A. Powers. George W. Walker, Aaron C. Waters, and Parke D. Snavely, Jr., made available unpublished chemical analyses of rocks from Oregon. The petrographic studies and the manuscript of this report have profited from constructive criticisms by colleagues in the U.S. Geological Survey and by Professors Billings and Thompson, of Harvard University.

ROCK NOMENCLATURE AND PETROGRAPHIC TECHNIQUES

In this report the classification of igneous rocks is based primarily on mineralogical composition, but is guided by pertinent chemical analyses. The classification is the same as that outlined by Williams (in Williams and others, 1954) with one exception: because of the paucity of volcanic rocks containing 63 to 68 percent silica, the rocks containing 58 to 63 percent silica are classified as andesite, even though the analyzed rocks in this range contain more than 10 percent normative quartz and more than one-eighth of their normative feldspar is orthoclase. A major basis of the classification is the sum of the percentage of mafic minerals (modal color index), that is, the sum of olivine, pyroxene, hornblende, biotite, magnetite, and ilmenite; in general, basalt has a color index equal to or greater than 40, andesite has a color index between 15 and 40, and dacite and rhyodacite have color indices less than 15. Rhyodacite is distinguished from dacite primarily on the basis of the composition of the feldspar phenocrysts—dacite contains plagioclase more calcic than An_{30}. The texture and mineral content of the major volcanic rock types are given in table 1. The names applied in this report to the volcanic rock types occurring in the Cascade Range are compared to the names according to other classifications in table 2.

Clastic volcanic rocks, no matter how deposited, are described in terms shown in figure 3, which is adapted from the classifications of Wentworth and Williams (1932), Anderson (1933, p. 220–222), and Fisher (1960a, 1960b). The size classification of Wentworth and Williams (1932) is followed. Volcanic breccia is used as a general term for tuff-breccia, volcanic rubble breccia, and lapilli breccia. Sandstone containing both volcanic and nonvolcanic debris are described using Gilbert's classification (1954, p. 289–297). The color of hand specimens was determined by comparison with the colored chips in the Rock-Color Chart (Goddard, 1948) distributed by the Geological Society of America.

About 600 rock samples were collected throughout the map area by Peck and Griggs. From 300 of these standard-size thin sections were prepared and were examined under a petrographic microscope by Peck. Thirteen of the samples were analyzed chemically, using rapid techniques, by P. L. D. Elmore, S. D. Botts, H. H. Thomas, and M. D. Mack, of the U.S. Geological Survey. Modal analyses of 80 thin sections were made with a point counter. In sections of chemically analyzed rocks 1,000 grains were counted; in most of the other thin sections only 300 grains were counted.

A powdered part of each of the 13 newly analyzed volcanic rocks was fused to a bead in a carbon arc, and the index of the bead determined by oil immersion. When plotted against the analyzed silica content (dry weight) of the rocks, the indices of the beads form a smooth, well-defined curve (fig. 4) similar to the curves determined by Mathews (1951, fig. 2). The silica content of other rocks, particularly andesitic and dacitic tuffs, was estimated from the indices of their fused beads by the use of the determined curve. The results probably are accurate only to ±3 percent silica.

Indices of refraction of mineral grains and fused beads were determined by oil-immersion techniques; standard liquids graduated in intervals of 0.01 were used except for oils between 1.50 to 1.60, which are graduated in intervals of 0.005; the indices were checked with a refractometer at the beginning of the investigation. Only moderate care was taken during most of the measurements of indices of mineral grains, and

TABLE 1.—*Texture and approximate mineral composition of the principal volcanic rock types in the Cascade Range in Oregon*

[Figures in parentheses are averages]

Rock type	Typical megascopic texture	Typical microscopic texture	Samples examined	Modal color index	Phenocryst constituents (percent): Olivine	Pyroxene: Salite	Pyroxene: Augite	Pyroxene: Hypersthene	Hornblende	Biotite	Magnetite and ilmenite
Flows of olivine basalt	Sparsely porphyritic; fine-grained groundmass.	Microporphyritic and seriate; intergranular and subophitic groundmass.	7	40–51 (47)	3–8 (6)	3–16 (10)	--------	0	0	0	Tr.
Flows of porous-textured olivine basalt.	Sparsely porphyritic; fine-grained groundmass; porous.	Subophitic and intergranular; contain abundant minute angular pores (diktytaxitic).	5	41–45 (42)	3–10 (6)	0	0–3 (½)	0	0	0	0–3 (½)
Flows of tholeiitic basalt and tholeiitic andesite.	Nonporphyritic; very fine grained.	Hyalo-ophitic and subophitic	11	18–36 (30)	0–5 (1)	0	0–tr.	0	0	0	0
Flows of basaltic andesite.	Porphyritic; fine-grained groundmass.	Intergranular and pilotaxitic	11	31–38 (33)	1–9 (3)	Tr.–6 (1)		0–4 (Tr.)	0	0	0–tr.
Flows of porous-textured basaltic andesite.	Porphyritic and sparsely porphyritic; fine-grained and aphanitic groundmass; porous.	Intergranular; contain abundant minute angular pores (diktytaxitic).	5	23–38 (29)	3–5 (3)	0	0–1	0	0	0	0–tr.
Flows and tuff of pyroxene andesite.	Flows, porphyritic; aphanitic groundmass. Vitric and vitric-crystal tuff.	Flows, pilotaxitic and hyalopilitic; vitroclastic tuff.	18	15–31 (23)	0–tr.	0	Tr.–6 (1)	Tr.–16 (5)	0	0	Tr.–2
Tuff and flows of dacite	Tuff, vitric and vitric-crystal. Flows porphyritic to aphyric; banded aphanitic groundmass.	Tuff, vitroclastic; flows, pilotaxitic, hyalopilitic, and felsitic.	10	2–5 (3)	0	0	0–2	0–1	0	0	Tr.–2
Tuff and flows of rhyodacite.	Tuff, vitric and vitric-crystal. Flows porphyritic; banded aphanitic groundmass, spherulitic in part.	Tuff, vitroclastic; flows, felsitic	7	2–5 (3)	0	0	0–tr.	0–2	0–1	0–3	Tr.–1

Rock type	Phenocryst constituents (percent)—Con.: Plagioclase: Total	Plagioclase: An content	Sodic sanidine	Quartz	Groundmass constituents (percent): Olivine	Pyroxene	Magnetite and ilmenite	Apatite	Plagioclase: Total	Plagioclase: An content	Cristobalite	Cryptocrystalline material and glass	Chlorophaeite	Minute voids	Units in which rock type is abundantly represented (major unit listed first)
Flows of olivine basalt	5–27 (16)	55–80	0	0	0–3	19–35 (28)	2–4 (3)	Tr.	17–40 (30)	50–60	0–3	3–14 (7)	0	0	Little Butte Volcanic Series.
Flows of porous-textured olivine basalt.	0–tr.	--------	0	0	0–15 (5)	24–33 (27)	0–5 (3)	0–tr.	55–59 (57)	50–60	0–tr.	0–tr.	0	Tr.–7 (2)	Volcanic rocks of the High Cascade Range.
Flows of tholeiitic basalt and tholeiitic andesite.	0–tr.	--------	0	0	0	15–31 (23)	3–9 (6)	Tr.	24–54 (35)	45–55	0	9–52 (28)	0–16 (7)	0	Columbia River Basalt.
Flows of basaltic andesite.	0–48 (20)	55–85	0	0	0–tr.	19–32 (25)	1–6 (4)	0–tr.	19–61 (40)	45–55	0–2	0–16 (6)	0	0	Little Butte Volcanic Series, Colestin and Sardine Formations.
Flows of porous-textured basaltic andesite.	0–36 (11)	60–70	0	0	Tr.–9 (3)	17–24 (21)	Tr.–5 (2)	0–tr.	35–69 (51)	45–55	0–tr.	0–22 (8)	0	Tr.–3 (2)	Volcanic rocks of the High Cascade Range.
Flows and tuff of pyroxene andesite.	7–38 (25)	40–65	0	0	0	9–26 (15)	1–5 (2)	0–tr.	25–53 (36)	30–45	0–14 (1)	2–28 (12)	0	0–tr.	Sardine Formation, Little Butte Volcanic Series, volcanic rocks of the High Cascade Range.
Tuff and flows of dacite.	7–27 (14)	30–55	0	0–tr.	--------	--------	--------	--------	--------	--------	--------	--------	0	0	Little Butte Volcanic Series, Sardine Formation.
Tuff and flows of rhyodacite.	8–35 (22)	15–30	0–4	2–13 (5)	--------	--------	--------	--------	--------	--------	--------	--------	0	0	Little Butte Volcanic Series.

TABLE 2.—*Comparison of the names of the volcanic rock types of the Cascade Range according to different classifications*

This report	Williams (1954)	Rittman (1952)	Johannsen (1939)	Shand (1943)
Basalt	Basalt	Basalt	Basalt	Lime subbasalt.
Basaltic andesite.	Andesite	Pigeonite-labradorite andesite.	do	Lime basalt.
Do	do	Pigeonite andesite.	Quartz-basalt	Soda basalt.
Andesite	do	Andesite	Andesite	Lime andesite.
Do	Dacite	Dark rhyodacite.	Dacite	Soda andesite.
Andesite	do	Rhyodacite	Rhyodacite	Soda dacite.
Dacite	do	Do	Rhyodacite and leucorhyodacite.	Soda rhyolite.
Rhyodacite	Rhyodacite	Quartz-latite		Do

in general the accuracy of the determinations probably does not exceed ±0.003. Optic angles were measured with a 4-axis universal stage and a polarizing microscope by using the conoscopic method; corrections for refraction were made with a graph of Emmons (1943, plate 8). The accuracy probably is ±2° in clinopyroxene and ±3° in orthopyroxene and olivine.

The composition of plagioclase more calcic than An_{50} was determined by measuring extinction angles, mostly in Carlsbad-albite twins, by applying the graphs in Wahlstrom (1955, figs. 22, 26); the results were checked in many samples by measuring Nx and Nz of grains

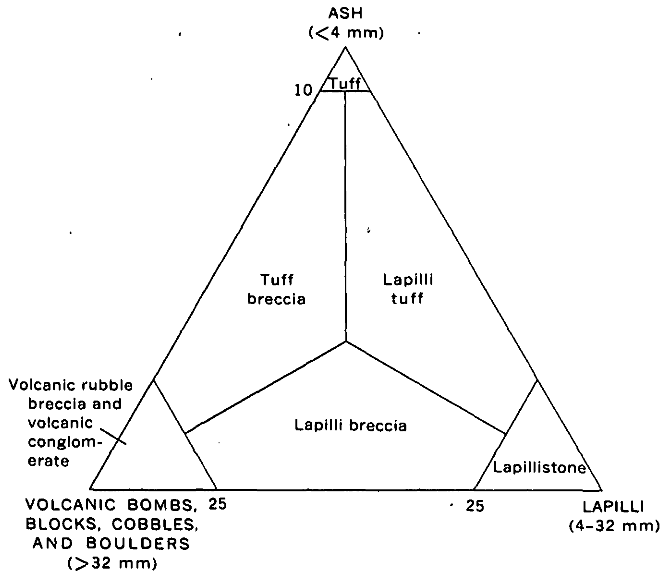

FIGURE 3.—Classification of clastic volcanic rocks.

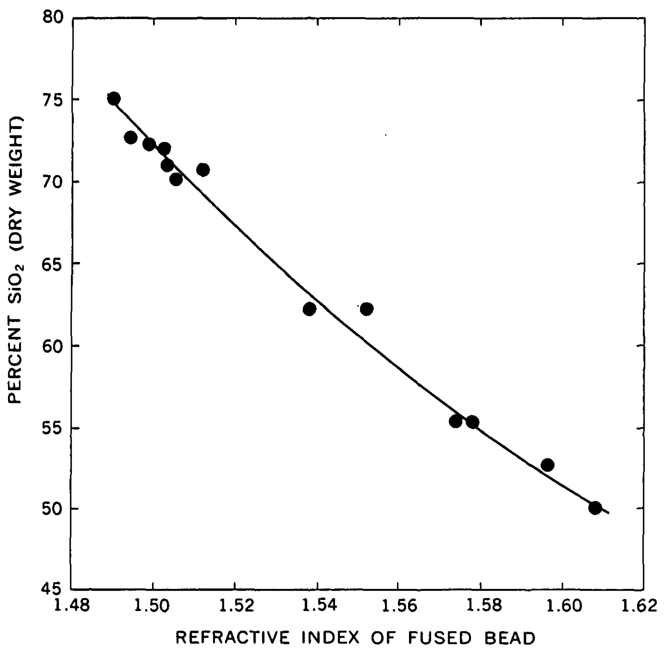

FIGURE 4.—Comparison of silica content and refractive index of fused bead for 13 chemically analyzed samples of volcanic rocks from the Western Cascade Range in Oregon.

by immersion in oils and comparing the results with the graph in Wahlstrom (1955, fig. 20). The composition of plagioclase more sodic than about An_{50} was determined by oil immersion.

The approximate composition of clinopyroxene was determined by measuring the optic angles of grains in thin section, determining Ny of grains from the same sample by immersion in oils, and comparing the results with the graph of Hess (1949, plate 1). The terminology of Poldervaart and Hess (1951) is followed. The composition of orthopyroxene was estimated by measuring optic angles of grains in thin section and Nz of grains by immersion in oils, and comparing the results with the graph of Kuno (1954, fig. 7). The composition of olivine was estimated by measuring optic angles of grains in thin section and comparing the results with the graph of Poldervaart (1950), fig. 2).

STRATIGRAPHY

The Cascade Range in Oregon is composed chiefly of volcanic rocks of Cenozoic age, which comprise two major sequences. The older sequence, the volcanic rocks of the Western Cascade Range, makes up most of the western slope of the range, and consists of deformed and partially altered flows and pyroclastic rocks of late Eocene to late Miocene age. The younger sequence, the volcanic rocks of the High Cascade Range, forms the crest and most of the eastern slopes of the range, and consists predominantly of unaltered and undeformed andesitic and basaltic flows and breccia of Pliocene to Recent age, which form nearly undissected shield and strato-volcanoes. Only a few of these volcanoes occur on the western slope of the range.

The volcanic rocks of the Western Cascade Range have been divided into the following units (table 3; figure 5): the Colestin Formation of late Eocene age, the Little Butte Volcanic Series of Oligocene and early Miocene age, the Columbia River Basalt of middle Miocene age, and the Sardine Formation of middle and late Miocene age. Pliocene nonmarine sedimentary rocks of the Troutdale Formation overlie volcanic rocks of the Western Cascade Range near Portland, and underlie basaltic Boring Lava, which has been grouped with the volcanic rocks of the High Cascades in this report. Along the foothills of the Cascade Range from Scotts Mills south to Dorena Dam, the Little Butte Volcanic Series interfingers with marine sedimentary rocks of middle and late Oligocene and early Miocene age. In the foothills of the Cascade and Coast Ranges between Eugene and Glide, the Colestin Formation overlies marine sedimentary rocks of the Spencer, Tyee, and Umpqua Formations of Eocene age, and in southern Oregon both volcanic and sedimentary rocks of the Western Cascade Range overlie pre-Tertiary plutonic and metamorphic rocks of the Klamath Mountains. The Colestin Formation and the Little Butte Volcanic Series are exposed principally in the southern part of the range in Oregon, the Columbia River Basalt and the Sardine Formation in the northern part.

TABLE 3.—*Summary of Cenozoic Formations in the Western Cascade Range in Oregon*

Age	Name	Lithologic character	Thickness (feet)	Distribution of outcrops
Quaternary	Alluvium	Gravel, sand, silt, and local till	0–500	Major stream valleys.
Pliocene and Quaternary.	Volcanic rocks of the High Cascade Range and Boring Lava.	Flows and less abundant pyroclastic rocks of basaltic andesite and olivine basalt, less abundant pyroxene andesite, and sparse dacite. Flows are typically porous textured and sparsely porphyritic, and contain phenocrysts of olivine that is partially altered to reddish iddingsite. Form constructional surfaces, modified in part by glaciation. Locally faulted but not folded.	0–>3,000	Limited mostly to crest and eastern slope of Cascade Range, but a few scattered cones and intracanyon flows farther west.
Pliocene	Troutdale Formation.	Conglomerate, sandstone, and micaceous siltstone; poorly indurated stream deposits. Conglomerate is massive and crossbedded in part and is composed chiefly of well-rounded pebbles of basalt and quartzite. Undeformed.	0–400 (>1,000 near Portland, Trimble, 1957).	Lower valleys of Sandy, Clackamas, and Molalla Rivers.
		Unconformity		
Middle and late Miocene.	Sardine Formation.	Flows, tuff brecica, lapilla tuff, and tuff of hypersthene andesite, less abundant basaltic andesite, augite andesite, and aphyric silicic andesite, and sparse dacite and olivine basalt. In Cascade Range in northern Oregon, composed of a lower pyroclastic unit and an upper unit of flows. Flows are typically platy and porphyritic and contain phenocrysts of calcic plagioclase and prismatic black hypersthene. Massive tuff breccia is locally abundant. Folded, faulted, and altered.	0–10,000, average about 3,000.	Western Cascade Range north of McKenzie River, and eastern edge of Western Cascade Range farther south.
Middle Miocene	Columbia River Basalt.	Flows of tholeiitic basalt and tholeiitic andesite. Flows typically are columnar and hackly jointed and are composed of very fine grained black basalt that contains abundant glass, plagioclase, augitic pyroxene, and chlorophaeite, but little or no olivine.	0–1, 500	Valleys of Bull Run, Sandy, Salmon, Clackamas, and Molalla Rivers, and foothills farther south to the vicinity of Sweet Home.
		Unconformity		
Middle and late Oligocene and early Miocene.	Marine tuff and sandstone.	Waterlaid tuff, volcanic-wacke arkosic-wacke, and less abundant siltstone, granule sandstone, pebbly conglomerate, and impure coquina. Shallow-water marine deposits that interfinger eastward with the Little Butte Volcanic Series.	0–600	Valleys of Butte, Abiqua, Silver, and Drift Creeks, and foothills between Lebanon and Dorena Dam.
Oligocene and early Miocene.	Little Butte Volcanic Series.	Dacitic and andesitic tuff and less abundant flows and breccia of olivine basalt, basaltic andesite, and pyroxene andesite, dacitic and rhyodacitic flows and domes, and rhyodacitic tuff. Massive pumice lapilli vitric tuff is the most abundant rock type. Basaltic flows typically contain sparse phenocrysts of calcic clinopyroxene (salite) and olivine, the latter altered to green clay, as well as microphenocrysts of calcic plagioclase and pyroxene. Basal member is rhyodacitic welded tuff containing abundant crystals of feldspar, quartz, and biotite. Folded, faulted, and altered.	3,000–15,000; average 5,000–10,000.	Western Cascade Range south of the McKenzie River; foothills and eastern edge of Western Cascade Range farther north.
		Local unconformity		
Late Eocene	Colestin Formation.	Andesitic lapilli tuff, tuff, conglomerate, volcanic-wacke sandstone, and less abundant flows and tuff breccia of basaltic andesite and pyroxene andesite. Massive pumice lapilli vitric tuff most abundant rock type.	0–3,000; average about 1,500.	Foothills of the Cascade Range between Calapooya Creek and the South Umpqua River, and scattered localities in the Range farther south to the vicinity of Hornbrook, Calif.

TABLE 3.—*Summary of Cenozoic Formations in the Western Cascade Range in Oregon*—Continued

Age	Name	Lithologic character	Thickness (feet)	Distribution of outcrops
Late, middle and early Eocene.	Spencer, Tyee, and Umpqua Formations.	Sandstone and siltstone of the Spencer Formation (not exposed within the map area) overlie micaceous sandstone and dark mudstone of the Tyee Formation, which in turn overlie sandstone, mudstone, conglomerate, and interbedded basaltic flows and tuff of the Umpqua Formation.	0–>500 (>9,000 southwest of Cottage Grove, Hoover, 1959).	Foothills of the Cascade Range between Calapooya Creek and Glide, and Coast Ranges of Oregon farther north and west.

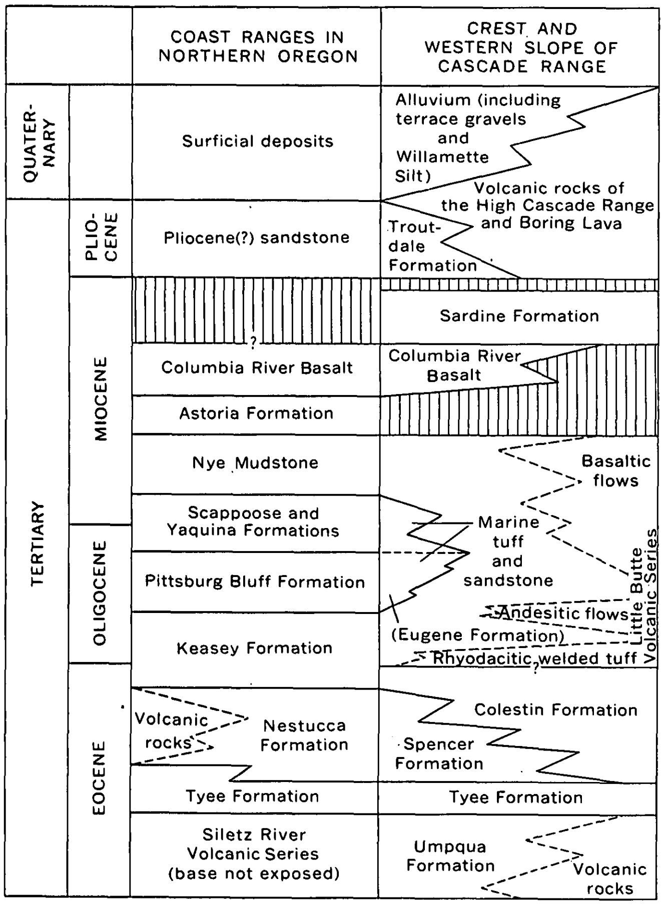

FIGURE 5.—Cenozoic formations in parts of western Oregon.

PRE-TERTIARY ROCKS

Rocks of pre-Tertiary age are exposed in the Cascade Range in Oregon, but only along the western edge of the range south of Glide, where the Cascades adjoin the Klamath Mountains. The Klamath Mountains consist mostly of folded and faulted Triassic, Jurassic, and Lower Cretaceous argillite, graywacke, and volcanic rocks (basaltic to rhyodacitic in composition) that have been intruded by ultramafic sills and dikes and by small batholiths and stocks ranging from gabbro to granite (Diller, 1898, 1903; Diller and Kay, 1924; Wells and others, 1940, 1949; Wells and Walker, 1953; Wells, 1956a, b; Imlay and others, 1959; Wells and Peck, 1961). Similar sedimentary, volcanic, and plutonic rocks of late Paleozoic and Mesozoic age are exposed in the Blue Mountains of eastern Oregon. Their general northeast structural trend is similar to that of the rocks in the Klamath Mountains, and all these older rocks are probably continuous underneath the cover of the Cenozoic volcanic rocks of the Cascade Range and central Oregon. The northeast trends of the folds in the volcanic rocks in the Western Cascade Range may also reflect the same structural grain.

Marine arkosic conglomerate, sandstone, and siltstone of middle and Late Cretaceous age (Albian to Turonian) unconformably overlap the folded edges of older rocks at the margin of the Klamath Mountains near Medford, Hornbrook, and Grave Creek (Peck and others, 1956; Jones, 1960). As discussed by Imlay and others (1959, p. 2779–2780), graywacke and argillite near Roseburg, originally mapped as part of the Myrtle Formation, are also of Late Cretaceous age (Cenomanian or Turonian); the dating of these rocks is based on Foraminifera from interbedded limestone lentils. Probably middle and Upper Cretaceous strata of both lithologic types underlie the Cascade Range.

Where exposed in the southwestern part of the map area, the pre-Tertiary rocks consist of slate, gneiss, schist, greenstone, quartz diorite, periodotite, and serpentine. These different rock types were not mapped separately in this investigation. As interpreted by Wells (Wells and Peck, 1961) from Diller's mapping (1898), the metamorphic rocks comprise the Galice and Rogue Formations of Late Jurassic age, and the intrusive rocks are Late Jurassic and Early Cretaceous in age.

EOCENE MARINE FORMATIONS

Sandstone, mudstone, conglomerate, and basaltic flows and pyroclastic rocks of the predominantly marine Umpqua, Tyee, and Spencer Formations of Eocene age underlie the Colestin Formation along the foothills of the Cascade and Coast Ranges from Eugene south to Glide, but crop out in a much smaller area within the map area. These rocks were not studied in detail in the present investigation.

The Umpqua Formation unconformably overlies Lower Cretaceous and older rocks southwest of Glide. It consists of mudstone, sandstone, basaltic flows, breccia and tuff, and conglomerate (Diller, 1898; Wells and Waters, 1935; Turner, 1938; Hoover, 1963). Only the upper few hundred feet of the formation, which consist of fine-grained sedimentary rocks, are exposed within the map area.

The Tyee Formation, which overlies the Umpqua Formation near Glide, consists of about 500 feet of thick- to medium-bedded sandstone and less abundant thin interbeds of dark carbonaceous mudstone. The sandstone is light to medium gray and medium and fine grained; it contains conspicuous flakes of muscovite and biotite. As determined by Hoover (1963), Tyee sandstone near Cottage Grove contains 60 to 85 percent clastic fragments, mostly of quartz, plagioclase, and glassy basalt, in a chloritic matrix.

The Spencer Formation was not mapped within the area of this investigation, but strata assigned to the formation crop out west of the map area between Fern Ridge Reservoir and Shoestring Valley and undoubtedly are present at depth beneath parts of the Western Cascade Range. Equivalent strata may be exposed within the map area on Taylor Ridge near the junction of Calapooya and Hinkle Creeks. Here, fine-grained tuffaceous beds, which have been mapped as the basal part of the Colestin Formation, contain sparse small mica flakes that are similar to, but smaller and less abundant than those that characterize the underlying Tyee. These strata resemble beds of the Spencer Formation mapped by Hoover (1963) a few miles to the north. As described by Vokes and others (1951), the Spencer Formation consists of beds of arkosic micaceous sandstone, and in the upper part contains lenses and layers of coal, highly tuffaceous sandstone, and grit.

The Umpqua, Tyee, and Spencer Formations have been dated as early, middle, and late Focene, respectively (fig. 5), and are considered equivalent to the Capay, Domingine, and Tejon stages of California (Weaver and others, 1944) on the basis of marine molluscs and Foraminifera (Turner, 1938; Hoover, 1963).

COLESTIN FORMATION

GENERAL FEATURES

Clastic volcanic rocks and andesitic flows of late Eocene age crop out discontinuously along the western margin of the map area between the valleys of Calapooya Creek and the South Umpqua River. These rocks are called the Colestin Formation in this report, following Wells (1956a), who first applied the name to clastic volcanic rocks of late Eocene age that overlie the Umpqua Formation in the Medford quadrangle. He later traced the rocks northward to the South Umpqua River (Wells and Peck, 1961). Rocks of similar age and lithology form the lower part of the Calapooya and Fisher Formations between Eugene and Calapooya Creek immediately west of the area of this report (Wells and Waters, 1934; Vokes and others, 1961! Hoover, 1963).

Within the map area the Colestin overlies a variety of rocks ranging from the Eocene Tyee and Umpqua Formations to pre-Tertiary ultramafic and metamorphic rocks. No discordance in attitudes was noted between the Colestin and the underlying Tyee and Umpqua Formations. The Colestin is about 1,500 feet thick on the average, but is 3,000 feet thick along Calapooya Creek and is locally missing across a partly buried ridge of pre-Tertiary rocks near White Rock. None of the source vents of the Colestin Formation were identified.

LITHOLOGY AND PETROGRAPHY

The Colestin Formation consists of lapilli tuff, tuff breccia, tuff, volcanic wacke sandstone, volcanic conglomerate, and intercalated lava flows, all of andesitic composition, as well as local deposits of nonvolcanic conglomerate and coal.

The formation along the South Umpqua River and the upper part of the formation along the North Umpqua and Little Rivers consists predominantly of greenish-gray massive lapilli tuff and tuff-breccia that weather olive gray. As much as 10 percent of these rocks consists of blocks of dark-gray porphyritic and aphyric andesite in a matrix of coarse to fine ash, angular lapilli—in part flattened pumice fragments—and crystals of feldspar and pyroxene. Carbonized wood fragments and logs are locally abundant.

The formation along Calapooya Creek and the lower part of the formation along the North Umpqua and Little Rivers consist predominantly of tuff, volcanic wacke sandstone, and siltstone. The rocks are light gray to yellowish and greenish gray and massive to medium bedded. Several coal prospects, which were first described by Diller (1898), lie within these strata along the North Umpqua River.

Conglomerate, which is interbedded in tuff along the North Umpqua and Little Rivers, is poorly sorted. It contains subangular pebbles and rounded cobbles and boulders as much as 5 feet in diameter in a tuffaceous matrix of crystals and ash. The clasts are dark-gray porphyritic andesite, a thin section of which contains about 25 percent andesine laths, 10 percent hypersthene and augite prisms, and less than 1 percent magnetite in a groundmass of glass that has devitrified to fine-grained patchy chalcedony and alkali feldspar. Conglomerate containing pebbles of quartz, diorite, and slate is interbedded in tuffaceous rocks in the lower part of the formation near White Rock (R. D. Brown, Jr., written communication, October 1956) and along Deadman Creek (Wells and Waters, 1934), adjacent to the partly buried ridge of pre-Tertiary rocks.

Andesite flows are abundant in the upper part of the formation along the North and South Umpqua and Little Rivers. The flows are 25 to 50 feet thick and consist of medium- to dark-gray fine-grained basaltic andesite and lesser pyroxene andesite. Two thin sections of these rocks contain about 60 percent plagioclase laths (calcic labradorite to calcic andesine), 25 percent intergranular augite, 5 percent magnetite, 1 to 2 percent olivine, and 5 to 10 percent interstitial glass, green montmorillonitic clays, and, in one specimen, biotite (table 1).

AGE AND CORRELATION

The Colestin Formation overlies rocks as young as the middle Eocene Tyee Formation on the flanks of Scott Mountain and Brown Mountain in the map area, and overlies rocks as young as the upper Eocene Spencer Formation just west of the map area between Comstock and the head of Shoestring Valley (Hoover, 1963). A diagnostic upper Eocene flora occurs in the basal part of the formation near the head of Elk Creek (USGS Paleobot. loc. 9464, the location of which is listed in fig. 6).

Sixteen other upper Eocene plant localities are listed in figure 6: of these, five occur in the lower part of the Fisher Formation between the Calapooya Mountains and Comstock (USGS locs. 8073, 9031, 9078, 9435, and 9504), three occur in the Colestin Formation near Siskiyou Pass (9242, 9277, and 9466), and eight occur in Sams Valley and the Rogue River Valley in tuffaceous strata assigned to the Umpqua Formation by Wells (1956a) (4654, 4656, 8074, 9276, 9278, 9284, 9463, and 9465). The fossil plants from these localities were identified by Roland W. Brown (written commun., 1958) and Jack A. Wolfe (written commun., Feb. 1962). Wolfe reports that "the climate under which these floras lived was almost certainly subtropical if not tropical."

In the Rogue River Valley near Eagle Point, the Colestin Formation, as described by Wells (1956a), consists of stratified volcanic conglomerate and massive tuff breccia; these rocks conformably overlie and grade down into tuffaceous sandstone and less abundant mudstone, nonvolcanic conglomerate, and coal, which make up the upper part of the Umpqua Formation. The upper part of the Umpqua as so defined has yielded upper Eocene plants from the eight localities in the Rogue River Valley and Sams Valley listed on page 11 (see also fig. 6); it thus is younger than the marine Umpqua Formation in the southern Oregon Coast Ranges and in the foothills of the Cascade Range near Roseburg, which has been dated as early Eocene on the basis of marine megafossils and Foraminifera (Turner, 1938; Hoover, 1963).

LITTLE BUTTE VOLCANIC SERIES

GENERAL FEATURES

Pyroclastic rocks and flows of Oligocene and early Miocene age overlie the Colestin Formation (fig. 5). They make up the bulk of the Western Cascade Range south of the McKenzie River, and are exposed farther north in the western foothills and in the axial parts of the Breitenbush and Clackamas anticlines. In this report these rocks are assigned to the Little Butte Volcanic Series. This name was first applied by Wells (1956a) to the volcanic rocks of Oligocene(?) age that overlie the Colestin Formation in the Medford 30-minute quadrangle. As typically exposed in the valley of Little Butte Creek, the series consists of "a lower sequence that is mostly flows, flow breccia and coarse agglomerate and an upper sequence about 1,100 feet thick composed predominantly of fine-grained siliceous tuffs" (Wells, 1956a). Wells (in Wells and Peck, 1961) traced rocks of the series northward to Jackson Creek. As mapped in the present study, the Little Butte Volcanic Series also includes the Mehama Volcanics and Breitenbush Series of Thayer (1939) in the North Santiam River basin, the Molalla Formation and pre-Butte Creek Lavas of Harper (1946) south of Molalla, and the Eagle Creek Formation and Bull Creek Beds of Barnes and Butler (1930) in the upper Clackamas River basin.

The thickness of the Little Butte Volcanic Series has been measured only in the southern part of the map area between the Calapooya Mountains and the South Umpqua River. Farther north, between the Calapooya Mountains and the latitude of Eugene, the base of the series, which lies west of the map area, has not been mapped. Still farther north, the lower part of the series is not exposed. The Little Butte Volcanic Series has a maximum thickness of 15,000 feet along the North Umpqua and Little Rivers between Glide and Illahee Rock. Over most of the Western Cascade Range, however, the series is probably between 5,000 and 10,000 feet thick. The series apparently decreases in thickness to the west and east from a zone near the eastern margin of the Western Cascade Range, which extends from near

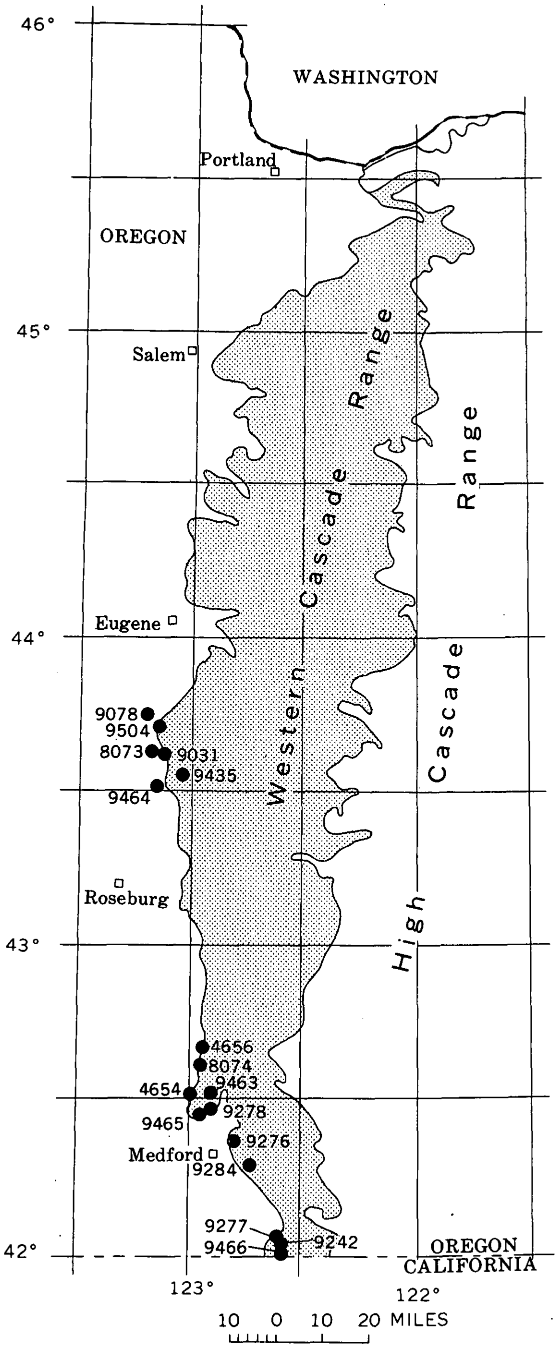

FIGURE 6.—Location of some upper Eocene plant localities in the Colestin Formation and equivalent strata in the Western Cascade Range and adjacent areas in Oregon. Localities indicated by USGS numbers. Western Cascade Range lightly shaded.

USGS Paleobot. loc.	*Location*
4654	SW¼ sec. 24, T. 35 S., R. 3 W.; in Sams Valley.
4656	Sec. 21, T. 33 S., R. 2 W.; on Evans Creek.
8073	SE¼ sec. 35, T. 22 S., R. 4 W.: on county road east of Scotts Valley.
8074	SW¼ sec. 16, T. 34 S., R. 2 W.; near Meadows.
9031	SE¼ sec. 36, T. 22 S., R. 4 W.; on Hobart Butte.
9078	SW¼ sec. 10, T. 21 S., R. 4 W. and NE¼NW¼ sec. 16, T. 21 S., R. 4 W.; on the Southern Pacific Railroad tracks about 2 miles north of Comstock. Flora described by Sanborn (1937).
9242	NE¼ sec. 32, T. 40 S., R. 2 E.; near the airplane beacon on Siskiyou Summit.
9276	SW¼ sec. 3, T. 37 S., R. 1 W.; at Hanson Coal mine and vicinity.
9277	NE¼ sec. 30, T. 40 S., R. 2 E.; near White Point.
9278	SE¼ sec. 2, T. 36 S., R. 2 W.; at Upper Table Rock.
9284	NE¼ sec. 16, T. 38 S., R. 1 E.; at Van Dyke cliffs, 4 miles north of Ashland.
9435	NW¼ sec. 27, T. 23 S., R. 3 W.; on Little River road.
9463	Sec. 22, T. 35 S., R. 2 W.; near Beagle School.
9464	NW¼ sec. 2, T. 24 S., R. 4 W.; on Elk Creek.
9465	NW¼ sec. 16, T. 36 S., R. 2 W.; at Lower Table Rock.
9466	Sec. 9, T. 41 S., R. 2 E.: near Siskiyou Summit.
9504	NW¼ sec. 34, T. 21 S., R. 4 W.; on Bear Creek.

Quartz Mountain at the south to near Breitenbush Hotsprings at the north.

The basal rhyodacite welded tuff of the Little Butte Volcanic Series overlies the Colestin Formation unconformably in the southwest corner of the map area, as shown by steeper dips in the Colestin and by the filling of eroded channels cut in the Colestin 2 miles southwest of Scott Mountain (R. D. Brown, Jr., written commun., October 1956). The Little Butte interfingers with marine tuff and sandstone of middle Oligocene to early Miocene age in the foothills of the Cascade Range between Dorena Dam and Scotts Mills.

LITHOLOGY AND PETROGRAPHY

Massive beds of andesitic and dacitic tuff, presumedly deposited by ash flows, make up most of the Little Butte Volcanic Series. Less abundant components are (1) flows, breccia, tuff, and small intrusives of olivine basalt, olivine andesite, and andesite, and (2) bedded tuff, welded tuff, flows, and small intrusives of dacite and rhyodacite. The silicic rocks are most abundant in the eastern and southern parts of the map area.

AREAL DISTRIBUTION

In the drainage basin of the North Umpqua River, the Little Butte Volcanic Series is 6,000 to 15,000 feet thick and has been divided into several lithologic units (pl. 1; fig. 7). About three-fourths of the section is tuff, mostly massive dacitic lapilli tuff. Lithologically distinctive are the basal unit of rhyodacitic welded tuff and two units of flows higher in the section, the lower composed of pyroxene andesite and the upper composed of olivine basalt and basaltic andesite. The strata immediately overlying the rhyodacitic tuff are lithologically similar to the Colestin Formation.

South of Little River, the series thins against a buried ridge of pre-Tertiary rocks. Along the South Umpqua River between the mouth of Ash Creek and Grasshopper Mountain, the series is about 3,000 feet thick and consists chiefly of massive dacitic and rhyodacitic tuff.

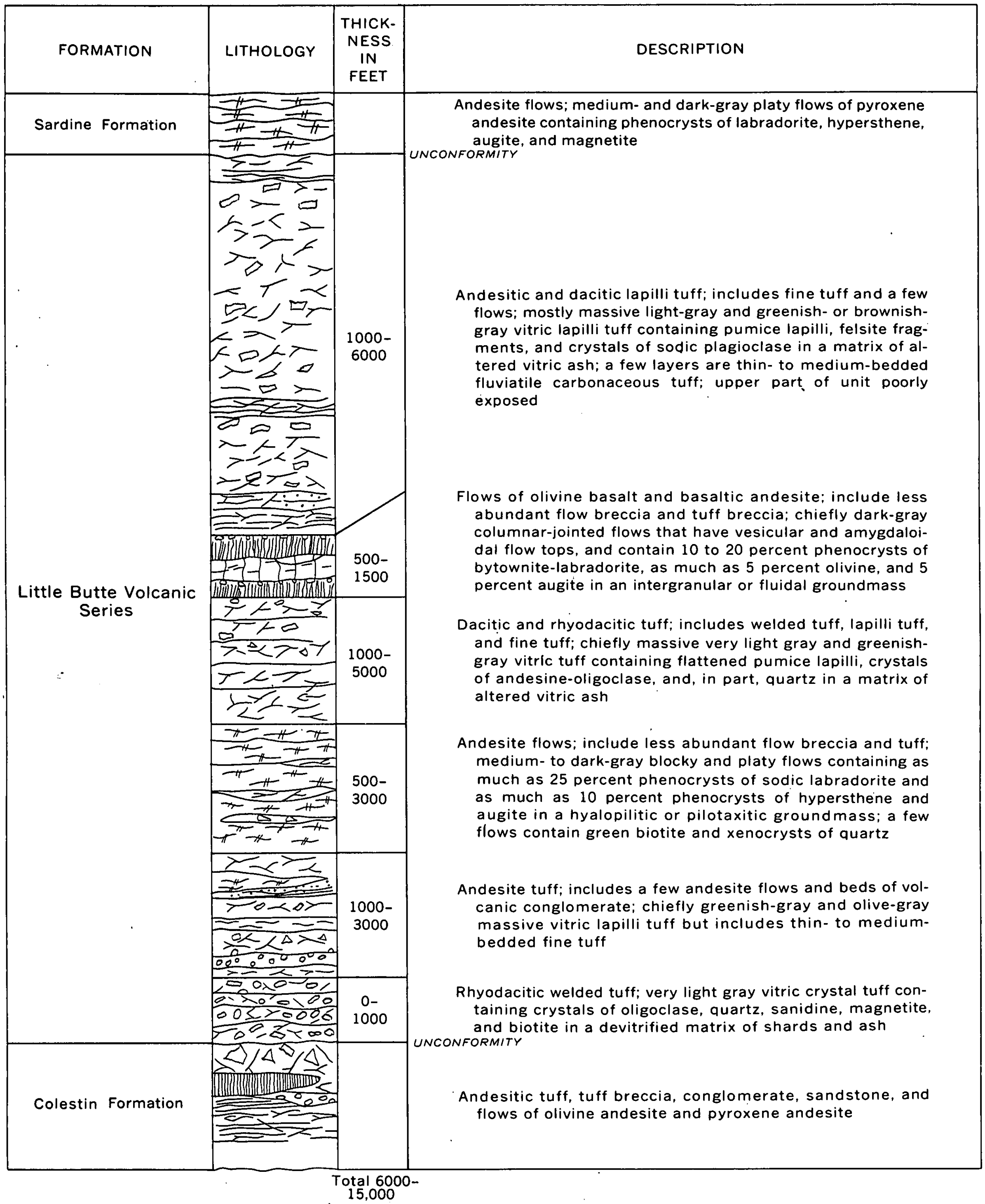

FIGURE 7.—Generalized columnar section of the Little Butte Volcanic Series along the Little River and the North Umpqua River between Glide and Illahee Rock, Oreg.

Thick units of mafic flows were not recognized here; they probably thin southward from the Little River and may even be missing along the South Umpqua.

In the drainage basins of the Middle Fork and Coast Fork of the Willamette River and the McKenzie River, the Little Butte Volcanic Series consists of about 8,000 feet of volcanic rocks, of which three-quarters to one-half are andesitic and dacitic tuff and the rest mostly flows and breccia of olivine basalt and andesite. The tuffaceous rocks are predominantly massive pumice lapilli tuff and vitric tuff, but they include less abundant water-laid tuff, volcanic conglomerate, and welded tuff.

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The pyroclastic rocks are mostly andesitic to the west of long 122°45′ and mostly dacitic to the east. Beds of water-laid tuff are abundant along the western flank of the Coburg Hills where they overlie the Eugene Formation, near Jasper, and also farther east near long 122°30′ (in Staley and Coal Creeks, along the ridge north of Oakridge, and in the upper part of Portland and Fall Creeks). Lenses of coarse conglomerate locally underlie a unit of basalt flows on the ridges west of Lost Creek and north of Little Fall Creek. Beds of welded tuff and silicic flows and domes are most abundant in a zone that extends from the Bohemia District to Blue River. Beds of welded tuff are particularly well exposed near the fork of Winberry Creek, below Pernot Mountain, along the north side of the Dorena Reservoir, and along Hehe Creek. Silicic flows and domes are exposed along Gale Creek, on the ridge south of the North Fork of Fall Creek, on the western slope of Saddleblanket Mountain, near the mouth of Hills Creek, on the ridge west of Dead Mountain, and at the southern end of the Coburg Hills.

Flows and tuff-breccia of olivine basalt and basaltic andesite form one to three mappable units in the Little Butte Volcanic Series in the drainage basins of the Coast Fork and Middle Fork of the Willamette River and the McKenzie River. Flows and breccia are also sparsely intercalated in the predominantly tuffaceous units. Individual sequences of flows reach a maximum thickness of about 3,000 feet, and the total thickness of mafic flows and breccia in the series ranges from about 1,000 to 5,000 feet. The basalt is best exposed along the western slope of the Coburg Hills and the ridge crest east of Bearbones Mountain. In the lower part of the Little Butte Volcanic Series, a unit of flows, which consists mostly of pyroxene andesite, is as much as 2,000 feet thick; it caps part of the ridge south of Row River and may extend farther north along the slope east of Sharps Creek.

In the hills along the Calapooya River between Brownsville and Dollar and along the South Santiam River between Waterloo and the Cascadia Ranger Station, the Little Butte Volcanic Series comprises a lower unit of tuffaceous rocks, mostly fine-grained bedded tuff, and an upper unit of flows and breccia of olivine basalt and basaltic andesite. The unit of flows thins to extinction to the east, possibly because of erosion prior to the extrusion of the Columbia River Basalt flows that overlie the tuffaceous rocks near Sweet Home. Farther north in the foothills, along Thomas and Crabtree Creeks and along the North Santiam River near Mehama, as much as 4,000 feet of massive and well-bedded andesitic tuff and lapilli tuff belonging to the Little Butte Volcanic Series is exposed. Olivine basalt flows are uncommon, but crop out on Thomas Creek near Jordan and locally along Crabtree Creek. Flows and breccia of olivine basalt, andesite, and dacite that are questionably assigned to the Little Butte are exposed east of Mehama along the Little North Santiam River.

The Little Butte Volcanic Series is covered by younger rocks from the ridge immediately north of the North Santiam and Little North Santiam Rivers to Butte Creek but crops out between Butte Creek and Molalla River. Here the series consists of a lower unit of flows, breccia, and tuff of olivine basalt and basaltic andesite, and an upper unit of nonmarine water-laid tuff. Both units are exposed along the Molalla River; to the west, the upper unit interfingers with tuffaceous marine beds of late Oligocene and early Miocene age (which are mapped and described separately from the Little Butte), and in the valleys of Rock Creek and Butte Creek the marine beds lie between the lower and upper units of the Little Butte.

Along the Molalla River, the water-laid upper unit is about 1,000 feet thick and consists chiefly of fine-grained andesitic vitric tuff. The tuff is thin bedded to massive, crossbedded in part, and contains abundant lenses of volcanic conglomerate composed of rounded pebbles and cobbles of finely porphyritic andesite, which are as much as 12 inches in diameter. The tuff unit thins to the west and is only a few hundred feet thick in the valleys of Rock and Butte Creeks.

In the axial parts of the Breitenbush anticline north from the McKenzie River to the vicinity of Breitenbush Hot Springs, silicic pyroclastic rocks and flows of the Little Butte Volcanic Series as much as 5,000 feet thick are exposed. The rocks are chiefly massive rhyodacitic to andesitic lapilli tuff and vitric tuff but include less abundant silicic flows and welded tuff. Well-bedded tuff is locally abundant, particularly in the upper part of the section. Silicic flows, some of which contain quartz phenocrysts, are exposed along Gate Creek, Canyon Creek, Upper Soda Fork, Blowout Creek, and Boulder Creek. The contact between the Little Butte Volcanic Series and the Sardine Formation is uncertain at many places along the Breitenbush anticline. Flows of altered olivine basalt that overlie tuffaceous rocks at Tombstone Pass, below Twin Buttes, and at Gold Hill were mapped with the Sardine Formation; more detailed mapping may show that these flows are a part of the Little Butte. In the North Santiam River basin, the upper contact of the Little Butte Volcanic Series is drawn beneath lenses of basalt that are questionably assigned to the Columbia River Basalt; more detailed mapping may shift the contact in the area.

In the valleys of the Clackamas and Collawash Rivers, andesitic flows and tuff of the Little Butte Volcanic Series, as much as 1,500 feet thick, are exposed beneath the Columbia River Basalt and Sardine Formation. The lower part of the Little Butte consists of flows and tuff-breccia of pyroxene andesite and basaltic andesite; the upper part consists mostly of poorly exposed volcanic clastic rocks; these include both massive and well-bedded, in part crossbedded, rocks that range from fine tuff to boulder conglomerate.

PYROCLASTIC ROCKS

Pyroclastic rocks make up about three-fourths of the Little Butte Volcanic Series. Massive vitric lapilli tuff is most abundant, whereas vitric tuff, vitric-crystal tuff, and water-laid tuff are less abundant. The pyroclastic rocks include both dacitic and andesitic varieties, as well as less abundant rhyodacitic tuff.

Lapilli tuff generally forms massive beds more than 20 feet thick; in a few exposures more than 75 feet high no bedding was seen. As a result, strikes and dips are difficult to obtain. Most of the massive tuff beds probably are ash-flow deposits. Some tuff, lapilli tuff, and volcanic conglomerate are thin to thick bedded. Carbonized and silicified wood and leaf fragments are locally abundant in the tuff. All variations between massive light-colored, poorly indurated tuff to streaky dark welded tuff that resembles obsidian flow rock were observed. Accretionary lapilli were observed in tuff in sec. 36, T. 23 S., R. 2 E., near Bearbones Mountain and in sec. 33, T. 17 S., R. 3 E., near Pernot Mountain. A specimen from the Bearbones Mountain locality is described and shown by Moore and Peck (1962).

Lapilli in tuff beds average 1 to 2 cm in diameter and consist mostly of dense to pumiceous altered glass. The lapilli range from angular, nearly equant fragments to flattened disk-shaped bodies in which the thickness is one-tenth the maximum diameter, but in most rocks the lapilli are equant or only moderately flattened, having a ratio of thickness to maximum diameter of 2 to 3, or 1 to 2. In most rocks, the lapilli are the same color as the matrix except for a few darker fragments. The lapilli include flattened fragments containing a few or no pores and also fragments that are noticeably frothy and contain abundant round pores. Some of the pores are not filled, but many are partly or completely filled with later minerals (fig. 8). Lapilli of andesite and dacite are sparse, and lapilli of basalt are rare except in tuff interbedded with basaltic flows.

Most tuff and lapilli tuff contain only about 10 percent original crystals and crystal fragments in a matrix of shards and fine ash. Of 60 thin sections of tuffs examined under the microscope, only five contained more than 25 percent original crystals. The greatest amount observed in any one specimen was 42 percent crystals. The crystals in the tuff are as much as 3 mm long, but average ½ to 1 mm. Shards appear undeformed in most samples, even in some rocks in which the pumice lapilli are flattened. In the few beds of welded tuff, however, the shards are strongly deformed.

Pumice, shards, and ash are devitrified in almost all the samples examined. X-ray diffraction studies show that some specimens that appear to be fresh under the microscope, except for minor filling of voids in pumice, are almost completely altered to zeolite. In others, alteration is more apparent; voids are filled, and shards and ash are altered to a fine-grained mineral aggregate, although the original texture is retained. In some samples, particularly those from areas of propylitic alteration, original textures have been partially or completely destroyed by the formation of anhedra of quartz and feldspar. In some samples of welded tuff and silicic flow rock, the matrix as well as the pumice fragments have partially or almost completely crystallized to spherulites, which range in size from ¼ to 2 mm. Deformed shards in a welded tuff from Winberry Creek contain abundant crystallites, mostly curved hairlike trichites, as shown in figure 9.

Distinguishing tuffaceous rocks of different composition under the microscope is difficult, because most

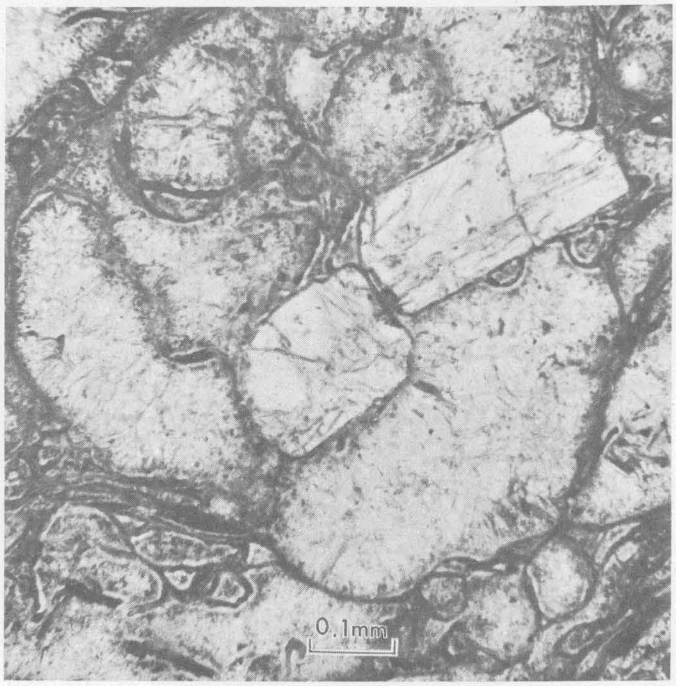


FIGURE 8.—Photomicrograph of an altered pumice lapillus in tuff in the Little Butte Volcanic Series. Lapillus contains crystals of andesine feldspar (center of photograph); voids in the pumice are now filled with radiating crystals of the zeolite clinoptilolite. Sample DLP-56-123.

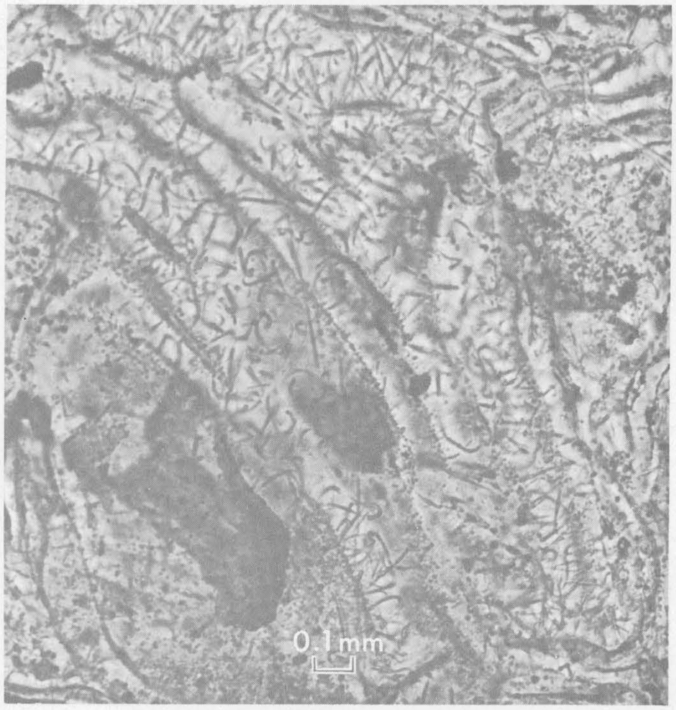


FIGURE 9.—Photomicrograph of curved hairlike crystallites (trichites) in welded tuff in the Little Butte Volcanic Series. Sample DLP-56-17.

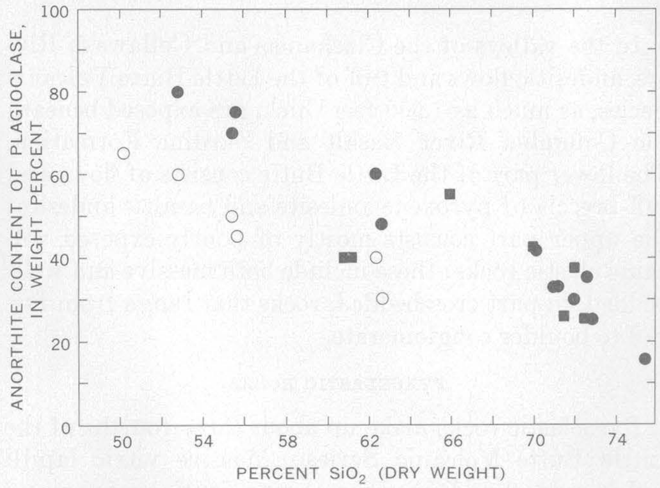


FIGURE 10.—Comparison of silica content of volcanic rocks of the Western Cascade Range in Oregon with the anorthite content of their plagioclase. Solid circles represent phenocrysts of chemically analyzed rocks, open circles represent grains in the groundmass, and squares represent phenocrysts in rocks whose silica content was estimated from refractive index of fused bead.

contain only a small proportion of original crystals. Therefore, the approximate composition of about 25 samples of tuff was determined by measuring the refractive index of a fused bead from each sample and comparing the index against a standard curve prepared from 13 chemically analyzed samples (p. 5; fig. 4). A silica content of 63 percent (dry weight) was selected as the division point between andesite and dacite. The following description of tuffaceous rocks of andesitic and dacitic composition is based in part on such determinations. This technique, however, is not sufficiently accurate to distinguish between most dacitic and rhyodacitic rocks, because the range of silica content of most such rocks is only 5 percent. However, a fairly good correlation exists between the composition of plagioclase crystals in tuff (or phenocrysts in lavas) and the bulk chemical composition of the rocks, as shown in figure 10, in which plagioclase composition is plotted against bulk silica content (dry weight) determined by chemical analyses and indices of fused beads. An anorthite content of the feldspar crystals greater than 30 percent was used as the major criterion to distinguish dacite from rhyodacite.

The thermal state of plagioclase in the older volcanic rocks of the Cascade Range was determined mostly from crystals from tuff in the Little Butte Volcanic Series. Plagioclase grains were separated from nine samples by the use of heavy liquids, the lower refractive index of the grains was determined by oil immersion, and the difference, $2\theta(1\bar{3}1)-2\theta(131)$, was measured on traces prepared with a Phillips X-ray diffractometer by the use of CuKα radiation and a rate of ¼° per minute. When the differences in 2θ are plotted against composition, seven of the nine points (fig. 11) lie between the two curves of Smith and Yoder (1956, fig. 3), which were determined (1) from plagioclase from intrusives and (2) from synthesized and heated plagioclase grains. The optical axial angles of plagioclase from three of these samples were measured on a universal stage. When the average optic angle from each sample is plotted against plagioclase composition, the points lie between Smith's (1958, fig. 3) curves for plagioclase of the two types, but close to the curve for synthesized and heated plagioclase.

Andesitic tuffaceous rocks are mostly drab shades of green and yellow, although the sparse undevitrified rocks are light gray. Feldspar crystals range in composition from intermediate andesine to intermediate labradorite, and in some rocks they are partially replaced by zeolite. One to 5 percent pyroxene (clinopyroxene or orthopyroxene or both) and magnetite are also present. In most rocks pyroxene is completely altered to green clay and iron oxides.

Most dacitic and rhyodacitic tuffaceous rocks are light gray or other pastel shades. Feldspar crystals in dacitic tuff range from sodic to intermediate andesine (An_{30-40}). Quartz crystals are rare or absent. One to 4 percent pyroxene (clinopyroxene or orthopyroxene or both) and less than 1 percent magnetite make up the remainder of the crystals. The composition of the pyroxene was determined optically in one speci-

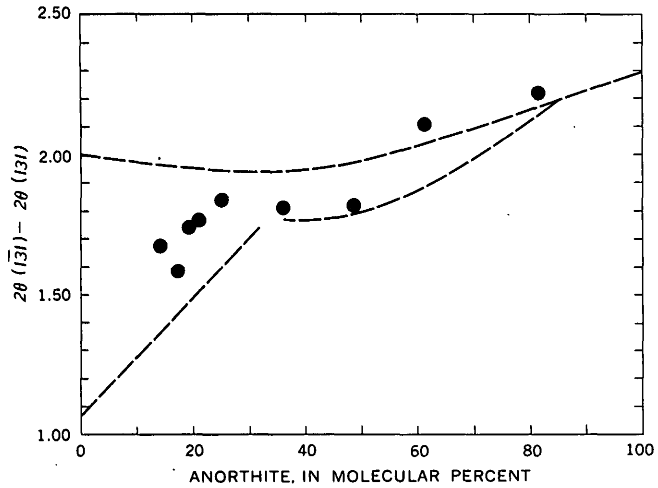


FIGURE 11.—Comparison of composition and angular spacing $2\theta(1\bar{3}1)-2\theta(131)$ of plagioclase from Tertiary volcanic rocks of the Western Cascade Range in Oregon. Composition determined from Nx; 2θ determined by X-ray diffraction. Dashed curves are from Smith and Yoder (1956); the upper curve was determined from plagioclase synthesized by the dry method; the lower curves were determined from plagioclase from thick stratiform intrusions, granite, and pegmatites.

men, an analyzed welded tuff (DLP–56–17), in which the clinopyroxene is ferroaugite (about $WO_{35}En_{10}Fs_{55}$) and the less abundant orthopyroxene is eulite (about En_{30}). Chemical analyses and modes of three samples of dacitic tuff are listed in table 7 (columns 15, 18 and 20). The analyzed sample from Pernot Mountain, DLP–56–82, (column 20, table 8) differs chemically from the other analyzed dacite samples. The analyses indicated a normative quartz content of 32 percent and normative feldspar of the composition $Or_{32}Ab_{55}An_{13}$, but the rock contains abundant crystals of andesine and no crystals of quartz or potassic feldspar. However, the rock is altered; the plagioclase is partially replaced by zeolite, and the groundmass by chalcedony, zeolite, and montmorillonitic clay. Probably silica has been introduced during alteration, and the proportion of CaO, Na_2O, and K_2O changed.

Rhyodacitic tuff contains crystals of feldspar, quartz, hornblende, biotite, and magnetite. The plagioclase feldspar is oligoclase (An_{15-30}). Although several samples were stained with potassium cobaltinitrite, crystals of potassium-rich feldspar were observed only in specimens from the basal rhyodacite welded tuff in the basin of the North Umpqua River. A chemically analyzed sample of this tuff (DLP–57–55) contains 5 percent crystals of soda sanidine ($2V=36°$ to $44°$, $Nx=1.522\pm.002$), in addition to more abundant sodic oligoclase. Partially resorbed bipyramids of quartz make up to 2 to 15 percent of the rocks. As much as 2 percent of strongly pleochroic brown biotite was found in about one-half of the rhyodacite tuffs. Less than 1 percent of hornblende occurs in about one-half of the specimens, typically occurring as subhedral prisms enclosed by coronas of fine magnetite and altered in part to magnetite and quartz. The hornblende is pleochroic from reddish brown to olive to pale yellowish brown. Magnetite composes as much as 1 percent of most rocks and occurs as small discrete grains, as alteration halos around hornblende, and as inclusions in biotite. Chemical analyses and modes of two rhyodacitic tuffaceous rocks are listed in table 7 (columns 19 and 22).

BASALTIC AND ANDESITIC FLOWS AND BRECCIA

Flows and coarse tuff-breccia of olivine basalt, basaltic andesite, and pyroxene andesite make up nearly one-quarter of the Little Butte Volcanic Series throughout the Western Cascade Range. The flows form mappable units and are also sparsely intercalated in tuffaceous units. The flows are predominantly olivine basalt and basaltic andesite, except in the lower part of the series south of Row River and along the Clackamas River.

Andesite and basalt are classified in this report mostly on the basis of the total percentage of mafics (modal color index), as determined in thin section. (See discussion, p. 5.)

The bulk specific gravity of nonvesicular andesite and basalt, as determined on a direct-reading beam balance, ranges from 2.57 to 2.93. The specific gravity increases with decreasing silica content (fig. 12) and with increasing modal color index (fig. 13).

The flows have columnar or blocky joints; they range in thickness from 20 to 200 feet, but average about 50 feet thick. Lewis (1950) has described a unit of 10 flows in the southern Coburg Hills that has an aggregate thickness of 1,000 feet. The upper and lower parts of flows are typically vesicular and amygdaloidal and contain cavity fillings of chalcedony, zeolite, calcite, and green to black clays. Five to 50 feet of reddish volcanic breccia separate many flows.

Basalt and basaltic andesite are medium dark gray to dark gray and fine grained to aphanitic. In the western part of the map area, the rocks weather to a porous ocherous rind in which the feldspars form rectangular cavities. For an inch or less beneath the rind, the feldspar phenocrysts are chalky white in contrast to the dark groundmass. Close examination of fresh rocks reveals abundant small phenocrysts of dark feldspar and scattered clots of dark green pyroxene and iridescent green to reddish olivine. Coarsely tabular phenocrysts of feldspar as much as 1 cm long are abundant in a few rocks. In a characteristic though not abundant type, scattered phenocrysts of pyroxene as much as 1 cm in diameter stand out as knots on weathered surfaces.

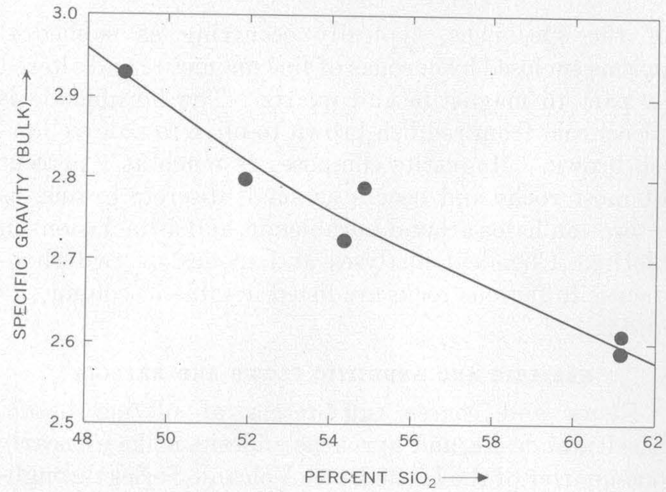


FIGURE 12.—Comparison of specific gravity (bulk) with silica content of chemically analyzed basalt and andesite from the Western Cascade Range, Oreg.

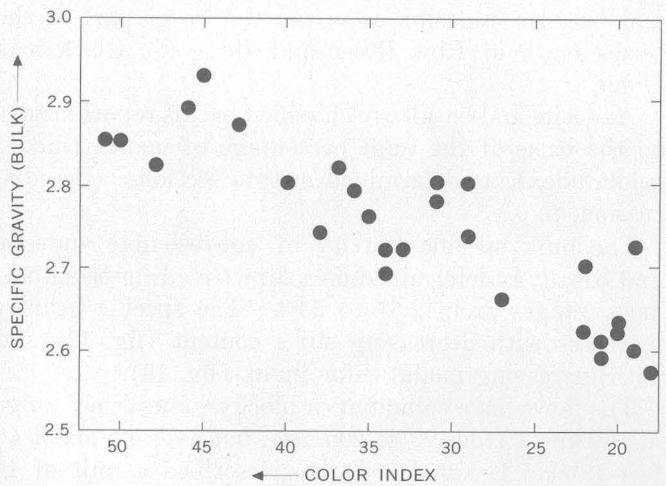


FIGURE 13.—Comparison of specific gravity (bulk) with modal color index of basalt and andesite from the Western Cascade Range, Oreg.

The basalt and basaltic andesite generally contain one-third phenocrysts, as much as 2 mm in diameter, of bytownite or labradorite feldspar, diopsidic to augitic pyroxene, olivine, and magnetite in a fine-grained to dense intergranular to subophitic groundmass of calcic andesine or labradorite, pyroxene, and magnetite and interstitial cristobalite(?), brown glass, and green clay (fig. 14). Typically the interstitial material is crisscrossed by long needls of apatite. The average diameter of grains in the groundmass ranges from 0.05 to 0.3 mm in different samples. The average mineralogical composition of olivine basalt, based on six modal analyses, is: plagioclase, 47 percent (1/10 to 1/2 phenocrysts); pyroxene, 37 percent (1/4 phenocrysts); olivine, 6 percent; magnetite, 3 percent; and glass, lesser cristobalite(?), and clay, 7 percent. The average mineralogical composition of basaltic andesite, based on three modal analyses, is as follows: plagioclase, 60 percent (1/6 to 2/3 phenocrysts); pyroxene, 26 percent (1/10 phenocrysts); olivine, 3 percent; magnetite, 4 percent; and glass, minor cristobalite(?), and clay, 7 percent. A chemical analysis and a mode of one olivine basalt sample from the Little Butte Volcanic Series is given in table 7 (column 3).

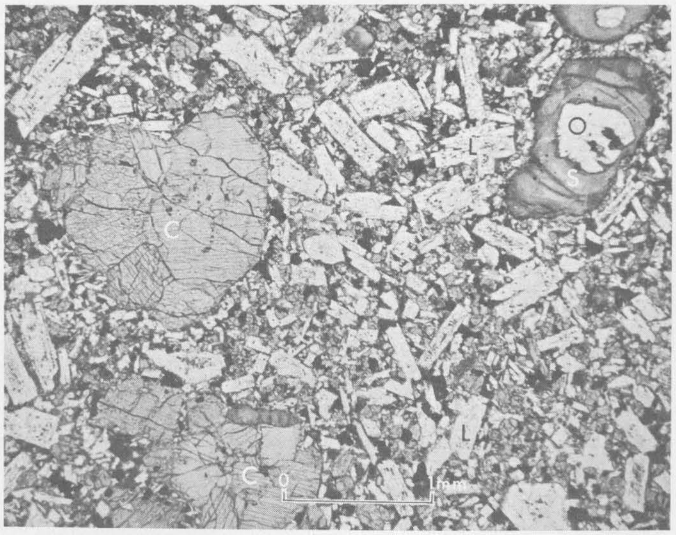


FIGURE 14.—Photomicrograph of olivine basalt in the Little Butte Volcanic Series. Phenocrysts of the clinopyroxene salite (C) and olivine (O) are set in an intergranular groundmass containing tabular microphenocrysts of labradorite (L), grains of augite, and less abundant Magnetite, glass, and alteration minerals. Olivine has partially altered to saponitic clay (S). Sample DLP–56–27.

Pyroxene andesite occurs as medium-gray blocky and platy flows and as flow breccia and tuff-breccia. Sparse to abundant tabular phenocrysts of feldspar, as much as 3 mm long, and sparse dark-green to black prismatic phenocrysts of pyroxene are set in an aphanitic groundmass. In thin section, the phenocrysts of sodic labradorite, pyroxene (either orthopyroxene or clinopyroxene or both), and magnetite are set in a dense hyalopilitic or pilotaxitic groundmass made up of subparallel microlites of andesine or oligoclase, intergranular pyroxene and magnetite, and interstitial material. In some rocks the interstitial material consists of dust-charged brown glass (N=1.510±0.005), in part accompanied by cristobalite(?), but in many rocks the glass has altered to patchy chalcedony, alkalic feldspar, and green clay. An average mineralogical composition, based on approximate modal analyses of five typical specimens of andesite, is as follows: plagioclase, 56 percent (1/8 to 1/2 phenocrysts); pyroxene, 20 percent (1/10 phenocrysts); magnetite, 3 percent; and fine-grained interstitial material, 21 percent. A few andesite flows contain as much as 4 percent quartz in rounded and embayed nearly equant xenocrysts (for example, the flow that caps Mace Mountain). Chemical analyses of four rock samples from the Little Butte that are described as andesite and labradorite andesite by Callaghan (1933) are quoted from him in table 7 (columns 5, 9, 10, and 14).

Feldspar occurs both as tabular microphenocrysts and as groundmass microlites in olivine basalt and basaltic andesite. In many rocks, distinction between phenocrysts and groundmass microlites is arbitrary because grains intermediate in size, also are present. The phenocrysts occur both singly and in complexly intergrown clusters, many of which have a stellate arrangement. Most phenocrysts are corroded and poorly terminated. Most have cores of bytownite (An_{75-90}) and thin discontinuous rims of labradorite (An_{55-65}), although in a few specimens the cores are calcic labradorite (An_{65}) and the rims sodic labradorite and calic andesine (An_{45-55}). The cores of some phenocrysts are unzoned, others have moderately formed progressive and oscillatory zoning near the core margins, but the rims of all have fully formed progressive zoning. Generally the rim of each feldspar phenocryst is separated from the core by an irregular curved surface of corrosion that cuts across zones in the core. Across this surface in most phenocrysts an abrupt break in composition of 10 to 20 percent anorthite takes place. Oscillatory zoning is present in many phenocrysts; variation in extinction angles indicate that this zoning involves little change in composition. Many of the phenocrysts contain inclusions of glass; in some of these are tiny anhedral pyroxene grains. These inclusions have curved irregular shapes or are elongate parallel to the *C* crystallographic axis of the host. They are either distributed erratically in the core or are concentrated in a zone just inside the more sodic rim. Most of the feldspar crystals are twinned, and the composition planes of most twins are parallel to (010). Almost all plagioclase grains are made up of several polysynthetic twin lamellae; combined Carlsbad-albite twins are so widespread that they were used to determine plagioclase composition in most basalts and andesites. The groundmass feldspar consists of randomly oriented, stubby tablets of labradorite (An_{55-65}) or, less commonly, intermediate plagioclase (An_{45-55}); these tablets are 0.05 to 0.2 mm long and two-thirds as wide. A little interstitial andesine occurs in a few samples.

Pyroxene forms stubby prisms as much as 1 cm long and anhedral grains or subhedral prisms in the groundmass. The phenocrysts are calcic clinopyroxene, mostly salite. They are dark green to black in hand specimen but faintly pleochroic from pale green to brown or pinkish brown in thin section. Many have corroded margins. Generally some of the pyroxene phenocrysts are intergrown with olivine to form glomerophenocrysts. Both glomerophenocrysts and separate phenocrysts are zoned; the zoning is apparent because of variation in extinction angles. The optic axial angle decreases outward from core to rim an average of 2° but as much as 6°. The composition of all clinopyroxene phenocrysts ranges from diopside (about $Wo_{50}En_{42}Fs_{8}$) to augite (about $Wo_{43}En_{29}Fs_{28}$) but mostly falls within the salite field (about $Wo_{45}En_{35}Fs_{20}$), as determined from measurements of optic axial angles on 30 grains from six specimens ($2V=49°-60°$, average 55°) and intermediate refractive indices determined on grains from five specimens ($Ny=1.683-1.705\pm.003$). In addition to clinopyroxene, a few well-formed prismatic phenocrysts of orthopyroxene occur in a few specimens. In most samples that were studied in detail, two types of pyroxene are present in the groundmass. Pale greenish-brown subhedral augite (average $2V=49°$ in 20 grains from five specimens) is most abundant; also present is less abundant pigeonite ($2V=0°-10°$, optic plane parallel to (010)), or subcalcic augite ($2V=23°-33°$ in four grains from two specimens), or bronzite, about En_{70-80} (based on 2V of 68°–78° in 10 grains from four specimens). Individual grains of both pigeonite and subcalcic augite have variable extinction and optic axial angles. In the groundmass of one specimen of basaltic andesite, careful search revealed only pigeonite, about $Wo_{10}En_{50}Fs_{40}$ ($2V=0°-10°$, $Ny=1.702\pm0.003$). The refractive index of groundmass augite was determined in only two specimens, in both of which $Ny=1.707\pm0.003$; this index indicates a composition of about $Wo_{40}En_{30}Fs_{30}$. Most groundmass bronzite is jacketed by clinopyroxene on the prism faces.

Olivine occurs as stubby, poorly terminated corroded prisms, which have conspicuous curved fractures. The olivine is light yellow or green in hand specimens, but is colorless in thin section. Olivine (or alteration product pseudomorphic after olivine) was noted in 35 of the 43 samples of mafic rocks from the Little Butte Volcanic Series that were examined in thin section, excluding samples from the lower unit of andesitic flows. Olivine occurs in glomerophenocrysts associated with clinopyroxene or as separate grains, but only in a very few specimens does it occur in the groundmass. Invariably the olivine is rimmed by anhedral grains of pyroxene; usually the pyroxene is pigeonite, but in some rocks it is orthopyroxene bronzite or augite. Inside the pyroxene corona of some olivine phenocrysts is an inner ring of dendritic magnetite. In a few specimens, the olivine has been completely replaced by finely granular pyroxene and magnetite or by magnetite and quartz. An average composition of olivine, determined by measuring the optic angles of 11 grains in two specimens, is chrysolite, Fo_{80}. In most specimens, the olivine has completely altered to an olive-green saponitic clay, which has refractive indices about the same as balsam and a birefringence of about 0.02. In a few specimens, the olivine has altered to orange iddingsite.

The zeolite minerals that fill cavities in many of the flow rocks were not studied in detail, but thomsonite, laumontite, stilbite, a heulanditelike zeolite, and chabazite were identified in five specimens by X-ray and oil-immersion methods.

DACITIC AND RHYODACITIC FLOWS AND DOMES

Dacitic and rhyodacitic flows and domes make up only a small part of the Little Butte Volcanic Series. They are generally composed of aphanitic rocks containing 10 percent or less phenocrysts, but a few are glassy, and a few contain as much as 30 percent phenocrysts. In many rocks, because the groundmass is devitrified and the original texture destroyed, it is difficult to ascertain whether the rock is a flow or welded tuff.

About one-half of the 14 samples of silicic flow rocks that were studied are flow banded. The lighter colored bands are thinner, ranging from 1 to 3 mm in width, and are coarser in grain size. Many of the bands contain feldspar phenocrysts or inclusions. One-half of a typical banded dacite from the northwest slope of Saddleblanket Mountain is made up of such light-colored bands; these lie in a darker microcrystalline groundmass crowded with minute laths of oligoclase. The light-colored bands contain about 15 percent phenocrysts of sodic andesine set in a fine-grained groundmass of oligoclase and tridymite, the latter occurring as the typical wedge-shaped twins.

The glassy groundmass of all but a few specimens has been divitrified, usually to an aggregate too fine grained to be identified under the microscope. Three such specimens were studied using X-ray diffraction; the groundmass of two consists of chalcedonic quartz, alkali feldspar, and cristobalite, and the groundmass of the third consists of chalcedonic quartz and heulandite. In most of the specimens, the pyroxene and hornblende have completely altered to either magnetite and quartz or magnetite and a green clay.

A few of the silicic flow rocks contain spherulites. The spherulites are particularly well-developed in a rhyodacite flow exposed along Hills Creek. A sample of the flow contains about 20 percent spherulites that range from ½ to 2 mm in diameter; most of the spherulites are clustered around phenocrysts of oligoclase.

The dacitic flow rocks contain sparse to moderately abundant plagioclase phenocrysts that range in composition from sodic andesine to sodic labradorite (An_{30-55}) and also contain a few percent pyroxene (orthopyroxene or clinopyroxene or both) or hornblende and magnetite. Dacitic rocks differ greatly in appearance, both in hand specimen and in thin section. The most abundant varieties are described below.

A widespread but not abundant type of dacite rock, exemplified by an olive-gray porphyritic flow along Gale Creek, contains about 4 percent quartz in partially resorbed bipyramids, 21 percent andesine, 1 percent orthopyroxene, and 1 percent magnetite in a finely devitrified groundmass consisting mostly of chalcedony and alkalic feldspar; the estimated silica content from the refractive index of a fused bead is 73 percent. Another type, exemplified by a black columnar-jointed aphanitic flow along Fall Creek due south of Green Mountain, contains about 7 percent sodic labradorite, 1 percent magnetite, 1 percent hypersthene, and a trace of augite in a very fine-grained groundmass containing felted microlites of alkalic feldspar and grains of magnetite in pale brown glass; the estimated silica content is 66 percent. A black pitchstone from the South Fork of the McKenzie River at the mouth of Cougar Creek contains about 5 percent phenocrysts of sodic labradorite and 1 percent hypersthene (En_{70}), in pale-brown glass containing felted microlites of sodic andesine and potash feldspar, rods of orthopyroxene, and grains of magnetite. The light-gray porphyritic dacite of a dome at the southern end of the Coburg Hills, which was described by Lewis (1950), contains about 20 percent intermediate andesine (An_{35-40}) and 2 percent magnetite in a fine-grained groundmass of chalcedony and alkalic feldspar, 59 percent; cristobalite, 16 percent; altered pyroxene, 2 percent; and magnetite, 1 percent; the estimated silica content is 72 percent. A greenish-gray platy flow from the valley of Sharps Creek between Walker and Bucks Creeks contains about 18 percent sodic labradorite, 4 percent brown hornblende that is largely altered to magnetite and quartz, and 1 percent additional magnetite, all in an intersertal groundmass of andesine and microcrystalline material. In table 7, column 14, is listed a chemical analysis of a flow rock which was described as augite andesite (Callaghan, 1933), but the analysis indicates that it would probably be classified as dacite in this investigation. The chemical analyses of two samples from dacite plugs and the mode of one are given in table 8, columns 13 and 16.

Rhyodacitic flows are composed of very light gray to pale-red flow-banded rocks. Four specimens examined under the microscope contain from 5 to 10 percent phenocrysts of oligoclase, 1 percent or less hornblende or pyroxene, and from 0 to 5 percent quartz in a devitrified groundmass. The hornblende is pleochroic from light brown to olive. The chemical analyses of two samples and the mode of one are given in table 7 (columns 17, 21).

DISTRIBUTION OF VOLCANIC VENTS

About 30 vents of the volcanic rocks of the Little Butte Volcanic Series, which have been identified as a result of this and earlier investigations, are plotted in figure 15. Those plotted undoubtedly are only a fraction of the total number of vents; few were identified because of the reconnaissance nature of the mapping and the extensive cover of younger rocks in the northern part of the map area.

Vents of the silicic rocks of the Little Butte that were located by mapping silicic plugs occur at Stone Mountain, on Fall Creek south of Goat Point, and at Jumpoff Joe Mountain (pl. 1). Other silicic plugs (on pl. 1) were mapped by Callaghan and Buddington (1938, p. 41–42, 83–84, 114–115; pl. 1, 13, 16, 20; fig. 7) in the Bohemia, Fall Creek, Blue River, and North Santiam districts. A vent along the upper part of Blowout Creek is inferred from the local abundance of silicic flows and breccia. A large mass of silicified rock at Quartz Mountain in the South Umpqua drainage is questionably interpreted as a plug (Ramp, 1960). The known silicic vents thus lie in a belt in the eastern part of the Western Cascade Range that extends from Quartz Mountain at the south, through the Bohemia district, to the North Santiam district at the north. Significantly, much of the Little Butte Volcanic Series in this belt consists of tuff, flows, and domes of dacite and rhyodacite.

Vents of the mafic rocks of the Little Butte Volcanic Series were identified from the local abundance of dikes and coarse scoriaceous rubble breccia at the following localities: 2 miles east of Jasper; 3 miles south of Mount June; Taft Mountain; 1 and 6 miles east of Mehama; and on Rock Creek, 3 miles south of Molalla. Other mafic plugs of this same series that were recognized and mapped in this study (pl. 1) include those also mapped by the following earlier investigators: Callaghan and Buddington (1928, pl. 13; also see Buddington and Callaghan, 1936, p. 428) in the Bohemia district 2½ miles south of Horse Rock; Wells and Waters (1934, p. 18–19) in the Black Butte district at Buck Mountain (their Steens Butte) and at Bald Mountain and Harness Mountain, a short distance west of the map area; and Allison and Felts (1956) at Peterson Butte. The known mafic vents lie in a belt in the western part of the Western Cascade Range that extends from Taft Mountain at the south to Peterson Butte and then northward along the foothills to Rock Creek. Flows, breccia, and tuff of basalt and andesite are, significantly, most abundant in the Little Butte Volcanic Series along this belt. The

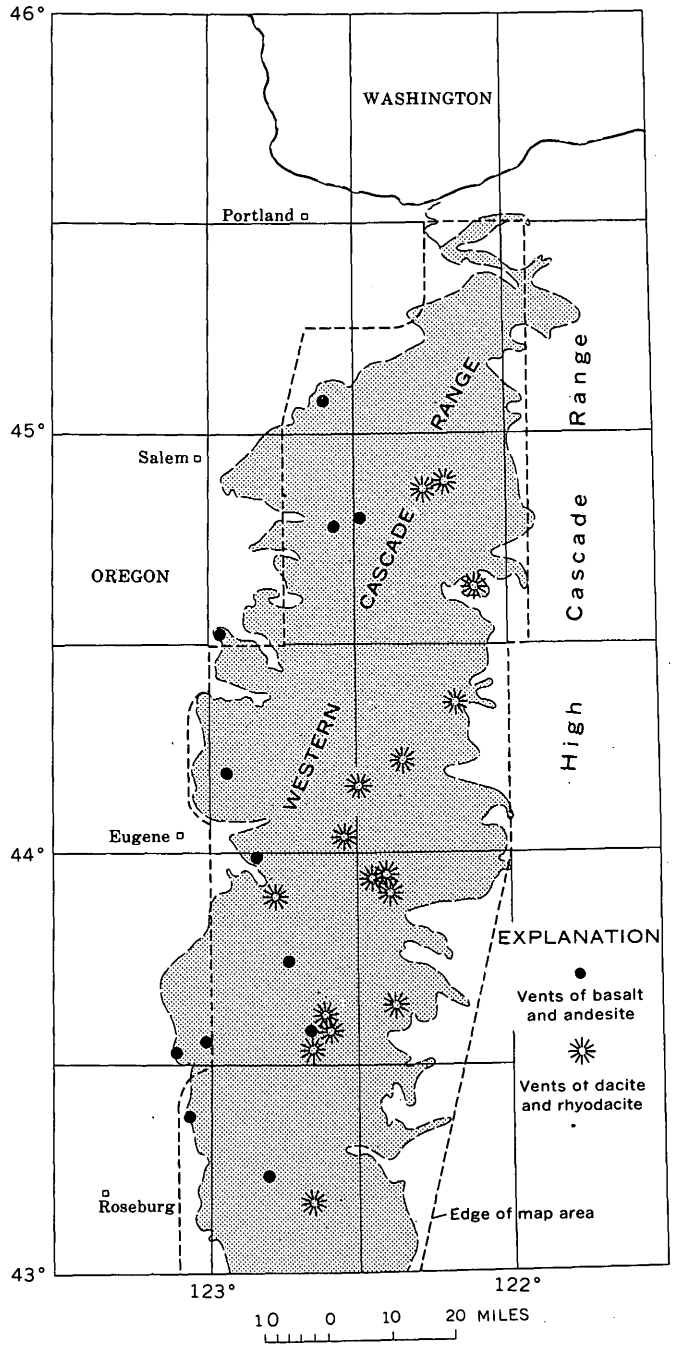


FIGURE 15.—Location of known volcanic vents of the Little Butte Volcanic Series of Oligocene and early Miocene age in the Western Cascade Range in Oregon north of lat. 43°. Western Cascade Range lightly shaded.

plugs in the Black Butte district, at the southwestern margin of this belt, may have fed andesitic rocks in the lower part of the Little Butte Volcanic Series. Possibly these plugs occur in a separate belt of vents.

The volcanoes fed by the vents of the Little Butte Volcanic Series thus lay in two or three belts; they probably formed north-trending mountain chains along the site of the present Western Cascade Range.

Williams (1949; 1957) has suggested that the bulk of the volcanic rocks of the Western Cascade Range was fed through fissures, now represented by dike swarms. Scattered dikes were noted in the present study, but no dike swarms were found; however, more detailed mapping in the future may reveal such swarms.

AGE AND CORRELATION

The age of the Little Butte Volcanic Series ranges from early or middle Oligocene to early Miocene. It overlies the upper Eocene Colestin Formation and interfingers with fossiliferous marine beds of middle and late Oligocene and early Miocene age (fig. 5). The Little Butte is overlain by unfossiliferous Columbia River Basalt of presumed middle Miocene age and by sparsely fossiliferous volcanic rocks of the middle and upper Miocene Sardine Formation.

Diagnostic fossil plant collections have been made from 21 localities in the map area and from 10 localities nearby. The floras from 25 of these, which have been identified by Jack A. Wolfe and Roland W. Brown, are given in table 4; locations are given in figure 16 and are plotted on the geologic map (pl. 1). The flora from Rujada (USGS Paleobot. loc. 8693) has been described by Lakhanpal (1958), and floras from localities a short distance west and north of the map area have been described by Chaney (1920), Chaney and Sanborn (1933), and Sanborn (1947). A plant locality in the Little Butte Volcanic Series near Quartz Mountain in the SW¼ sec. 26, T. 28 S., R. 1 E, was recently described by Ramp (1960).

TABLE 4.—*Checklist of fossil plants from the Little Butte Volcanic Series in the Cascade Range in Oregon*

[Identified by Jack A. Wolfe and Ronald W. Brown. Locality numbers shown on figure 16]

Species	U.S. Geological Survey Paleobot. locality									
Middle Oligocene age										
	9105	9107	9291	9292	9386	9419	9431	9432	9462	9468
Lastrea fischeri				X						
Woodwardia sp., n. sp				X						
Metasequoia glyptostroboides			X	X				X		
Sequoia affinis	X	X	X					X	X	
Fokienia praedecurrens					X					
Pinus sp						X			X	
Fissus goshenensis						X				
Cercidiphyllum crenatum			X					X		
Ocoteo eocernua				X	X	X				
ovoidea		X								
Nectandra presanguinea					X					
Phoebe oregonensis	X	X		X				X	X	
Hydrangea sp	X									
Platanus sp., n. sp	X	X	X							
Prunus franklinensis			X							
pristina	X									
Rhus magnafolia				X						
Meliosma aesculifolia	X			X				X		
rostrata						X				
Allophylus wilsoni	X									
Tetracera oregona		X				X	X			X
Saurauja sp., n. sp			X	X				X		
Alangium thomae			X	X				X		
Cordia oregona	X	X								
Grewiopsis? dubium	X									
Holmskioldia speiri							X			

TABLE 4.—*Checklist of fossil plants from the Little Butte Volcanic Series in the Cascade Range in Oregon*—Continued

Species	U.S. Geological Survey Paleobot. locality					
Late Oligocene age						
	8639	8903	9262	9351	9434	9444
Ginkgo biloba				X		
Metasequoia glyptostroboides		X		X		
Sequoia affinis	X	X		X	X	
Cunninghamia chaneyi	X			X		
Pinus ponderosa		X			X	
Abies concolor	X		X			
Fokienia praedecurrens			X	X		
Engelhardtia sp., n. sp	X					X
Juglans orientalis				X	X	
Alnus carpinoides	X	X	X	X		X
Quercus consimilis	X	X	X		X	X
Ulmus speciosa				X		
Cinnamomum bendirei				X		
Hydrangea sp					X	
Platanus sp., n, sp	X	X	X		X	
Exbucklandia oregonensis	X					
Crataegus newberryi	X					
Sophora sp				X		
Rhus magnafolia				X		
varians	X	X			X	
Acer glabroides				X		
macrophyllum			X	X		
Terminalia sp	X			X		
Alangium thomae	X	X				
Holmskioldia speiri			X			

Early Miocene age									
	8962	9256	9350	9418	9424	9448	9486	9673	9674
Cunninghamia chaneyi		X							
Metasequoia glyptostroboides	X	X	X		X				X
Sequoia sempervirens	X	X	X		X				
Taxodium distichum	X	X		X	X				
Pinus ponderosa		X					X		
Picea magna							X		
Chamaecyparis nootkatensis							X		
Fokienia praedecurrens	X	X			X				
Populus delicata		X							
voyana		X							
lindgreni	X	X		X					
Salix inquirenda	X	X							
Juglans oregoniana	X	X							
Engelhardtia olsoni								X	
Carya bendirei	X	X							
Pterocarya mixta		X	X		X			X	
Alnus sp., n.p		X			X			X	
relata	X	X							
Betula sp., n. sp			X				X		
Fagus sp., n. sp	X	X		X	X			X	
sanctieugeniensis	X								
Quercus sp., n. sp	X	X	X	X	X	X			X
sp., aff. *Q. pseudolyrata*	X	X					X		
columbiana	X	X							
Ulmus speciosa	X	X			X			X	
Zelkova oregoniana	X	X			X				
Cocculus heteromorpha		X							
Magnolia oregoniana	X	X						X	
Cinnamomum bendirei								X	
Lindera sp., n. sp		X			X				X
Litsea sp., n. sp					X				X
Ocotea ovoidea					X				
Sassafras hesperia			X						
Hydrangea bendirei		X							X
Exbucklandia oregonensis	X	X	X						
Liquidambar pachyphylla	X	X			X			X	
Platanus sp., aff. *P. dissecta*	X	X	X		X	X	X		
Crataegus pacifica		X							
Sophora spokanensis	X	X				X			
Cedrela traini	X						X	X	
Rhus sp., aff. *P. magnafolia*	X	X						X	
sp. aff. *P. varians*		X			X			X	
Acer chaneyi		X	X						
glabroides		X							
macrophyllum		X	X				X		X
minutifolium		X					X		
Thouinia sp., n. sp								X	
Meliosma sp., n. sp	X				X				
Berchemia sp., n. sp	X	X						X	
Vitis sp. ,n. sp	X	X							
Idesia sp., n. sp		X			X				
Xylosma sp., n. sp		X						X	
Nyssa knowltoni	X	X							
Arbutus sp., n. sp		X	X						
Symplocos sp., n. sp	X	X						X	
Paulownia columbiana		X						X	

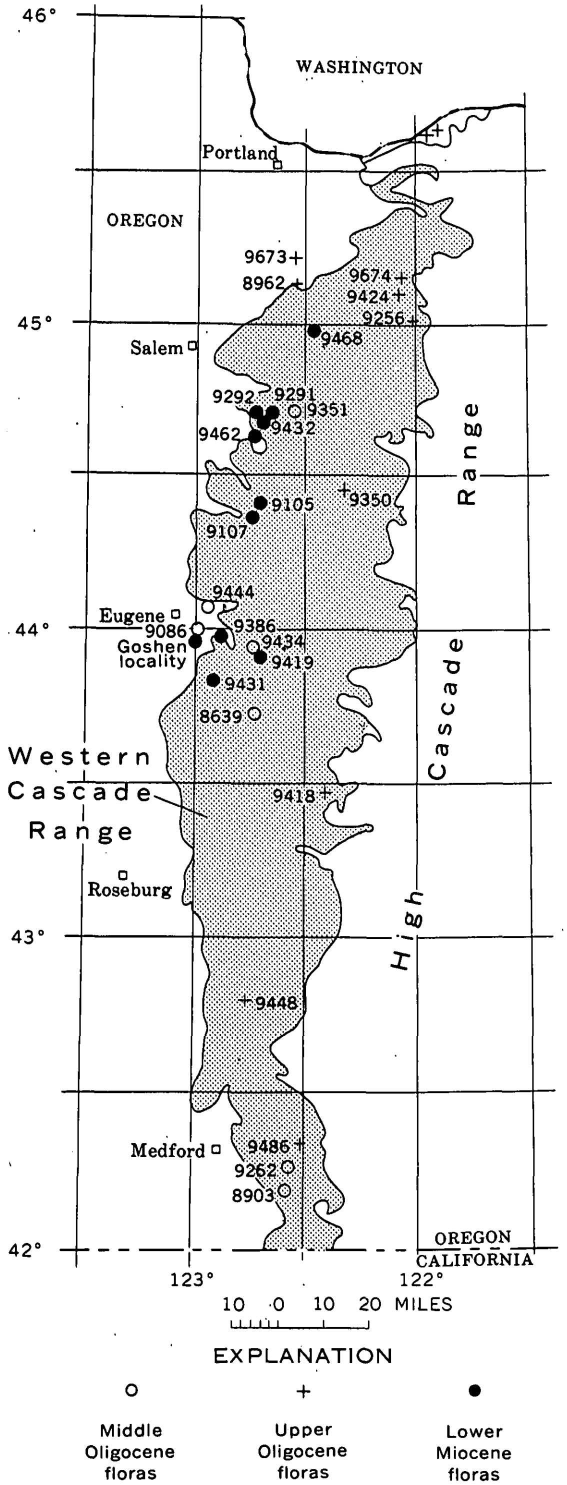


FIGURE 16.—Location of Oligocene and lower Miocene plant localities in the Little Butte Volcanic Series in the Cascade Range in Oregon. Numbers are USGS Paleobot. locality numbers. Plants are given in table 4. Western Cascade Range lightly shaded.

USGS Paleobot. loc.	*Location*
8639	NE¼SE¼ sec. 30, T. 21 S., R. 1 E.: near Rujada.
8903	Sec. 8, T. 39 S., R. 2 E.; on the former Kincaid ranch, east of Ashland (south of the area of this investigation).
8962	Ctr. sec. 22, T. 5 S., R. 2 E.; near Molalla.
9105	NE¼SW¼ sec. 20, T. 13 S., R. 1 E.; near Sweet Home.
9107	SE¼ sec. 36, T. 13 S., R. 1 E.; near Sweet Home.
9256	SW¼NE¼ sec. 36, T. 6 S., R. 6 E.; on the slope east of the Collawash River.
9262	SE¼ sec. 9, T. 38 S., R. 2 E.; at Shale City (south of the area of this investigation).
9291	SE¼SW¼ sec. 9, T. 10 S., R. 1 E.; on Bilyeu or Neal Creek.
9292	SW¼SE¼ sec. 5, T. 10 S., R. 1 E.: on lower Thomas Creek.
9350	NE¼ sec. 16, T. 13 S., R. 4 E.; north of Cascadia.
9351	NW¼NE¼ sec. 16, T. 10 S., R. 2 E.; on the slopes north of Thomas Creek.
9386	SE¼SW¼ sec. 10, T. 18 S., R. 2 W.; near Jasper.
9418	NE¼ sec. 22, T. 24 S., R. 3 E.; on Coal Creek at Bristow Trail crossing.
9419	NW¼ sec. 36, T. 19 S., R. 1 E.; on the ridge above the former village of Landax.
9424	SW¼ sec. 33, T. 5 S., R. 6 E.; on the Sandstone Creek road.
9431	SE¼NE¼ sec. 13, T. 20 S., R. 2 W.; near the head of Rat Creek.
9432	SE¼NW¼ sec. 28, T. 10 S., R. 1 E.; on the Burmester Creek road.
9434	NW¼ sec. 28, T. 19 S., R. 1 E.; on the east side of the Lookout Point Reservoir.
9444	SW¼ sec. 20, T. 17 S., R. 2 W.; near Hayden Bridge.
9448	NW¼ sec. 1, T. 32 S., R. 1 W.; near Timbered Rock (south of the area of this investigation).
9462	SW¼NW¼ sec. 7, T. 11 S., R. 1 E.; at the mouth of Crabtree Creek.
9468	NW¼SW¼ sec. 16, T. 7 S., R. 3 E.; at the mouth of Gawley Creek.
9486	NE¼ sec. 13, T. 37 S., R. 2 1.; along Little Butte Creek (south of the area of this investigation).
9673	SW¼SW¼SW¼ sec. 27, T. 4 S., R. 2 E.; near Liberal.
9674	NW¼SE¼ sec. 16, T. 5 S., R. 6 E.; near Three Lynx Power Station on the Clackamas River.

Ae described by Jack A. Wolfe (written commun., February 1962), the floras range in age from middle Oligocene to early Miocene:

* * * The oldest floras are approximately contemporaneous with the Goshen flora (Chaney and Sanborn, 1933), and are characterized by the following species: *Ocotea eocernua, Phoebe oregonensis, Meliosma aesculifolia, Tetracera oregona,* and *Alangium thomae.* All of these species belong to genera that are today tropical or subtropical, thus indicating that the middle Oligocene climate of western Oregon was tropical or subtropical.

Younger floras that are equivalent to the Bridge Creek flora of the lower member of the John Day Formation are of late Oligocene age:

* * * These floras have all been considered to be warm temperate, but the plants from a late Oligocene locality (USGS Paleobot. loc. 9086) indicate that the flora was subtropical, at least in the coastal regions. This locality contains species of supposedly temperate *Alnus, Quercus, Acer,* and *Crataegus* in association with species of subtropical genera such as *Engelhardtia, Cinnamomum, Trema, Exbucklandia, Tetracera, Alangium* and *Paleophytocrene.* The last genus is particularly significant because all of its living relatives are lianas of the

tropics. The more warm-temperate aspect of the late Oligocene floras located within the present Cascades probably results from their growth at higher elevations with less influence of a marine climate.

The floras of early Miocene age include two distinct types:

* * * The older type (9350, 9424, 9673, 9674) contains a mixture of Miocene and Oligocene species. The most notable aspect of this type is the complete lack of lobed black and white oaks, in contrast to the younger type of flora (9418, 9448, 8962, 9256, 9486), which contains an abundance and diversity of these oaks. The older early Miocene floras appear to be similar climatically to the late Oligocene floras, that is, subtropical to very warm temperate. By the end of the early Miocene, the subtropical element was considerably reduced, and the floras are generally warm temperate.

Marine sandstone and tuff of middle Oligocene age (described on p. 25) are exposed beneath tuff and flows of the Little Butte Volcanic Series at several localities between Dorena Dam and Lebanon, such as the western flank of Cougar Mountain and of the Coburg Hills. These marine beds are assigned to the upper part of the Eugene Formation by Vokes and others (1951). Marine beds of the Eugene Formation in turn overlie nonmarine tuff of the Little Butte at several localities less than a mile west of the map area between Creswell and Springfield; 2 miles south of Goshen this tuff has yielded a large flora of middle Oligocene age (J. A. Wolfe, written communication, 1962; flora described by Chaney and Sanborn, 1933). Four miles south of Brownsville, basaltic lavas and tuff of the Little Butte contain a tongue of fossiliferous marine tuff of middle Oligocene age that extends east to sec. 28, T. 14 S., R. 2 W. Ten miles farther east, fossil wood in tuff of the Little Butte contains cubic pseudomorphs of quartz after halite (Staples, 1950). Staples (1950) has concluded that the halite formed in the wood in a saline marine lagoon and was later replaced by silica when the wood was buried by ash. The marine beds along the flank of Cougar Mountain and the Coburg Hills very probably interfinger with nonmarine beds of the Little Butte a few miles east of their outcrop; marine beds at this horizon were not observed in the cores of the anticlines that extend through Cougar Mountain and Leaburg Dam.

Marine sandstone and tuff of late Oligocene and early Miocene age (described on p. 25) underlie tuff of the Little Butte Volcanic Series in the valleys of Butte and Rock Creeks. These marine beds (Butte Creek Beds of Harper, 1946) in turn overlie basaltic flows and tuff that are exposed along Rock Creek and also along Butte Creek 3 miles east of Scotts Mills. The sequence of plant-bearing tuff, fossiliferous marine tuff, and basaltic flows and tuff is well exposed between Beaver Lake School and Teasel Creek. The basaltic rocks were questionably assigned to the Eocene on the basis of a few fragmentary marine fossils in an underlying conglomeratic sandstone (Harper, 1946). These are now tentatively assigned to the Little Butte Volcanic Series, because they have yielded fossil plants of Oligocene age from the mouth of Gawley Creek (USGS Paleobot. loc. 9468, table 4; figure 16) and because they are petrographically similar to the basaltic rocks in the Little Butte farther south in the Western Cascade Range.

Other rocks that are assigned to the Little Butte Volcanic Series in this report have been assigned to older or younger formations in the map area and adjoining regions by previous workers. The stratigraphic assignment of these rocks is discussed in the following pages.

Flows of olivine basalt and andesite that cap the Coburg Hills and the hills west of the Coast Fork of the Willamette River between Eugene and Cottage Grove were mapped as post-Oligocene basalt by Vokes and others (1951); they described the flows as overlying the Eugene and Fisher Formations with an angular unconformity and suggested that the flows are of middle Miocene or younger age. These flows are assigned to the Little Butte Volcanic Series of Oligocene and early Miocene age in this report for the following reasons: (1) intercalated with the unit of flows are beds of tuff of the Little Butte that have yielded plants of late Ologocene and early Miocene age near Hayden Bridge (USGS Paleobot. loc. 9444) and on the north side of Lookout Point Reservoir (9418), (2) the unit of flows contains a tongue of fossiliferous marine tuff of middle Oligocene age 4 miles south of Brownsville, and (3) the flows are overlain unconformably by Columbia River Basalt of middle Miocene age near Holley. The angular unconformity at the base of the unit of flows, which was noted by Vokes and others (1951) in the Eugene area, was not observed in the Western Cascade Range. The base of the unit of flows and the underlying beds are conformable in those areas of the Western Cascades east of Eugene where the base of the flows has been mapped with adequate precision, and dips and strikes in the underlying beds are sufficiently abundant; two such areas are the hills immediately east of Jasper and Natron and the slopes west of Lost Creek. The angular discordance apparently dies out a short distance east of Eugene. However, the widespread occurrence of volcanic conglomerate at the base of this unit of flows suggests that the angular unconformity may be represented by a disconformity in parts of the Western Cascade Range east of Eugene; conglomerate was noted at this horizon near Walker Lookout in the Fall Creek drainage and at several places on the ridge between Lost Creek and Row River (sec. 23 and 25,

T. 19 S., R. 2 W.; sec. 2, T. 20 S., R. 2 W.; sec. 17, T. 20 S., R. 1 W.).

Approximately 1,000 feet of water-laid tuff (Molalla Formation of Harper, 1946), which dips gently northward along the Molalla River between the mouth of Trout Creek and Dickey Prairie, was considered to be younger than the Columbia River Basalt by Harper (1946), Lowry and Baldwin (1952), and Trimble (1957). These rocks have been included in the Little Butte Volcanic Series, thus are considered to be older than the Columbia River Basalt, for the following reasons: (1) the water-laid tuff has yielded fossil plants of early Miocene age from road banks near the Molalla River in sec. 22, T. 5 S., R. 2 E., (USGS Paleobot loc. 8962, table 4 and fig. 16). (2) Two to 6 miles west of the Molalla River and at about the same stratigraphic position as the water-laid tuff along the Mollala River, is 200 to 600 feet of fossiliferous marine tuff and sandstone of late Oligocene and early Miocene age (age discussed on p. 26); these beds underlie about 200 feet of nonmarine tuff that is similar to the water-laid tuff along the Molalla River. (3) The water-laid tuff along the Molalla River is not in contact with Columbia River Basalt, but the marine beds of late Oligocene and early Miocene age and the overlying nonmarine tuff are exposed beneath Columbia River Basalt at many localities; for example, on the road 3 miles east of Beaver Lake School, near the top of the cliffs above Butte Creek due south of Beaver Lake School, and at Scotts Mills.

Volcanic conglomerate and water-laid tuff in the upper Clackamas River valley south and west of the Oak Grove Ranger Station were named the Bull Creek Beds by Barnes and Butler (1930) and questionably correlated with the Umpqua Formation by Hodge (1932, 1938a). The Bull Creek Beds were separated from the overlying flows, breccia, and tuff of the Eagle Creek Formation (part of the Little Butte Volcanic Series of this report) because the Bull Creek Beds dip steeply in contrast to the almost flatlying strata of the Eagle Creek Formation. The Bull Creek Beds are assigned to the Little Butte Volcanic Series in this report because the steep dips and variable strikes are not the result of tectonic deformation but of slumping, which is widespread in the upper Clackamas River valley where Columbia River Basalt overlies soft tuff.

MARINE TUFF AND SANDSTONE

Marine beds of tuff and sandstone interfinger with the nonmarine Little Butte Volcanic Series in the foothills of the Cascade Range between Dorena Dam and Scotts Mills (fig. 5). The inferred location in the area of the Cascade Range of marine shorelines during the middle Oligocene and the early Miocene is shown in figure 17. The marine beds between Dorena Dam and Lebanon are of middle Oligocene age and are assigned to the Eugene Formation by Allison and Felts (1956) and Vokes and others (1951). The lithologically similar marine beds near Scotts Mills are of late Oligocene and early Miocene age and were called the Butte Creek Beds by Harper (1946). The beds in the two areas are treated as a unit in this report because they could not be separated on the basis of lithology and because further work may show them to be partly contemporaneous.

South of Lebanon, there marine beds are exposed within the map area at Peterson Butte, below Washburne Butte, along the western flank of the hills from Brownsville to Springfield, along the western flank of Cougar Mountain, and at Dorena Dam. The marine

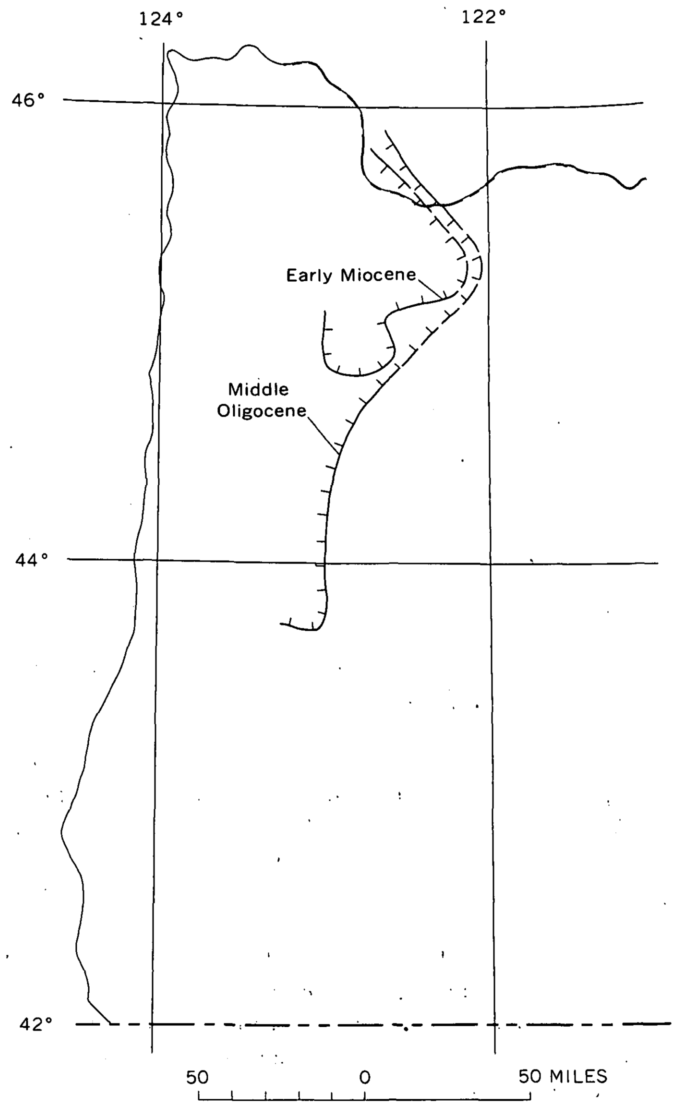


FIGURE 17.—Inferred location of middle Oligocene and early Miocene marine shorelines in the area of the present Cascade Range, Oreg.

beds are a few hundred feet thick and represent only the upper part of the Eugene Formation. The base of the marine unit is not exposed, except for the base of a thin tongue that is intercalated in basaltic rocks near Brownsville. The Eugene Formation thickens rapidly westward, as Vokes and others (1951) estimate it to be about 8,000 feet thick near Eugene. However, if it is faulted along the edge of the Coburg Hills, as suggested by Washburne (1914) and Lewis (1950), the formation may be only about half that thick. Near Scotts Mills, as much as 600 feet of marine beds is exposed along Rock, Butte, Abiqua, and Silver Creeks. The beds overlie basaltic rocks tentatively assigned to the Little Butte Volcanic Series, and interfinger eastward with nonmarine tuff of the Little Butte.

The marine rocks in both areas are thin-bedded to massive shallow-water deposits of tuff, volcanic wacke, arkosic wacke sandstone, and less abundant siltstone, granule sandstone, pebbly conglomerate, and impure coquina. Most of the sandstone and tuff is medium or fine grained and light gray or shades of greenish gray. Pebble and granule layers and carbonized plant debris are locally abundant. Molds and casts of molluscs are found in some beds. A 6-foot layer of thin-bedded olive-green coquina containing abundant volcanic debris has been quarried for agricultural lime 1½ miles east of Marquam.

Thin sections of volcanic wacke from the head of Pierce Creek and from beneath the bridge at Scotts Mills contain rounded to subangular grains of andesite (30 percent), andesine feldspar (10–20 percent), quartz (5–10 percent), and traces of augite, magnetite, blue-green hornblende, muscovite, and biotite, in a matrix (40–50 percent) of ash altered to green clay and zeolite. Two thin sections of arkosic wacke from Butte Creek near the mouth of Coal Creek contain one-third subrounded grains of quartz, alkali feldspar, and quartzite, as well as scattered grains of muscovite, biotite, and glauconite, in an abundant matrix of kaolinitic(?) clay. Calcite has replaced many feldspar grains and some of the matrix, and iron oxides have stained some of the matrix. A water-laid dacitic tuff from the valley of Rock Creek 1 mile northwest of Beaver Lake School contains abundant angular pumice fragments and shards and about 5 percent oligoclase and 1 percent pyroxene, in a matrix of fine ash; the pumice, shards, and ash are altered to zeolite and green clay. The fact that volcanic material in these marine rocks ranges from well-rounded lithic grains to nonabraded angular shards indicates that the material includes both pyroclastic and epiclastic debris.

The marine tuff and sandstone exposed in the map area between Lebanon and Dorena Dam include only the younger beds of the Eugene Formation. On the basis of fossil molluscs collected from 10 localities, these beds are considered middle Oligocene in age, equivalent to the "Lincoln" stage of Weaver and others (1944). The fauna and the location of eight localities along the western edge of the Coburg Hills and near Dorena Dam are listed by Vokes and others (1951). Collections from other localities a few miles south of Brownsville (NE¼ sec. 7, T. 15 S., R. 2 W., and SE¼ sec. 24, T. 14 S., R. 3 W.) were identified by Ellen Moore of the U.S. Geological Survey (written comm., 1956). Vokes and others (1951) concluded that the age of the Eugene Formation in the Eugene area is early and middle Oligocene, equivalent to the upper part of the "Keasey" and the "Lincoln" stages of Weaver and others (1944).

The marine tuff and sandstone near Scotts Mills are dated on the basis of several small collections of marine molluscs, most of which came from the valley of Butte Creek. The strata were considered equivalent to the lower Miocene Vaqueros Formation of California by Durham (*in* Durham, Harper, and Wilder, 1942) and equivalent to the upper Oligocene and lower Miocene Blakeley stage of Weaver and others (1944) by H. E. Vokes (written commun., November 1955). Vokes reports the following fauna from a collection by W. C. Warren from the N½ of sec. 30, T. 6 S., R. 2 E.: *Bruclarkia* cf. B. *acuminata* (Anderson and Martin), *Echinophoria* cf. *E. apta* (Tegland), *Natica Calyptraca*, *Acmaea*, *Anomia*, *Mytilus*, *Chlamys* aff. *C. columbianum* (Clark and Arnold), and two species of brachiopoda. On the basis of this fauna, he suggests a correlation with the Scappoose Formation in the upper Nehalem River basin.

Tuffaceous marine strata that are correlative with the marine Oligocene and Miocene beds of the Cascade Range crop out along the western side of the Salem and Eola Hills (tuffaceous sandstone unit of Oligocene age of Baldwin and others, 1955) and in the upper Nehalem River basin (Pittsburg Bluff Formation of middle Oligocene age and Scappoose Formation of late Oligocene and early Miocene age, described by Warren and Norbisrath, 1946).

COLUMBIA RIVER BASALT

GENERAL FEATURES

Thick columnar-jointed flows of dark fine-grained basalt, which overlie the Little Butte Volcanic Series and marine sandstone and tuff of Oligocene and Miocene age in the Western Cascade Range in northern Oregon, are assigned to the Columbia River Basalt in this report. Outcrops of the basalt along the Bull Run River at the northern edge of the map area are separated by a covered interval, only 4 miles wide, from outcrops of similar basalt in the Columbia River Gorge. Williams (1916), Hodge (1938b), Waters (1961), and others have traced the basalt from the gorge eastward into the widespread flows of basalt called Columbia River Basalt by Russell (1893, 1901), Merriam (1901), and later workers. Basalt flows east of Stayton also have been mapped as Columbia River Basalt. These were described as the Stayton Lavas by Thayer (1936, 1939), who suggested a correlation with the Columbia River Basalt.

Within the map area, the Columbia River Basalt is discontinuously exposed in the foothills of the Cascade Range from Holley to Molalla and along the Clackamas, Sandy, Salmon, and Bull Run Rivers (pl. 1; fig. 18). The distribution of outcrops of Columbia River Basalt in the map area north of lat. 45° and the outcrops mapped by Waters (in Wells and Peck, 1961) between Mount Hood and Maupin indicate that the basalt probably extends across the Cascade Range beneath younger rocks along an east-west belt that extends 40 miles south of the Columbia River. Several small isolated outcrops of basalt questionably correlated with the Columbia River Basalt were mapped 3 miles southeast and 6 miles northeast of Detroit and on the Molalla River in T. 7 S., R. 4 E.

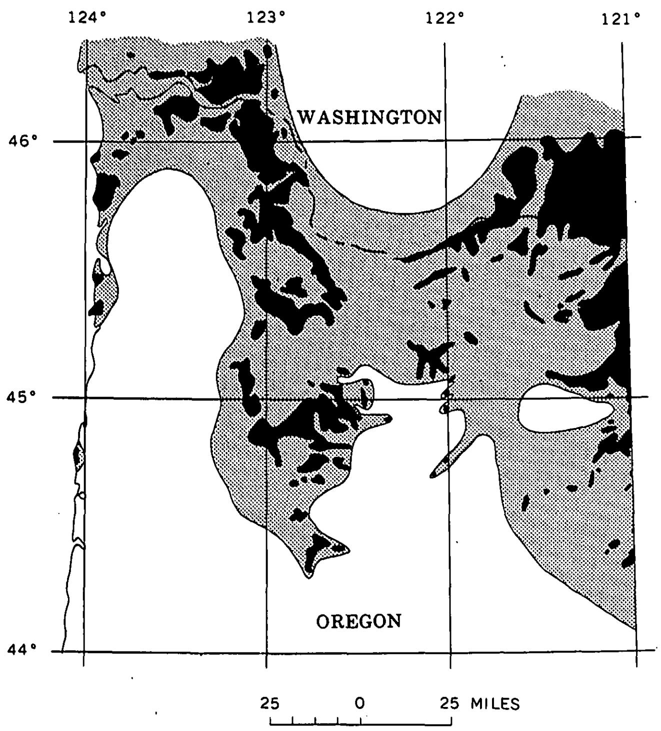


FIGURE 18.—Outcrop areas and inferred original extent of Columbia River Basalt and volcanic rocks of the Astoria Formation in northwestern Oregon and parts of southwestern Washington (data on outcrop areas from Wells and Peck, 1961; A. C. Waters, written comm., 1959; Hutting and others, 1961).

The maximum thickness of the Columbia River Basalt in the map area is about 1,500 feet along the Clackamas River; near Sweet Home and southeast of Scotts Mills, it is about 600 feet thick. To the north within the Columbia River Gorge, it is 2,500 feet thick according to Williams (1916). The basalt thins eastward to a feather edge along North and South Santiam Rivers, Thomas Creek, and the Molalla and Clackamas Rivers. Except for three questionable outcrops, it is missing in the higher parts of the Western Cascade Range south of lat 45° and throughout the Western Cascade Range south of lat 44°15′, even though the appropriate stratigraphic horizon reaches the surface in these areas.

An angular unconformity at the base of the Columbia River Basalt is present in the western foothills of the Cascade Range in Oregon. In the valley of Thomas Creek the base of the basalt rises smoothly eastward from an altitude of 600 feet at Franklin Butte (Allison and Felts, 1956) to 1,200 feet at McCully Mountain, while the underlying tuffs of the Little Butte Volcanic Series dip consistently eastward or are flat lying. Southeast of Scotts Mills the top of the basalt rises eastward from an altitude of 1,200 feet in sec. 17, T. 7 S., R. 1 E., to an altitude of 1,800 feet in sec. 7, T. 8 S., R. 2 E.; the underlying marine beds of late Oligocene and early Miocene age along Abiqua and Butte Creeks dip to the southeast.

The original extent of Columbia River Basalt in the Cascade Range in Oregon apparently has not been much reduced by erosion; the basalt has been protected by a conformable cover of middle and upper Miocene strata (see p. 31). Its present distribution in the range thus does not reflect subsequent erosion but rather distance from sources and the topography of the prebasalt surface. The sources apparently were in northern Oregon and Washington outside the Cascade Range (p. 28), and the extent of the basalt in the range in northern Oregon was limited by topographic highs; the basalt lapped out against an ancestral Cascade Range. The location of the basalt in the map area accordingly is in former low-lying areas adjacent to this ancestral range; the belt of outcrops that cross the present range just south of the Columbia River was a broad valley that crossed the Miocene range—perhaps the valley of an ancestral Columbia River. In the western foothills of the present range in northern Oregon, the basalt poured out upon a surface of at least 800 feet of relief and filled stream valleys near Sweet Home and Scotts Mills. The relief at the base of the basalt is clearly shown by irregularities in the contact between the basalt and underlying marine beds southeast of Scotts Mills along Butte Creek and the Crooked Finger Road.

Along the Clackamas River, the Columbia River Basalt thins southeastward from 1,500 feet to 0 in a distance of 6 miles. The basal flows along the Clackamas contain pillow structures and spiracles and are intercalated with palagonite tuff. The tuff contains sand, gravel, and angular blocks of andesite and tuff that were derived from the Little Butte Volcanic Series (this relationship is particularly well exposed at an altitude of 2,950 feet along a logging road in sec. 36, T. 5 S., R. 6 E.). In this area, flows of Columbia River Basalt terminated against a highland of Little Butte rocks, and debris eroded from the highland was deposited between successive basalt flows. The pillow lavas and palagonite tuff that are abundant at the margin of the highland suggest that streams or lakes were formed along the margin during rearrangement of drainage by the lava flows.

No vents for the Columbia River Basalt were identified in the map area. The almost total absence of flows of Columbia River Basalt in the higher parts of the Western Cascade Range south of lat 45° and the increased thickness of the basalt to the west in the foothills and to the northwest along the Clackamas River indicate that the basalt probably came from sources outside the Western Cascade Range. The basal flows along the Clackamas River flowed westward, as indicated by the bending of spiracles at three localities in secs. 8 and 16, T. 5 S., R. 6 E.; thus, at least some flows came from sources to the east, possibly from dike swarms in central Oregon or Washington, such as those described by Waters (1961, p. 587) near Monument and along the Tieton River. However, some of the flows may have come from dikes reported near Astoria (Warren and others, 1945) and in the upper Nehalem River basin (Warren and Norbisrath, 1946, p. 233) or from unknown vents.

LITHOLOGY AND PETROGRAPHY

The Columbia River Basalt consists almost entirely of thick columnar- and hackly-jointed flows of hard, tough dark-gray to black basalt and basaltic andesite. The basalt and basaltic andesite are very fine grained and consist of sodic labradorite, augitic pyroxene, magnetite, ilmenite, and occasional olivine in an abundant groundmass of dark dust-charged glass and chlorophaeite.

Where the basalt is particularly well exposed along the Clackamas River, individual flows range in thickness from 25 to 100 feet. Well formed columnar jointing is in the lower part of most flows, and the upper part has either poorly formed columnar jointing or hackly jointing. In a few flows, a third tier of columnar joints is present in the middle part of the flow. Platy jointing and blocky jointing are uncommon. Vesicles are moderately abundant near the top and less common near the base of most flows. Pillow structures, spiracles, and pipe vesicles were observed only along the upper Clackamas River, where they are associated with palagonite tuff in the lower part of the unit.

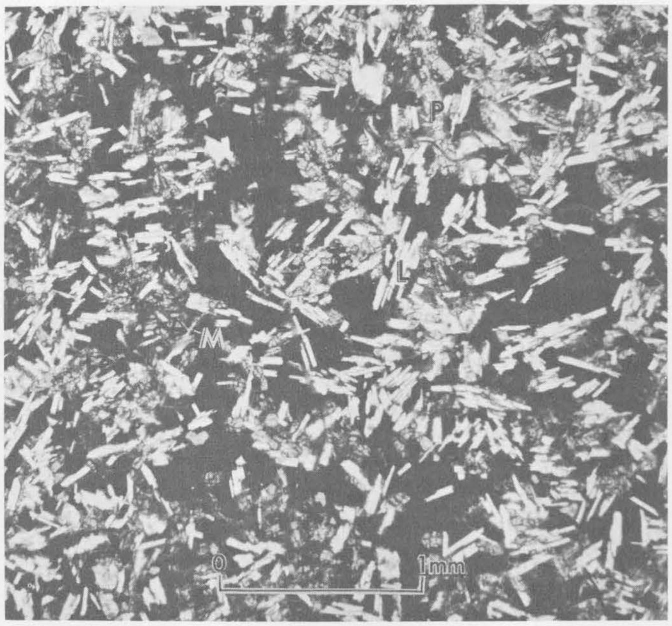


FIGURE 19.—Photomicrograph of hyalo-ophitic basalt in the Columbia River Basalt. Poorly terminated laths of sodic labradorite (L), prisms of pigeonitic and augitic pyroxene (P), and skeletal crystals of magnetite (M) are set in dark dust-charged glass. Sample P-55-6-24F.

With few exceptions, the basalt contains rare phenocrysts of feldspar, pyroxene, and olivine, as much as a few millimeters in diameter, in a groundmass in which thin, randomly oriented feldspar laths less than 1 mm in length are discernible with a hand lens. Weathering of the basalt yields a pale yellowish-brown to dark yellowish-orange rind in which a network of minute white feldspar laths form a framework for interstitial reddish material. The few flows that differ from the above description are medium to dark gray and contain abundant phenocrysts of feldspar and pyroxene as much as several millimeters long.

Almost all Columbia River Basalt contains nearly equal proportions of sodic labradorite and a groundmass of dust-charged glass and chlorophaeite, together with less abundant augitic clinopyroxene, accessory magnetite and ilmenite, and occasional olivine (fig. 19). The average grain size is generally about 0.2 mm but ranges from 0.1 to 0.5 mm. The textures range from the hyalo-ophitic to intersertal, to intergranular, or to subophitic as the amount of groundmass decreases. The average mineralogical composition of the Columbia River Basalt along the Clackamas River and in the foothills between the Molalla River and Thomas Creek, based on modal analyses of eight typical samples, is as follows: Plagioclase, 33 percent; glass, 33 percent; clinopyroxene, 22 percent; chlorophaeite, 6 percent; magnetite and ilmenite, 5 percent; and olivine, 1 percent. Olivine is present in only two of the eight samples, both of which are from the base of flows. The chemical analysis of a similar Columbia River Basalt flow from 4 miles north of Stayton is quoted from Thayer (1937) in table 7, column 1. The Columbia River Basalt near Sweet Home contains less glass and has a subophitic texture; the average of three modal analyses is as follows: plagioclase, 42 percent; clinopyroxene, 24 percent; glass, 15 percent; chlorophaeite, 10 percent; magnetite and ilmenite, 8 percent; and olivine, 1 percent.

Plagioclase in Columbia River Basalt forms unzoned poorly terminated laths, each of which is made up of two to six twin lamellae parallel to (010). Composition of the plagioclase from 10 samples, determined by measurement of Nx, ranges from about An_{45} to An_{55}, and in all but one of the samples is slightly more calcic than An_{50}.

Pyroxene occurs in very pale brown subhedral to euhedral prisms, which range from nearly equant to elongate. In most of the samples examined in detail, the pyroxene is ferroaugite, the composition of which is about $Wo_{35}En_{30}Fs_{35}$, on the basis of an average 2V of 45° (2V=30°–58° in 22 grains from three samples) and an average Ny of 1.710 (Ny=1.705–1.720±0.003 in grains from five samples). In a few samples, the pyroxene is wholly or in part pseudo-uniaxial pigeonite or ferropigeonite.

The glass is generally very dark brown and charged with "dust." Under an oil immersion lens each "dust" gain appears to be a gas bubble that is partly filled with a grain of magnetite(?). In many samples, incipient crystallization of the glass has yielded long thin crystallites and poorly formed crystals of pyroxene, feldspar, ilmenite, apatite, and dendritic magnetite.

Chlorophaeite, or a montmorillonitic clay formed from chlorophaeite, fills some of the interstices of almost all the rocks examined in thin section. The chlorophaeite is isotropic or very weakly birefringent; fresh material is blue green and has a refractive index about that of balsam, but weathered chlorophaeite is olive to red and has a refractive index greater than balsam. Most of the chlorophaeite occupies the same interstitial position and contains the same concentration of crystallites as adjacent glass; however, some occurs as incrustations on the walls of cavities, and a very minor amount occurs as discrete grains. The chlorophaeite appears to be deuteric in origin; that is, it formed in interstices where the volatiles concentrated from the crystallizing lava.

Magnetite appears to be more abundant than ilmenite in most of the thin sections of Columbia River Basalt that were examined, but the ratio of the two minerals in different specimens ranges from nearly 1:1 to abundant magnetite with practically no ilmenite. In one polished section of Columbia River Basalt, 2 percent magnetite and 2 percent ilmenite are present; in another polished section, 3.3 percent magnetite and less than 0.1 percent ilmenite are present (1,500 grains counted in both sections). Relative abundance of the two minerals is difficult to estimate accurately in thin section, because grains of ilmenite that are cut at a low angle to the basal pinacoid are nearly equidimensional and are easily mistaken for magnetite. Magnetite typically occurs in skeletal octahedral crystals (fig. 20) of about the same size as accompanying pyroxene and feldspar grains, as small overgrowths on ilmenite and pyroxene, and as minute grains in the interstitial glass. In the two polished sections examined, the magnetite grains are laced with a network of veinlets of very fine grained iron-rich chlorite(?). Ilmenite occurs in hexagonal plates, most of which appear as blades in thin section. The ilmenite is unaltered except for sparse replacement by magnetite along grain margins.

Most specimens of Columbia River Basalt contain no olivine, but as much as 5 percent olivine is present in the basal part of some flows. The olivine occurs as small

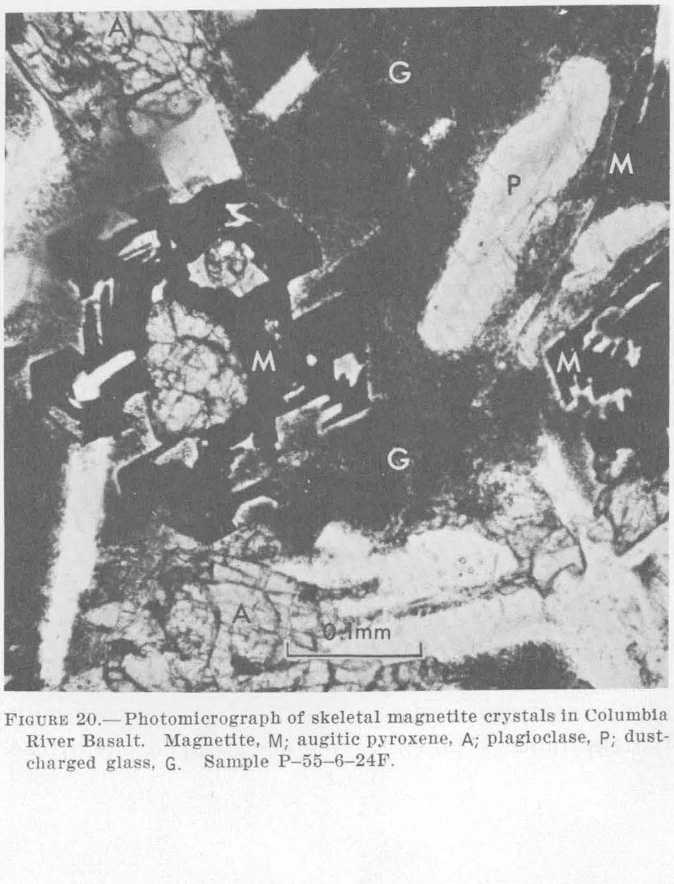


FIGURE 20.—Photomicrograph of skeletal magnetite crystals in Columbia River Basalt. Magnetite, M; augitic pyroxene, A; plagioclase, P; dust-charged glass, G. Sample P–55–6–24F.

colorless anhedral grains, which are in part altered to montmorillonitic clay or iddingsite.

A very few flows differ greatly from the above descriptions. A platy flow of medium-gray aphanitic andesite from near Stayton contains microphenocrysts of sodic labradorite (25 percent), clinopyroxene and orthopyroxene (15 percent), and magnetite (4 percent), in a dense felted groundmass containing microlites of oligoclase, interstitial cristobalite and glass, and minor magnetite and clinopyroxene. A similar flow has been described by Thayer and analyzed chemically (table 7, column 2 in this report, from Thayer, 1937). A flow exposed in the canyon of the Clackamas River is made up of dark-gray very fine grained basalt that contains sparse phenocrysts of olivine and pyroxene as much as 3 mm in diameter. A thin section of the basalt contains phenocrysts of mantled olivine (5 percent), salite (5 percent), and a trace of calcic plagioclase in an ophitic groundmass of labradorite (45 percent), clinopyroxene (30 percent), magnetite (3 percent), and interstitial glass, chlorophaeite, and cristobalite (12 percent).

AGE AND CORRELATION

The Columbia River Basalt in the area of this report is middle Miocene in age. The dating of the basalt is based entirely on the age of the enclosing formations, for the Columbia River Basalt has not yielded any diagnostic fossils. Within the map area, the basalt overlies fossiliferous marine and nonmarine strata as young as early Miocene. The Sardine Formation, which overlies the Columbia River Basalt, has yielded fossil plants of middle and late Miocene age at two localities along the Clackamas River, near Cazadero (USGS Paleobot. loc. 9281) and on Fish Creek Mountain, 9672; see fig. 23 and table 5).

In Clatsop County, 75 to 100 miles northwest of the area, locally derived Columbia River Basalt flows and breccia overlie the marine Astoria Formation of middle Miocene age (Warren and others, 1945). In southwestern Washington, basalt flows that are correlated with the Columbia River Basalt are intercalated with and overlie fossiliferous marine and nonmarine middle and upper Miocene strata of the Astoria (?) and unnamed formations (Pease and Hoover, 1957; Snavely and others, 1958).

The abundant glass and sparse olivine in the Columbia River Basalt in the map area, both in the flows along the Clackamas River and the foothills between the Molalla River and Thomas Creek and in the flows near Sweet Home, suggest that the basalt is of the Yakima type of Columbia River Basalt of Waters (1961; compare modes on p. 29 of this report with Waters' tables 6 and 7). Waters grouped one of the chemical analyses of basalt from near Stayton (table 7, col. 2 of this report) with the analyses of Yakima type (Waters 1961, table 3, col. 4) and the other analysis (table 7, col. 1 of this report) with the analyses of late Yakima and Ellensburg flows (Waters, 1961, table 4, col. 4).

SARDINE FORMATION

GENERAL FEATURES

The Sardine Formation consists predominantly of flows, breccia, and tuff of hypersthene andesite; it overlies the Columbia River Basalt and older formations over much of the Western Cascade Range in Oregon. Thayer (1936, p. 703–704) applied the name Sardine Series to the lavas, tuff, and breccia typically exposed on Sardine Mountain northwest of Detroit. He distinguished three formations near Mehama, in ascending order, the Mehama Volcanics, the Stayton Lavas, and the Fern Ridge Tuffs. Farther east, however,

> * * * andesitic lavas are so abundant in the Mehama and Fern Ridge Formations that their formational identity is lost, and the unconformity between the Mehama Volcanics and Stayton Lavas is not traceable. The Mehama, Stayton, and Fern Ridge Formations therefore are grouped in the Sardine Series * * *. Along the Breitenbush River the Sardine Series grades down into the dominantly tuffaceous Breitenbush Series some 7,500 feet thick.

In this report the Sardine Formation includes the Fern Ridge Tuffs, most of the Sardine Series, and the upper part of the Breitenbush Series, all of which consist mostly of hypersthene andesite; the dissimilar lower parts of the Breitenbush and Sardine Series are included in the Little Butte Volcanic Series (p. 14). Farther north in the drainage basins of the Clackamas and Sandy Rivers, strata that were previously called the Rhododendron Formation by Hodge (1933) and the Boring Agglomerate by Treasher (1942) are included in the Sardine Formation.

Most of the Western Cascade Range of Oregon north of the North Santiam River is covered by the Sardine Formation; south of the North Santiam as far as the McKenzie River, the formation is restricted mostly to the axial part of the Sardine syncline, and still farther south the formation is limited to discontinuous areas near the western margin of the High Cascade Range.

The Sardine Formation is in most places less than 3,000 feet thick; however, near Detroit, the thickness reaches 10,000 feet. This greater thickness is puzzling. It probably results in large part from the extrusion of much lava and breccia from nearby vents, such as those on Sardine Mountain, and from the rapid subsidence of a basin along the eastern limb of the present Sardine syncline in which a thick prism of pyroclastics accumulated.

The Sardine Formation conformably overlies the Columbia River Basalt along a surface of little relief in the Western Cascade Range between Thomas Creek and the Molalla River and along the Clackamas and Bull Run Rivers. The patchy distribution of the basalt along Rock and Beaver Creeks and the Molalla River probably is due to the flows being confined to valleys and not to pre-Sardine erosion of the basalt. The Sardine overlies the Little Butte Volcanic Series with an angular unconformity over much of the Western Cascade Range. Along the South Santiam and Calapooya Rivers and Crabtree Creek, beds of the Little Butte dip eastward, whereas the base of the overlying Sardine Formation is nearly horizontal. Along Hehe Creek, a few miles south of the McKenzie River, the base of the Sardine has at least 1,000 feet of relief. In the Umpqua drainage basin, the Sardine Formation overlaps progressively lower beds of the Little Butte from the Calapooya Mountains on the north to Grasshopper Mountain on the south; a thickness of as much as 5,000 feet of Little Butte rocks was apparently removed by pre-Sardine erosion over a distance of 30 miles.

About a dozen vents of the volcanic rocks of the Sardine Formation were identified; these occur in a belt that extends from Hershberger Mountain and Rabbit Ears, near the southern boundary of the map area, to Squaw Mountain and Cazadero, near the northern boundary, as shown in figure 21. Andesitic plugs (pl. 1) were mapped at the following localities: Hershberger Mountain, Rabbit Ears, Sardine Butte (southeast of Nimrod), Lost Dog Rock (north of Sweet Home), Sardine Mountain and Dome Rock (near Detroit), Evans Creek (near Elkhorn), Rooster Rock and a locality 3 miles east of High Camp (Molalla River drainage), and Squaw Mountain (Clackamas River drainage). The local abundance of cindery rubble breccia suggests vents 2 miles north of Bald Peter (north of Sweet Home), between the mouths of Wolf and Dobbin Creeks (near Cascadia), and near Cazadero. Some stocks and pipes of quartz monzonite and granodiorite probably are related to the Sardine volcanism; examples are the stocks along the Middle Santiam River and at Detroit Dam (pl. 1). That the centers of maximum volcanism may have been in that part of the belt that extends from the Middle Fork of the Santiam River to the headwaters of the Collawash River is indicated by the abundance of flows there and the greater thickness of the formation. The belt of volcanoes that were fed by these vents probably formed a north-trending mountain chain along the present eastern margin of the Western Cascade Range, at least in northern Oregon.

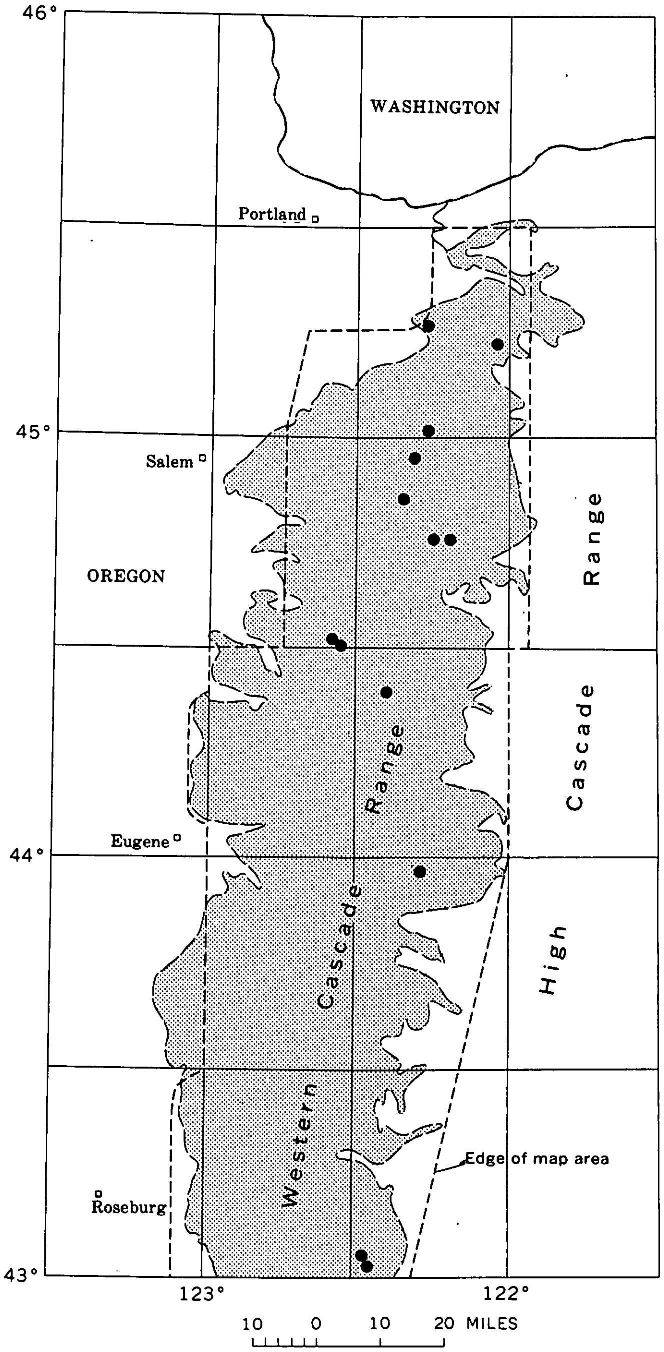


FIGURE 21.—Location of known vents of the Sardine Formation of middle and late Miocene age in the Western Cascade Range in Oregon north of lat. 43°. Vents represented by black dots. Western Cascade Range lightly shaded.

LITHOLOGY AND PETROGRAPHY

The Sardine Formation consists of flows, flow breccia, tuff-breccia, lapilli tuff, tuff, and conglomerate. Flows constitute between 50 and 90 percent of the formation. More than three-quarters of the rocks are hypersthene andesite and contain phenocrysts of plagioclase and hypersthene in a dark aphanitic groundmass. Less abundant rock types are basaltic andesite, olivine basalt, dacite, and rhyodacite.

South from the North Fork of the Middle Fork of the Willamette River, the Sardine Formation consists of platy hypersthene andesite flows and sparse breccia and tuff. Near Quartz Mountain, flows contain scattered xenocrysts of quartz.

In the drainage basins of the McKenzie and Santiam Rivers, drab andesitic pyroclastic rocks are intercalated with flows, particularly in the lower part of the formation. The pyroclastic rocks are mostly massive lapilli tuff, but they include tuff-breccia, as well as water-laid tuff and conglomerate, which are particularly abundant near Detroit and in the Quartzville District. Basaltic andesite and olivine basalt flows, which are intercalated with tuff and hypersthene andesite flows, crop out at several places along the crest of the Breitenbush anticline between the McKenzie and North Santiam Rivers and again in the foothills to the west. In this report, these rocks are considered to be within the basal part of the Sardine Formation, but more detailed mapping may show that most if not all of these are a part of the Little Butte Volcanic Series.

Between the Little North Santiam and Sandy Rivers, the Sardine Formation comprises two units: the lower is 1,000 to 2,000 feet thick and consists mostly of massive tuff-breccia, lapilli tuff, and tuff, and less abundant volcanic conglomerate, water-laid tuff, and lava flows, all of hypersthene andesite; the upper unit, 1,000 to 2,000 feet thick, consists almost entirely of hypersthene andesite flows. These flows were assigned to the volcanic rocks of the High Cascade Range early in this investigation but are now assigned to the Sardine Formation. They are megascopically and microscopically similar to flows in the underlying pyroclastic rocks and in the Sardine Formation elsewhere and are different from the distinctive porous-textured olivine basalt and olivine andesite flows that form most of the High Cascade Range. Also, the original volcanic surfaces are rarely preserved on them, whereas such surfaces are almost completely preserved on rocks of the High Cascade Range.

FLOWS

Most of the abundant andesite flows in the Sardine Formation are broken along curved platy joints; columnar and blocky jointing is uncommon. In a few flows, combined platy and columnar jointing has yielded blocks that resemble stacked biscuits. The thickness of individual flows, in the few places where it could be determined, ranges from 10 to 100 feet but averages about 30 feet. Vesicles and amygdules are smaller and less abundant than in flows of Columbia River Basalt or flows of the Little Butte Volcanic Series. The flow rocks are typically medium to dark gray and contain about one-third conspicuous plagioclase tablets and less abundant black to dark green pyroxene prisms in an aphanitic groundmass.

In thin sections of hypersthene andesite, phenocrysts of labradorite and hypersthene, less abundant augite and magnetite, and occasional olivine are set in a hyalopilitic to pilotaxitic groundmass (fig. 22). The groundmass contains microlites of andesine, pyroxene, and magnetite in finely crystalline alkali feldspar, chalcedony or cristobalite, and sparse clay. Approximate modal analyses of 10 typical samples yield the following percentages of phenocrysts: labradorite, 28 percent; hypersthene, 8 percent; augite, 1 percent; and a trace of magnetite. Three of these samples contain olivine, which constitutes as much as 1 percent of the individual sample. The mineralogical composition of the groundmass was estimated in 5 of the 10 samples to be as follows: andesine, 33 percent; pyroxene, 15 percent; magnetite, 1 percent; and finely crystalline material, 18 percent. Rapid chemical analyses, norms, and modes of two hypersthene andesite flows from the Sardine Formations are given in table 7 (cols. 11 and 12).

Basaltic andesite and basalt are porphyritic to aphyric and have intergranular or, less commonly, pilotaxitic textures. Approximate modal analyses of seven samples of basaltic andesite yield the following average: 58 percent plagioclase, 28 percent pyroxene, 4 percent magnetite, 1 percent olivine, and 9 percent finely crystalline material. Rapid chemical analyses, norms, and modes of three samples of basaltic andesite are given

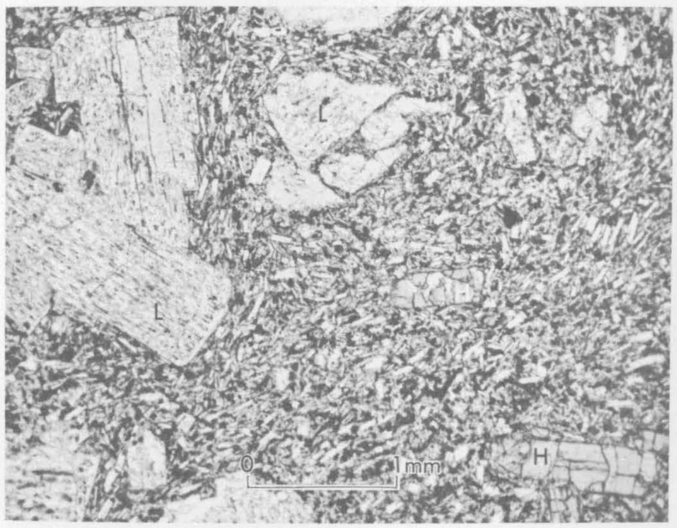


FIGURE 22.—Photomicrograph of hypersthene andesite in the Sardine Formation. Phenocrysts of labradorite (L) and hypersthene (H) are set in a pilotaxitic groundmass. Sample P–55–6–27A.

in table 7 (cols. 4, 7, 8). A chemical analysis of an olivine basalt flow from Gold Hill is quoted from Callaghan and Buddington (1938) in table 7, column 6.

Platy flows of dense aphyric silicic andesite generally have a trachytic texture. A typical flow east of Sardine Butte contains 73 percent sodic andesine, 17 percent granular pyroxene, 2 percent magnetite, and 7 percent finely crystalline alkalic feldspar and cristobalite. One percent cristobalite and a trace of quartz and green hornblende occur along flow cleavage planes.

Feldspar phenocrysts in andesite and basalt of the Sardine Formation average 3 mm long, 2 mm wide, and 1 mm thick. The phenocrysts are labradorite (An_{50-65}) in most of the rocks, but range from calcic labradorite to bytownite in basaltic andesite and basalt. They are marked by conspicuous oscillatory and normal progressive compositional zoning and contain abundant minute inclusions of glass and mineral grains along the zones. The composition of feldspar in the groundmass is difficult to determine because of the small size of the laths, but it appears to range from oligoclase to andesine in hypersthene andesite, from andesine to sodic labradorite in basaltic andesite, and from sodic to intermediate labradorite in basalt.

Pyroxene phenocrysts in andesitic rocks of the Sardine Formation are predominantly hypersthene. The hypersthene occurs in elongate well-terminated prisms, that average 2 mm in length and 0.5 mm in width. They display the typical pink and green pleochroism under the microscope. The composition of hypersthene from four samples averages magnesian hypersthene, En_{65}, but it ranges from En_{60} to En_{75} (on the basis of determination of N_z by oil immersion). In all but a few samples, stubby prisms of augite are subordinate. The pale green augite is faintly pleochroic in thin section and generally has an optic angle greater than 50°. Both orthopyroxene and clinopyroxene are generally present in the groundmass of hypersthene andesite; the orthopyroxene is coarser grained than the clinopyroxene and is jacketed by pigeonite. In the groundmass of one sample the composition of orthopyroxene is about En_{50}, as indicated by the measured 2V of 50°. In more mafic rocks of the Sardine Formation, orthopyroxene is sparse or absent, and the groundmass mostly contains augitic clinopyroxene but includes less abundant pigeonitic clinopyroxene.

Olivine occurs in some flows of the Sardine Formation as colorless subhedral phenocrysts mantled by pyroxene or dendritic magnetite. In about one-third of the olivine-bearing samples, it is partially altered to iddingsite; in other samples the olivine has partially or completely altered to green clay, carbonate minerals, or iron oxides. Olivine is rare in hypersthene andesite, but as much as 9 percent olivine was noted in samples of basalt.

Hornblende is rare in rocks of the Sardine Formation; in fact, it is rare in all formations of the Oregon Cascade Range. Hornblende phenocrysts, all peripherally altered to fine-grained magnetite, were noted in only four samples from the Sardine Formation.

A finely crystalline silicic material lies between phenocrysts and microlites in most andesite samples that were examined. Undevitrified glass, noted in only a few samples, is pale brown and has an index less than balsam; the glass in an andesite from House Mountain constitutes about 25 percent of the rock and has an index of 1.515±0.005. In most samples, the material consists of finely microcrystalline or cryptocrystalline alkalic feldspar, either cristobalite or chalcedony, and sparse green clay.

Cristobalite was identified in about one-fifth of the samples examined from the Sardine Formation. It occurs as fine anhedral grains in the groundmass and less commonly as round masses on cavity walls. The maximum cristobalite content observed was 14 percent. Optical identification was verified by use of an X-ray diffractometry on low-density mineral separates from two samples.

PYROCLASTIC ROCKS

Massive tuff-breccia, presumedly mudflow, ash flow, and landslide deposits are abundant in the Sandy, Clackamas, and Molalla drainage basins. The angular to rounded fragments in the breccia range from sand size to more than 4 feet in diameter. The coarser fragments are mostly medium- to dark-gray hypersthene andesite. The matrix, which ranges from greenish gray to light olive gray, contains coarse angular ash of andesite and crystals of plagioclase, less abundant hypersthene, sparse augite and magnetite, and rare hornblende, in fine ash of volcanic glass and mineral fragments. In many places massive beds of tuff-breccia are interbedded with and grade into water-laid conglomerate, grit, and sandstone.

Lapilli tuff is commonly massive and drab (mostly shades of green and brown) and contains angular lapilli of pumice and andesite and less abundant crystals of intermediate plagioclase and pyroxene in a matrix of devitrified shards and ash. The tuff is similar to andesitic lapilli tuff in the Little Butte Volcanic Series, but it generally contains more abundant hypersthene crystals.

A few beds of vitric welded tuff occur in the Sardine Formation, particularly near the base of the formation between Abiqua and Thomas Creeks. The tuff is white to olive gray and contains flattened pumice lapilli, less abundant fragments of andesite, and crystals of andesine, hypersthene, augite, and magnetite, in a matrix of slightly to thoroughly welded shards and ash. An unusual tuff exposed near High Camp (sec. 28, T. 6 S., R. 4 E.) contains brown hornblende.

TABLE 5.—*Checklist of fossil plants from the Sardine Formation in the Cascade Range in Oregon*

[Identified by Jack A. Wolfe and Roland W. Brown. Location given in figure 23]

Species	USGS Paleobot. loc.					
	9281	9349	9352	9353	9441	9672
Metasequoia glyptostroboides		X				X
Sequoia sempervirens	X	X				
Taxodium distichum	X	X				X
Pinus ponderosa		X				
Abies spp	X	X			X	
Picea magna		X				
breweriana		X				
Thuja dimorpha	X	X				
Populus lindgreni	X					
voyana		X				
tremuloides	X					
trichocarpa	X	X				
Salix inquirenda						X
hesperia	X	X				
Juglans oregoniana	X	X				X
Carya bendirei	X					
Pterocarya mixta	X	X				
Alnus harneyana	X	X			X	
relata		X				X
Betula lacustris		X				
Fagus sanctieugeniensis	X		X			X
Quercus pseudolyrata		X		X		X
winstanleyi	X					
simulata		X			X	X
chrysolepis		X	X			
deflexiloba	X					
Ulmus speciosa		X				X
Zelkova oregoniana		X				X
Liriodendron hesperia		X				
Magnolia sp., n. sp						X
Lindera sp., n. sp						X
Persea sp				X		
Cocculus heteromorpha						X
Exbucklandia oregonensis						X
Liquidambar pachyphylla	X	X				
Platanus sp., aff. *P. dissecta*		X				X
dissecta	X					
Amelanchier coulleana		X				
Sophora spokanensis		X				X
Ilex sp., n. sp		X				
Acer macrophyllum	X	X				
circinnatum	X					
Arbutus idahoensis		X				
traini	X					
Symplocos sp., n. sp	X					X
Paulownia columbiana	X					

AGE AND CORRELATION

The Sardine Formation is dated as middle and late Miocene on the basis of fossil plants and stratigraphic position. The formation overlies fossiliferous strata as young as early Miocene (Little Butte Volcanic Series and the marine tuff and standstone of Butte Creek) and overlies unfossiliferous Columbia River Basalt of presumed middle Miocene age. The Sardine is overlain near Portland by the fossiliferous Troutdale Formation of Pliocene age, and is overlain along the eastern margin of the Western Cascade Range by poorly dated volcanic rocks of the High Cascade Range of Pliocene and Quaternary age.

Diagnostic fossil plant collections were made from six localities in the Sardine Formation within the map area. The floras, which were identified by Jack A. Wolfe and Roland W. Brown, are given in table 5, and each locality is shown in figure 23 and plotted on the geologic map. (pl. 1).

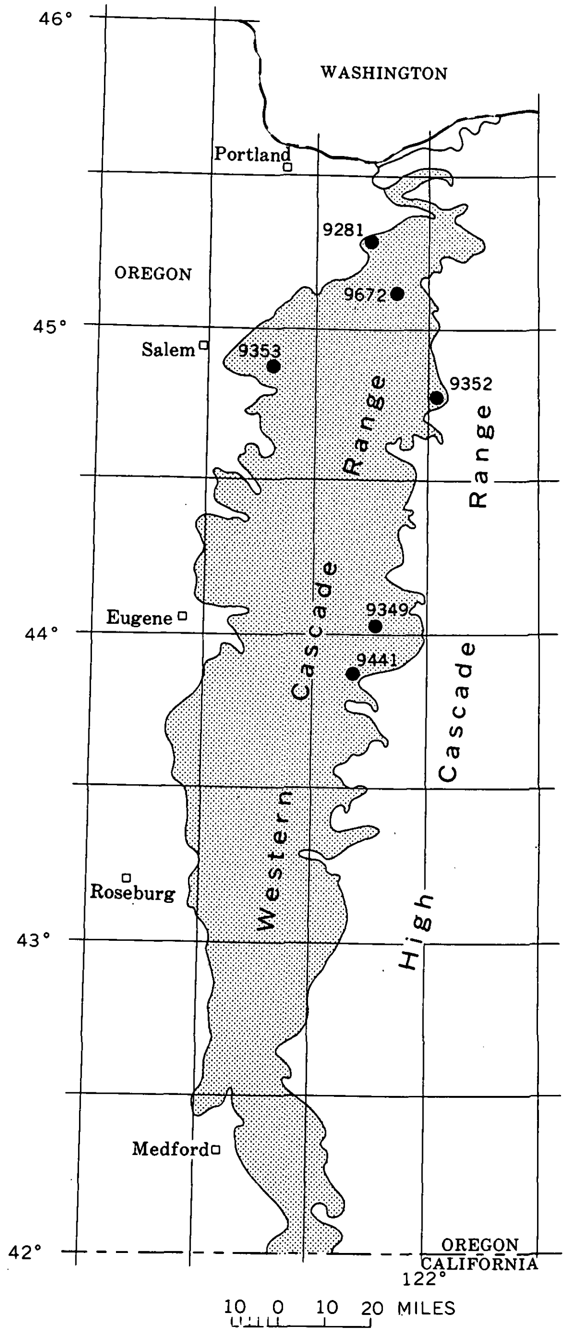


FIGURE 23.—Location of plant localities in the Sardine Formation of middle and late Miocene age in the Western Cascade Range in Oregon. Floras listed in USGS Paleobot. locality numbers in table 5. Western Cascade Range lightly shaded.

USGS Paleobot. loc.	*Location*
9281	SW¼NE¼ sec. 33, T. 3 S., R. 4 E.; at Faraday Power Station, near Cazadero.
9349	SW¼SE¼ sec. 8, T. 18 S., R. 5 E., and NW¼ sec. 16, T 18 S., R. 5 E.; near Hidden Lake.
9352	SE¼NW¼ sec. 28, T. 9 S., R. 7 E.; on Devils Creek, near Breitenbush Hot Springs.
9353	NE¼NE¼ sec. 20, T. 8 S., R. 1 E.; on Drift Creek.
9441	NW¼NE¼ sec. 13, T. 37 S., R. 4 E.: on Brock road at White Rock Creek.
9672	NW¼SW¼ sec. 36, T. 5 S., R. 5 E.; on Fish Creek road.

According to Jack A. Wolfe (written commun., February 1962),

* * * One locality (USGS Paleobot. loc. 9672) contains plants correlative with the latah flora of Washington, that is early middle Miocene in age. Another locality (9353) is also probably of middle Miocene age, and a third (9352) could be either middle or late Miocene. Two localities (9349, 9281) are of late Miocene age, and one of these (9281) falls in the latest part of the epoch. The Sardine floras show a definite cooling from older to younger floras. Although all of these are warm temperate, the large amounts and diversity of coniferous pollen at the youngest locality (9281) indicate that an extensive cool temperate flora may have been present at moderate elevations.

The Fern Ridge Tuff of Thayer, mapped with the Sardine Formation in this report, was considered Pliocene by O'Neill (1939), Libby and others (1945), and Lowry and Baldwin (1952), because near Sublimity (west of the map area) weathered gravel that they assigned to the Fern Ridge Tuff unconformably overlies the Columbia River Basalt and contains gibbsite nodules near the base. Thayer (1939, p. 28) considered the gravel to be Pleistocene. The occurrence of Miocene plant fossils near the base of the Fern Ridge Tuff only 5 miles northeast of Sublimity (USGS Paleobot. loc. 9353) and the intercalation of Fern Ridge Tuff with flows and tuff breccia of the Sardine Formation farther east along Silver and Abiqua Creeks make a Pliocene age for the lower part of the Sardine Formation untenable. However the upper age limit of the formation is not well determined, and Sardine volcanism could have continued into the Pliocene, at least locally. All the fossil localities in the Sardine are stratigraphically located well below the top of the formation, and these localities, as well as the overlying Troutdale Formation of Pliocene age, occur at some distance from major vents.

Flows of porphyritic andesite that are probably correlative with the Sardine Formation have been mapped as Heppsie Andesite south of lat 43° near Abbott Butte and at Whetstone Peak and Heppsie Mountain (Wells, 1956a; Wells and Peck, 1961).

TROUTDALE FORMATION

Nonmarine conglomerate, sandstone, and siltstone of the Troutdale Formation unconformably overlie strata of the Sardine Formation and older units in the northwest corner of the map area, between Molalla and Bull Run. The Troutdale Formation was named by Hodge (1933), presumedly for the excellent exposures along the Sandy River near Troutdale, a few miles north of the area of this report. According to Trimble (1957), the Troutdale Formation is more than 1,000 feet thick and consists of a lower member of mudstone and an upper member of sandstone and conglomerate.

The Troutdale Formation forms bluffs along the lower Sandy and Clackamas Rivers and their tributaries, and near Molalla it forms steep slopes below a capping of basalt. About 200 feet of the formation is exposed along the Sandy River and about 400 feet near Molalla.

Horizontal beds of the Troutdale overlie gently dipping tuff breccia of the Sardine Formation along the Sandy, Bull Run, and Clackamas Rivers. Near Estacada, pisolitic ferruginous bauxite is present in tuff of the Sardine Formation immediately below the base of the Troutdale (Trimble, 1955). Near Molalla, horizontal beds of the Troutdale overlie northwest-dipping strata of the Sardine Formation, Columbia River Basalt, and Little Butte Volcanic Series. In this area the Troutdale is distinguished only with difficulty from siltstone, sandstone, and conglomerate of the Little Butte Volcanic Series and from Pleistocene terrace deposits.

Along the Sandy and Bull Run Rivers, the Troutdale Formation consists of moderately consolidated thick beds of conglomerate and less abundant lenses and beds of sandstone and siltstone. Crossbedding is common. The conglomerate contains well-rounded gravel that averages 2 to 3 inches in diameter but ranges from ½ to 12 inches. Where studied in sec. 6, T. 1 S., R. 4 E., the gravel is nearly three-fourths Columbia River Basalt and one-fourth quartzite, gneiss, schist, and granitic rocks.

The matrix of the conglomerate, as well as intercalated lenses of sandstone, consists of grains of mixed origin. A sample of coarse-grained sandstone contains moderately well-sorted subangular grains of basalt, 40 percent; quartz, 20 percent; feldspar, 15 percent; andesite, 10 percent; quartzite, schist, and gneiss, 10 percent; and accessory minerals, 5 percent. The basalt grains are mostly hyalo-ophitic, consisting of cores of sideromelane and rims of chlorophaeite. About one-half of the accessory mineral grains are clinopyroxene; less abundant are biotite and blue-green hornblende, and sparsely abundant are orthopyroxene, muscovite, garnet, rutile, and zircon.

Near Molalla, the Troutdale Formation consists of light-colored siltstone and sandstone, which contain lenses of pebbly conglomerate. The strata are thin-bedded to massive, in part cross-bedded, and are composed predominantly of andesite fragments. Only a few of the siltstone beds contain conspicuous white mica, and less than 1 percent of the pebbles in the conglomerate are metamorphic rocks.

The Troutdale Formation overlies beds of middle and late Miocene age (Sardine Formation) and has yielded fossil plants of Pliocene age from several localities in the Portland basin (Chaney, 1944; Roland W. Brown, written comm., August 1958).

BORING LAVA AND VOLCANIC ROCKS OF THE HIGH CASCADE RANGE

GENERAL FEATURES

Andesitic and basaltic flows and breccia of Pliocene and Quaternary age that are relatively undeformed or unaltered, and only moderately eroded, overlie part of the older Tertiary volcanic rocks of the Western Cascade Range and the Troutdale Formation. These younger flows and breccia make up the higher parts of the Cascade Range in Oregon, including the prominent volcanic cones along the crest such as Hood, Jefferson, and McLoughlin Mountains, and occur at scattered farther west. The flows and breccia in the northwest part of the map area are called Boring Lava, following Treasher (1942), Trimble (1957), and others. The correlative and lithologically similar flows and breccia to the east and south are informally called the volcanic rocks of the High Cascade Range in this report, following Callaghan (1933). Parts and all of the volcanic rocks of the High Cascade Range have been called the Cascades, Cascade, and Cascan Formation by Ira Williams (1916), Hodge (1938b) and others, and the High Cascade Series by Howel Williams (1949). Thayer (1936, 1939) divided the volcanic rocks of the High Cascade Range west of Mount Jefferson into the following units: Outerson Volcanics, Minto Lavas, Battle Axe Lavas, Olallie Lavas, and Santiam Basalts.

In the present investigation, the Boring Lava and the volcanic rocks of the High Cascade Range were studied only to the extent necessary to distinguish them from the volcanic rocks of the Western Cascade Range. They have been mapped and described in more detail by Williams (1932 a, b; 1933, 1935, 1942, 1944, 1949, 1957), Thayer (1936, 1937, 1939), Hodge (1932, 1938b), and Bogue and Hodge (1940).

The volcanic rocks of the High Cascade Range are limited mostly to the higher parts and eastern slopes of the Cascade Range; however, a few intracanyon flows and isolated volcanoes occur farther west. Near Portland, the Boring Lava covers most of the area between the Sandy and Columbia Rivers and occurs as isolated small shield volcanoes, such as Lenhart and Highland Buttes, capping the Troutdale Formation. Intracanyon flows extend westward from the High Cascade Range along the following river valleys: Clackamas, North Santiam, McKenzie, North and Middle Forks of the Willamette, and North Umpqua. Some volcanic rocks of the High Cascade Range occur as isolated volcanoes in the Western Cascade Range at Battle Ax Mountain, Snow Peak, Quartzville, Galena Mountain, Harter Mountain, Soapgrass Mountain, Mt. Hagen, Saddleblanket Mountain, Battle Peak, Arnet Creek, Dead Mountain, and Pinard Butte. Future mapping will no doubt reveal other isolated High Cascade volcanoes in the Western Cascade Range. Along the eastern edge of the Western Cascade Range are a few areas of volcanic rocks that have been isolated by erosion from the main mass of the volcanic rocks of the High Cascade Range, such as Blowout Cliff and Pyramid Mountain. Erosion has not greatly reduced the extent of the volcanic rocks of the High Cascade Range, however; these rocks never covered all the Western Cascade Range and probably did not extend originally much farther west than at present.

The thickness of the volcanic rocks of the High Cascade Range varies greatly. This variation in thickness largely reflects distance from the volcanic vents and irregularities of the land surface on which the rocks poured out; erosion has played a lesser part. Intracanyon flows may be a few hundred feet thick, but usually are less; the isolated volcanoes are as much as 2,000 feet thick and along the eastern edge of the map area the volcanic rocks of the High Cascade Range are generally more than 3,000 feet thick.

The volcanic rocks of the High Cascade Range unconformably overlie the Sardine Formation, Columbia River Basalt, and Little Butte Volcanic Series. Near Portland, the Boring Lava conformably overlies the Troutdale Formation. In contrast to the Sardine and older units, the volcanic rocks of the High Cascade Range are not folded. The flows and tuff breccia are generally flat lying; most exceptions can reasonably be explained as initial dips around former volcanic vents or by deposition on an irregular ground surface. However, the volcanic rocks of the High Cascade Range have been tilted and displaced along faults in the upper basin of the Clackamus River and on the eastern slopes of the Cascade Range (see A. C. Waters, in Wells and Peck, 1961), and the rocks may be faulted along the Rogue River west of Crater Lake, as suggested by Williams (1942).

LITHOLOGY AND PETROGRAPHY

Vesicular flows of porous aphyric olivine andesite and olivine basalt are abundant and characteristic of the volcanic rocks of the High Cascade Range and the Boring Lava. Less abundant are flows of dense basalt, porphyritic basaltic andesite, and aphyric to porphyritic pyroxene andesite. Hornblende andesite and dacite are rare. Plugs and dikes have been exposed by dissection of some of the volcanic cones.

The volcanic rocks of the High Cascade Range and the Boring Lava range from light to dark gray, but the most abundant types are light to medium gray. In general, the color appears to be related to crystallinity rather than composition; olivine basalt and basaltic andesite are typically light or medium light gray, in contrast to the medium- to dark-gray pyroxene andesite. Aphyric rocks are more abundant than porphyritic rocks; however, some of the basaltic andesite and much of the pyroxene andesite is conspicuously porphyritic, containing tabular plagioclase phenocrysts ⅓ to ½ cm in length. Typically the rocks have a diktytaxitic texture; that is, they consist of an open network of feldspar laths enclosing abundant minute angular pores, as shown in figure 24. Small phenocrysts of olivine, tarnished yellow to red, are sparse to moderately abundant in most rocks.

Most volcanic rocks of the High Cascade Range and the Boring Lava can be distinguished readily from the older volcanic rocks of the Western Cascade Range. The minutely porous texture of many flows of the younger rocks is very distinctive, even in the hand specimen. The flows are fresher in appearance: olivine for example is more conspicuous in them because of the colorful iddingsite rim around a fresh core; in contrast, olivine in most of the older rocks is altered to green clay. The volcanic rocks of the High Cascade Range and the Boring Lava include many thin basaltic flows, which are also common in part of the Little Butte Volcanic

FIGURE 24.—Photomicrograph of porous-textured basaltic andesite in the volcanic rocks of the High Cascade Range. A phenocryst of olivine (O), which is partially altered to iddingsite (I), is set in an intergranular diktytaxitic groundmass of labradorite (L), hypersthene (H), magnetite (M), and angular voids (V). Hypersthene prisms are jacketed by pigeonite (P). Nichols crossed. Sample ABG–92–55.

Series, but the younger flows are usually lighter in color and contain vesicles that are commonly not filled with secondary products. The small minority of the volcanic rocks of the High Cascade Range that are difficult to assign stratigraphically are porphyritic pyroxene andesite, aphyric andesite, and dense basalt, which also occur in the Sardine Formation, Columbia River Basalt, and Little Butte Volcanic Series. Areas where distinctive flows are sparse or missing and the rocks are questionably assigned to the volcanic rocks of the High Cascade Range include the Calapooya Mountains north of Toketee Falls, Squaw Butte (northwest of McCredie Springs), Lookout Ridge (north of McKenzie Bridge), and Rhododendron Ridge (between the Callowash and Clackamas Rivers).

The basaltic rocks of the High Cascade Range and the Boring Lava typically contain phenocrysts of olivine ½ to 1 mm in diameter in a fine-grained nearly holocrystalline groundmass. The groundmass consists of a network of feldspar laths that enclose granular clinopyroxene, olivine, magnetite, ilmenite (which may be absent in some), and angular pores, as well as sparse anhedral feldspar, cristobalite, and apatite. Four typical basalt specimens, for which modal analyses were determined, contain on the average 6 percent olivine phenocrysts in a groundmass of feldspar, 56 percent; clinopyroxene, 27 percent; olivine, 7 percent; magnetite and ilmenite, 4 percent; an additional 3 percent of the rocks consists of minute angular pores.

The feldspar in most of the basaltic rocks occurs as laths or as less abundant interstitial anhedral grains. The laths are intermediate labradorite (An_{55-65}), some rimmed by more sodic plagioclase, whereas most of the interstitial grains are sodic labradorite or andesine and a few are oligoclase or albite. Olivine occurs as subhedral tablets, both in phenocrysts and in the groundmass. It is rimmed and veined by iddingsite or, less commonly, by dendritic magnetite and occasionally contains minute octahedra of brown translucent spinel. The average composition of 19 olivine grains in five samples, as determined by measuring 2V, is about Fo_{75} (chrysolite). Clinopyroxene occurs in the groundmass as stubby, poorly terminated pale-green prisms and granules. It is commonly augite having a moderately high 2V (average 53° in five samples).

The andesitic rocks range from conspicuously porphyritic to aphyric, from holocrystalline to hemicrystalline, and from intergranular to pilotaxitic and hyalopilitic. Basaltic andesite is much more abundant than pyroxene andesite, and hornblende andesite is rare. Two typical basaltic andesite samples contain on the average 3 percent olivine phenocrysts, 70 percent feldspar, 21 percent pyroxene, 3 percent magnetite, 3 percent cryptocrystalline material, and a trace of cristobalite. A sample of hypersthene andesite from an intracanyon flow along the Clackamas River contains phenocrysts of hypersthene (4 percent), feldspar (31 percent), and a trace of augite, in a dense trachytic groundmass of feldspar, pyroxene, magnetite, and cryptocrystalline material. The average composition of feldspar phenocrysts in andesite ranges from intermediate labradorite to calcic andesine. Groundmass feldspar is predominantly calcic andesine. In contrast to olivine basalt, most of the andesite contains more than one pyroxene in the groundmass. The coarser pyroxene microlites includes both hypersthene and augite. Typically the hypersthene prism faces are jacketed by pigeonite, and minute rods of pigeonite(?) are present in the groundmass.

The intrusive plugs and dikes of the High Cascade Range were not studied in any detail by us. As described by Williams (1933, 1942, 1944) and Thayer (1937), the plugs are round to elliptical in plan, generally less than half a mile in diameter, and are massive or have irregular or subvertical downward flaring joints. Some are surrounded by radial swarms of thin irregular dikes, mostly limited in extent to the tuff cone. The plugs and dikes are petrographically similar to related flows but are in part slightly coarser grained. The groundmass of a sample from the plug at Snow Peak has an unusual texture, which was also observed in a few samples of older plug rocks. The labradorite and olivine phenocrysts of the rock are similar to the surrounding flows, but the groundmass differs strikingly, consisting of minute blebs of clinopyroxene and less abundant magnetite poikilitically enclosed in andesine anhedra and in the marginal zones of labradorite phenocrysts, as shown in figure 25. This texture may result from partial recrystallization of rocks in a volcanic vent as a result of repeated passage of lava through the vent.

No additional chemical analyses of the volcanic rocks of the High Cascade Range were obtained during the present investigation. Chemical analyses have been published by Hague and Iddings (1883), Diller and Patton (1902), Moore (1937), Thayer (1937), Bogue and Hodge (1940), and Williams (1942) and are plotted on the silica-variation diagram of figure 28.

AGE AND CORRELATION

The volcanic rocks of the High Cascade Range and the Boring Lava probably range in age from Pliocene to Recent, but fossil evidence is sparse within the area of this report. Trimble (1957) concluded that the Boring Lava may be wholly Pliocene in age or may be in part early Pleistocene, because it overlies the Troutdale Formation of Pliocene age and is in turn

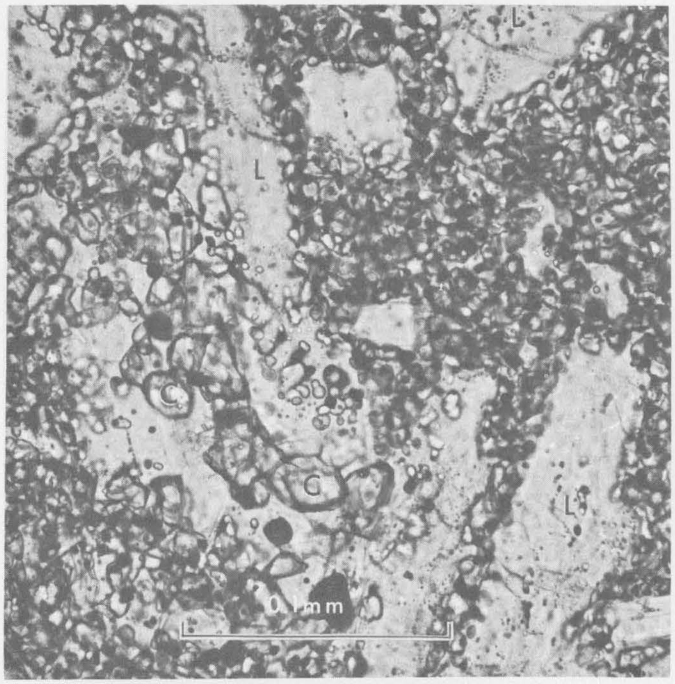


FIGURE 25.—Photomicrograph of olivine basalt from plug at Snow Peak. Phenocrysts of labradorite (L) that contain blebs of clinopyroxene (C) and magnetite (black) are set in a groundmass of anhedral andesine crowded with blebs of clinopyroxene and magnetite. Sample P–55–8–25B.

overlain by terrace deposits thought to be early or middle Pleistocene in age. Williams (1957) concluded that the volcanic rocks of the High Cascade Range in the central part of Oregon are of Pliocene to Recent age on the basis of physiographic evidence. Many of the intracanyon flows in the Western Cascade Range, such as the flows along the North Santiam and McKenzie Rivers, are probably Pleistocene in age; they occupy former valleys that are adjacent to and only a few hundred feet above the present streams, but they are cut by canyons that contain glacial deposits. A Recent age is indicated for some of the volcanic rocks. These include unglaciated cones in the higher part of the range as well as flows that have little or no vegetative cover, such as those at McKenzie Pass from Belnap Crater and Little Belnap. A century ago, Mount St. Helens, in southern Washington, erupted ash. Fremont wrote (1845, p. 193): "On the 23d of the preceding November St. Helens had scattered its ashes like a light fall of snow, over the Dalles of the Columbia, 50 miles distant."

QUATERNARY ALLUVIUM

Gravel, sand, and silt of Pleistocene and Recent age form terraces and line the present stream courses in the Western Cascade Range. All these deposits were mapped as Quaternary alluvium. Many small areas of till and alluvium, as well as all areas of landslide, were not mapped. The larger areas of alluvium are along the lower valleys of the Cascade streams and the floor of the Willamette Valley, where the Quaternary deposits have been studied by Allison (1936, 1953), Allison and Felts (1956), Thayer (1938, 1939), Piper (1942), and Trimble (1957).

Two or three terrace levels are present along the lower valleys of the major streams; they occur at 50 to 100 feet, 100 to 200 feet, and 200 to 500 feet above the present stream levels. Most of the terrace deposits are unconsolidated or poorly consolidated fluvial deposits in which the gravel ranges from pebbles to boulders as much as several feet in diameter, and which are made up of Tertiary and Quaternary volcanic rocks. The gravel in the higher terraces is deeply weathered to saprolite. The lowest terrace level along the lower valleys of the major streams and the floor of the Willamette Valley is covered in many places by silt (Willamette Silt).

In the Lebanon and Albany quadrangles and adjacent areas, the Pleistocene deposits have been divided into four major units (Allison, 1953; Allison and Felts, 1956), which from oldest to youngest are the Lacomb, Leffler, and Linn Gravels and the Willamette Silt. Allison has suggested that the first two units belong to pre-Wisconsin stages of glaciation and the last two units to the Wisconsin stage.

INTRUSIVE ROCKS OF THE WESTERN CASCADE RANGE

Small bodies of intrusive rocks that range in composition from rhyodacite to basalt cut the volcanic rocks of the Western Cascade Range. On the geologic map (pl. 1), the intrusive bodies are divided into three rock types: medium-grained rocks (diorite, quartz diorite, granodiorite, and quartz monzonite), fine-grained mafic and intermediate rocks (basalt and andesite), and fine-grained felsic rocks (dacite and rhyodacite). Little has been added to the study of Buddington and Callaghan (1936) on these intrusive rocks. Intrusive rocks related to the volcanic rocks of the High Cascade Range of Pliocene and Quaternary age are described separately on page 38.

MEDIUM-GRAINED INTRUSIVE ROCKS

The medium-grained intrusive rocks occur as pipes, dikes, and small stocks. The intrusives are as much as 4 square miles in area, but most are less than 1 square mile. They usually are round to elliptical in plan and have nearly vertical margins; however, the eastern margin of the Champion stock (Bohemia district) dips gently eastward concordantly with the surrounding strata (Buddington and Callaghan, 1936, p. 426), and the stock at Detroit Dam has a flat roof at about 2,000 feet altitude. As described by Buddington and Callaghan (1936), some of the larger stocks are compositionally zoned and have more mafic margins than cores. Dark flinty hornfels are present locally in the country rocks marginal to the intrusives. (See p. 42.)

The medium-grained intrusive rocks range in composition from augite diorite to biotite-quartz monzonite. They are porphyritic, and contain phenocrysts as much as 5 mm in length of zoned intermediate plagioclase and one or more dark minerals in a fine-grained holocrystalline groundmass. The groundmass in quartz monzonite and granodiorite consists predominantly of quartz and a potassium-rich feldspar, which are intergrown graphically in many samples. The groundmass of samples from some of the intrusives is only slightly finer grained than the phenocrysts, and the rocks have a granitoid appearance. As the grain size of the groundmass decreases, some rocks grade into conspicuously porphyritic types similar to the extrusive rocks. Many of the intrusive rocks are propylitically altered, and the primary minerals are partly replaced by chlorite, epidote-clinozoisite, and albite or zeolite; calcite, pyrite, and iron oxides may be present. Chemical and modal analyses of seven samples, mostly from the Bohemia district, are quoted from Buddington and Callaghan (1936), in table 7 (cols. 23, 25, and 30). Approximate modal analyses of samples from two additional stocks and the marginal facies of the stock at Nimrod are given in table 6.

TABLE 6.—*Modal composition of samples from three stocks in the Western Cascade Range in Oregon*

Mineral	Stock near Detroit (Sec. 7, T. 10 S., R. 5 E.)	Stock on the Middle Fork of Santiam River (Sec. 15, T. 12 S., R. 4 E.)	Stock at Nimrod marginal facies (Sec. 5, T. 17 S., R. 3 E.)
	1	2	3
Plagioclase	42	44	34
Quartz	21	22	23
Potassium-feldspar	13	25	38
Hornblende	11	3	2
Magnetite	1	2	1
Biotite			2
Chlorite, epidote, and clinozoisite	12	4	
Apatite	Trace		

AGE OF THE MEDIUM-GRAINED INTRUSIVE ROCKS

The intrusive rocks probably range in age from late Eocene to late Miocene. Different intrusives cut strata of the Colestin Formation, Little Butte Volcanic Series, and Sardine Formation. The intrusives may well include intrusive equivalents of several or all of these units because they display about the same range of chemical composition and have similar ratios of their oxides, as shown in figure 28, and because many of them occur near vents that fed the extrusives.

Lead-radioactivity ratios were determined for zircon from samples from the stocks at Nimrod and at Detroit Dam by Howard Jaffe, of the U.S. Geological Survey. The quartz monzonite stock at Nimrod intrudes the Little Butte Volcanic Series. Zircon from a sample of the stock (taken from the SW¼SE¼, sec. 4, T. 7 S., R. 3 E.) has a lead content of 8.0 ppm (parts per million) and an alpha activity of 540 mr per hr (milliroentgens per hour), corresponding to an age of 35 ± 10 million years. The granodiorite stock near Detroit (Hall's diorite of Thayer, 1939), intrudes rocks of the Sardine Formation. Zircon from a sample of the stock (taken from the NE¼SE¼, sec. 7, T. 10 S., R. 5 E.) has a lead content of 1.65 ppm and an alpha activity of 180 mr per hr, corresponding to an age of 25 ± 10 million years.

FINE-GRAINED INTRUSIVE ROCKS

Fine-grained intrusive rocks occur as dikes, sills, pipes, plugs, and domes and are similar lithologically to the related extrusive rocks of the Colestin Formation, Little Butte Volcanic Series, and Sardine Formation. In fact, it was seldom possible to determine whether fine-grained rocks were intrusive or extrusive. A few plugs were identified by their distinctive, nearly vertical jointing, which flares toward the bottom. Many dikes, most of which were less than 10 feet wide, were seen, but only a few of the larger and more continuous were plotted on the map.

The fine-grained intrusive rocks include porphyritic and aphyric types of basalt, andesite, dacite, and rhyodacite. An analyzed sample (table 7, col. 16) from the dacite plug at Stone Mountain contains phenocrysts of andesine, hypersthene, and magnetite in a felsitic groundmass containing laths of oligoclase in a cryptocrystalline material. A sample from the larger dacite plug on Little Fall Creek contains phenocrysts of calcic andesine, 17 per cent; altered pyroxene, 2 percent; and magnetite, 1 percent; these phenocrysts are in a felsitic groundmass that is made up of laths of oligoclase and poikilitic anhedra of quartz and potassium-rich feldspar. A sample from a thick columnar-jointed dike of basaltic andesite 1½ miles southeast of Jordan Dam contains 2 percent phenocrysts of altered olivine and 1 percent phenocrysts of labradorite in a fine-grained subophitic groundmass of plagioclase (about An_{40}), 53 percent; augitic pyroxene and less abundant hypersthene, 26 percent; magnetite, 5 percent; and interstitial clays and cristobalite(?), 2 percent. Chemical and modal analyses of samples from three andesite and dacite plugs are given in table 7 (cols. 13, 16, 24).

ALTERATION

In the Western Cascade Range, most of the volcanic rocks that are of Miocene age or older are partially or completely altered. The most widespread alteration has resulted in mineral assemblages that are characteristic of the lower grade of the zeolite metamorphic facies, as defined by Coombs and others (1959). In several restricted areas, the rocks are propylitically altered. Near the margins of some intrusives, the rocks are altered to quartz-tourmaline hornfels.

The least altered of the older rocks are those farthest from the former centers of volcanism; most of these are along the margin of the Willamette Valley. Examination of thin sections of tuffaceous rocks from along the margin of the valley showed that the glassy parts of a few of the rocks are not devitrified; the same conclusion was reached from an X-ray diffraction study of a sample of tuff from near Thomas Creek (at USGS Paleobot. loc. 9291). The glassy groundmass of some andesite flows in the Sardine Formation is also not devitrified, as for example a flow near the top of House Mountain, northeast of Mehama.

ZEOLITIC ALTERATION

Over most of the Western Cascade Range, outside the restricted areas of propylitic alteration, pyroclastic rocks are thoroughly altered, although andesitic and basaltic flows are relatively fresh. Pumice, shards, and fine ash are completely devitrified to a fine-grained aggregate of minerals that are difficult to identify optically. In most rocks the glass is completely replaced by zeolite and green clay, which may also be accompanied by chalcedonic quartz, cristobalite or opal, and a carbonate mineral. The zeolite was identified by X-ray diffraction studies as mordenite in four samples and as clinoptilolite in three samples. The green clay was identified as montmorillonitic clay in two samples and as celandonite and montmorillonitic clay in one sample. Pyroxene and hornblende in these rocks are replaced almost completely by green clay. Feldspar in some of the rocks is partially replaced by zeolite, which may be accompanied by a carbonate mineral.

In most silicic flows and welded tuff beds, the glass is altered to an assemblage that consists mostly of alkalic feldspar and one or more of the following silica minerals: chalcedonic quartz, cristobalite, tridymite, and opal. Perhaps this assemblage is deuteric in origin, having formed during the cooling of the hot lava and ash flows. However, the zeolitic alteration, which occurs mostly in nonwelded tuff, probably took place during circulation of hot water in the more permeable fragmental rocks some time after they were deposited.

In contrast to the pyroclastic rocks and silicic flows, andesitic and basaltic flows are relatively fresh. The interstitial glassy material of most andesite flows is completely replaced by a fine-grained aggregate of alkalic feldspar, chalcedonic quartz or cristobalite, and sparse green clay. The interstitial glassy material of most basaltic rocks is not completely replaced, although the glass is accompanied by sparse cristobalite(?) and green clay. Amygdules of calcite, chalcedonic quartz, zeolites (thomsonite, laumontite, stilbite, a heulandite-like zeolite, and chabazite were identified in five samples), and clay are abundant in mafic flows. Olivine and, to a lesser extent, hypersthene, are generally altered to green clay. Feldspar and clinopyroxene are generally fresh.

PROPYLITIC ALTERATION

The rocks of the Western Cascade Range are propylitically altered in discontinuous areas that form a band extending from the South Umpqua River to the Collawash River (pl. 1; fig. 26). An area of similar alteration has been reported east of the northern part of the map area between the Salmon and Zigzag Rivers (A. C. Waters, oral commun., 1957). Most of these areas of propylitic alteration surround small stocks, dikes, and plugs and are associated with gold- and silver-bearing sulfide deposits.

The altered rocks are well-indurated greenish-gray rocks that fracture across rather than around fragments. Their characteristic suite of alteration minerals includes albite, epidote-clinozoicite, chlorite, quartz, carbonate minerals, sericite, celadonite, magnetite, and pyrite. Feldspar in andesite and basalt is partially altered to albite, epidote-clinozoicite, and chlorite; a carbonate mineral may be present. Pyroxene and olivine are partially or completely altered to chlorite or epidote-clinozoicite or both, and they may be accompanied by a carbonate mineral, magnetite, and pyrite. The groundmass is altered to epidote-clinozoicite, chlorite, and alkali feldspar; a carbonate mineral, celadonite, and chalcedonic quartz also may be present. The chlorite in these rocks is very pale green, is almost isotropic, and has a high positive relief (mean refractive index is 1.63±0.01 in several samples). In more silicic rocks, the feldspar is altered to albite, sericite, and epidote-clinozoicite, which may be accompanied by a carbonate mineral; the groundmass is altered to the same minerals plus chalcedonic quartz and magnetite; mafic minerals are replaced by chlorite or epidote or both, and a carbonate mineral, magnetite, and pyrite may be present.

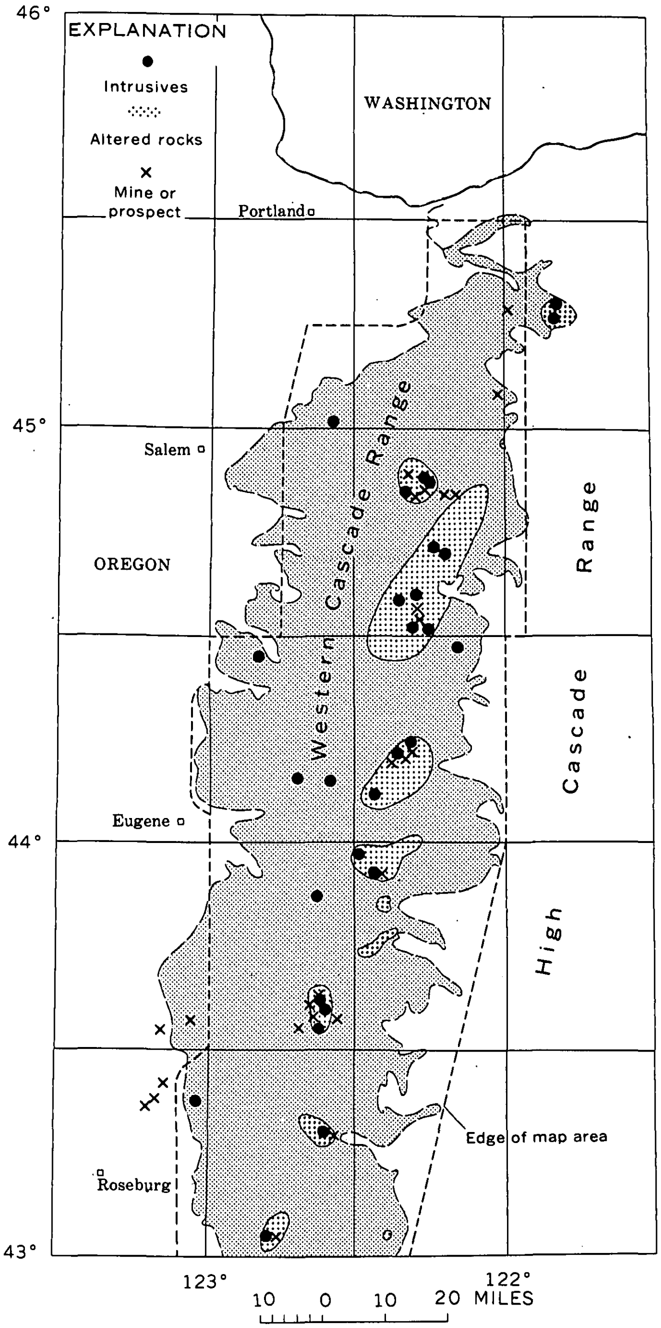


FIGURE 26.—Location of diorite, quartz diorite, granodiorite, and quartz monzonite intrusives, areas of propylitically altered rocks, and mines and prospects in the Western Cascade Range in Oregon north of lat 43°. Mines and prospects from Callaghan and Buddingham (1938) and Wells and Waters (1934). Western Cascade Range lightly shaded.

Adjacent to the areas of propylitic alteration shown on plate 1 and figure 26, the rocks are less severely altered and lack epidote-clinozoicite. In silicic flows and pyroclastic rocks, feldspar and glass are replaced by albite, chalcedonic quartz, chlorite or celadonite, and in some rocks a carbonate mineral. In mafic flow rocks, olivine and pyroxene are replaced by celadonite or chlorite with or without a carbonate mineral, and feldspar is partially replaced by albite.

CONTACT METAMORPHISM

Aureoles of dark flinty hornfels have formed adjacent to the medium-grained intrusives. As described by Buddington and Callaghan (1936, p. 442–449), the major effect of contact metamorphism is silification, and the following mineral assemblages are formed tourmaline-quartz, epidote-tourmaline, tourmaline-specularite-sericite, epidote-chlorite-magnetite (or pyrite), and quartz-sericite-pyrite. The minerals either completely along fractures; the alteration extends from a few inches to as much as 2,000 feet from the intrusive contacts in different areas.

STRUCTURE

The Cascade Range is a downwarped pile of volcanic rocks, elongate in a northerly direction, which has been warped into broad northeast-trending folds and broken along northwest-trending faults. The structural picture is still incomplete, in part because of the paucity of stratigraphic horizon markers and reliable dips and strikes.

GROSS STRUCTURAL FEATURES OF THE CASCADE RANGE IN OREGON

The area of the Cascade Range in Oregon is a broad north-trending downwarp, complementary to the Coast Ranges upwarp on the west, as shown by contours on the top of Eocene rocks (fig. 27). North of lat 43° the undulating axis of the downwarp lies west of the present crest of the range. Near lat 43° it abuts an upwarp that extends northeast from the Klamath Mountains across the Cascade Range to the Ochoco Mountains. On this upwarp, upper Eocene rocks extend almost completely across the Western Cascade Range along Jackson Creek, south of the map area (Wells and Peck, 1961). It is not known whether the downwarp of the range formed as compensation for the transfer to the surface of volcanic material from the underlying crust, from regional tectonic forces, or both.

The most prominent geomorphic feature of the Cascade Range is the north-south belt of Quaternary volcanoes that form the crest of the range (Waters and others, 1961). Similar but older belts lie farther west and are defined by vents of the Sardine Formation and the Little Butte Volcanic Series (figs. 15, 21) and areas of propylitic alteration, stocks, and gold- and silver-bearing sulfide deposits (fig. 26; Callaghan, 1933; Waters, 1933). These belts probably are related to deep northward-trending fracture zones that channeled ascending magmas.

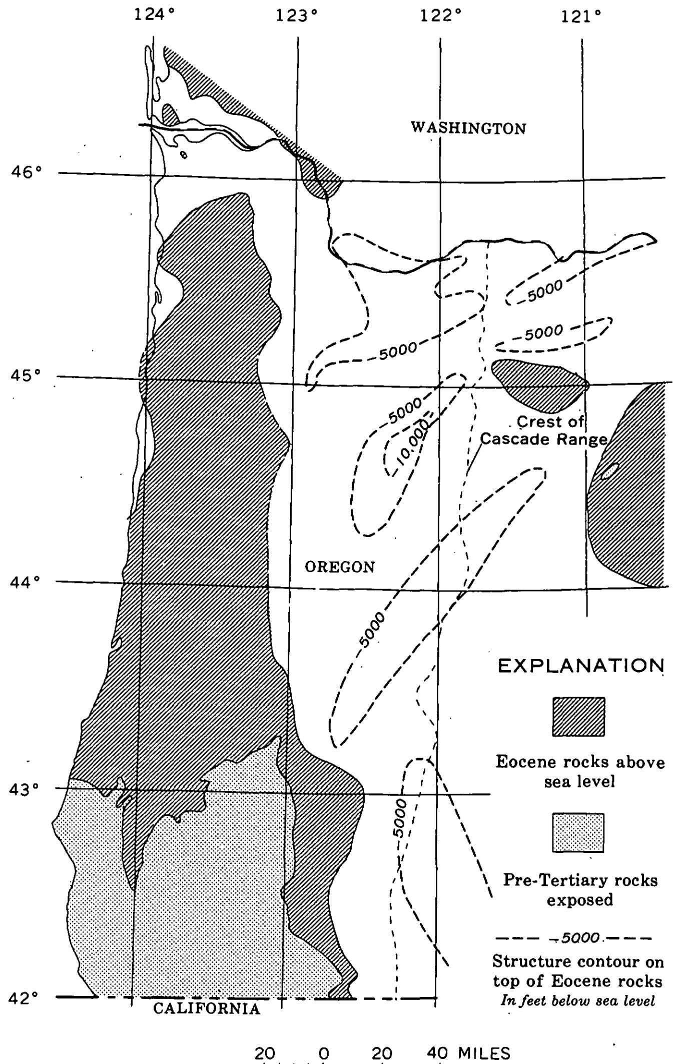


FIGURE 27.—Inferred contours on top of rocks of Eocene age.

FOLDS

In the northern and central parts of the map area, the structure is dominated by several major folds that trend northeastward across the Western Cascade Range—the en echelon Mehama and Clackamas anticlines, the Sardine syncline, and the Breitenbush anticline (pl. 1). The Sardine syncline plunges northward and southward from a high in the Quartzville District and dies out to the south near the head of Indian Creek. The Mehama anticline was not traced south of Snow Peak, but several small anticlines lie on strike with it between Brownsville and Holly. Northwest of the Mehama and Clackamas anticlines are small north- to northeast-trending anticlines—one near Wilhoit, one near High Camp, and perhaps one near

Brightwood; the postulation of the latter is based on very meager data.

In the southern part of the map area, the prevelant easterly dip of the rocks is seldom reversed between the crests of anticlines that extend through Big Rock and Bear Mountain and the trough of a major syncline that lies east of Oakridge. The axis of this syncline has not been satisfactorily traced; it may continue southward into the upper part of the North Umpqua River drainage basin, but the evidence is inconclusive. The anticline that extends through Big Rock is the northward extension of the Sutherlin anticline, which was mapped by R. D. Brown, Jr., (in Wells and Peck, 1961) and by Hoover (1959) west of the map area.

With few exceptions, the dips of strata on the flanks of folds in the Western Cascade Range are less than 20°; most are less than 10°. The only major exception is the western flank of the Breitenbush anticline, where dips of 30° to 50° are common.

Folding in the Western Cascade Range probably took place several times between the late Eocene and late Miocene. All formations older than Pliocene are folded. In the western foothills of the range, strata of the Little Butte Volcanic Series dip more steeply than the overlying flows of Columbia River Basalt and strata of the Sardine Formation. Beds of the Colestin Formation locally dip more steeply than beds of the overlying Little Butte Volcanic Series. Waters (1955a, p. 674–675; and in Gilluly, Waters, and Woodford, 1959, p. 118–119) showed that along the eastern flank of the Cascade Range in northern Oregon and Washington, folding was recurrent along nearly coincident axes during the Cenozoic. Whether or not folding recurred along coincident axes in the Western Cascade Range has not been determined.

FAULTS

Northwest-trending faults are the major structural feature of the southern part of the Western Cascade Range in the drainage basins of the Middle Fork of the Willamette River and the North Umpqua River. In the northern part of the map area, few faults were identified, but this absence of known faults probably reflects the paucity of marker horizons and the reconnaissance nature of the mapping rather than a general lack of faulting.

In the drainage basin of the Middle Fork of the Willamette River, units of mafic flows in the Little Butte Volcanic Series are apparently displaced along north to northwest-trending faults at the following places: the southern end of the Coburg Hills; along the Willamette River at Jasper, Lookout Point Dam, the mouth of Tire Creek, and the mouth of Coffee Pot Creek; and near Bohemia Mountain. Except for the fault at the mouth of Tire Creek, the downthrown side of these faults is to the southwest. Fault planes were seen only at Dorena Dam and on the north side of the Lookout Point Reservoir, but the local vertical attitude of tuff beds along Coal Creek must have been caused by faulting.

In the drainage basin of the North Umpqua River, the Little Butte Volcanic Series and the Colestin Formation are displaced along two nearly vertical faults that trend almost due west near Red Butte and Taft Mountain; downthrow on each is to the north. South of Scott Mountain, Eocene marine rocks on the west are dropped down along a northeast-trending fault that continues southwest beyond the map area; lenses of slickensided serpentine occur along the fault. At the southern edge of the map area are the northern extensions of two northeast-trending faults that were mapped by Wells (Wells and Peck, 1961). A parallel fault may be concealed beneath Quaternary lava and tuff in the valley of the Rogue River to the east; as Howel Williams (1942) pointed out, high-standing rocks of the Western Cascade Range are bordered on the east by relatively low-lying younger volcanic rocks of the High Cascade Range. Williams (1942) also suggested that the apparent linearity of the contact over great distances indicates that much of the boundary between the volcanic rocks of the High Cascade Range and the volcanic rocks of the Western Cascade Range may be faulted. However, this linearity has not been substantiated by later, more detailed mapping.

Only two small faults were mapped in the northern part of the map area, both in the drainage basin of the Clackamas River. The possible southerly extension of the eastern of these faults, beyond what was mapped, is suggested by the location of the Austin hot springs along the Clackamas River, but a displacement of units in that area was not noted in the reconnaissance mapping.

Callaghan and Buddington (1938, pl. 1) mapped several veins during their study of the mineral deposits of the Cascade Range. These veins, which probably were deposited along fault planes, trend mostly 50° to 60° northwest.

The age of the faulting is not completely known. Inasmuch as volcanic rocks of the High Cascade Range of Pliocene and Quarternary age are displaced along faults both in the map area and on the eastern flank of the Cascade Range (A. C. Waters, in Wells and Peck, 1961; Newcomb and Hart, 1958), at least a part of the faulting is as young as Pliocene and Quaternary.

TABLE 7.—*Chemical analyses, norms, and modes*

Analyses

	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	51.44	53.54	48.9	51.9	53.27	54.25	54.3	54.8	55.18	57.47	61.1	61.1
Al_2O_3	13.29	14.10	14.7	18.8	17.08	16.46	19.1	16.9	15.57	14.95	16.9	17.6
Fe_2O_3	2.16	1.73	3.5	3.6	2.93	3.08	2.9	4.0	3.20	2.05	2.4	2.7
FeO	12.00	10.33	6.6	7.0	6.06	5.92	4.4	6.3	6.06	7.18	3.3	2.6
MgO	4.28	4.59	9.6	3.2	5.12	4.46	3.7	3.5	4.15	2.74	3.4	2.7
CaO	8.23	8.54	11.3	9.4	9.60	8.79	8.2	6.8	7.60	6.63	5.0	5.6
Na_2O	2.93	3.14	1.8	2.9	2.28	3.46	3.5	4.1	3.08	3.45	3.8	4.2
K_2O	1.40	1.21	.58	.52	.72	.80	.74	1.0	1.40	2.15	1.7	1.2
H_2O-	.07	.03	} 2.5	1.7	.15	.26	} 2.1	1.2	.40	.45	} 2.1	2.0
H_2O+	.66	.26			1.52	1.32			2.03	.55		
TiO_2	2.80	2.01	1.1	1.4	1.04	1.28	1.0	1.6	1.46	1.60	.79	.66
MnO	.23	.22	.18	.18	.15	.13	.15	.18	.14	.12	.10	.08
P_2O_5	.61	.35	.15	.16	.20	.23	.14	.22	.14	.32	.13	.12
CO_2	-----	-----	.11	.14	.08	-----	.09	.18	.07	-----	.15	<.05
Total	100.10	100.05	101	101	100.20	100.44	100	101	100.48	99.66	101	101
Specific gravity (powder)	-----	-----	2.93	2.72	-----	-----	2.76	2.79	-----	-----	2.66	2.62
Refractive index of fused bead	-----	-----	1.608	1.596	-----	-----	1.574	1.578	-----	-----	1.552	1.538

Norms

	1	2	3	4	5	6	7	8	9	10	11	12
Quartz	3.24	3.84	-----	7.1	3.82	6.12	7.9	7.0	9.42	10.32	16	16
Orthoclase	8.34	7.23	3.0	2.8	3.89	5.00	4.4	5.6	8.34	12.79	10	7.2
Albite	24.63	26.72	15	25	19.39	29.34	29	35	26.20	28.82	32	36
Anorthite	18.90	20.57	30	37	34.47	26.97	34	25	24.46	19.18	24	26
Corundum	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	.1	-----
Wollastonite	7.77	8.24	10	3.8	5.34	6.61	2.3	3.2	5.45	4.99	-----	.58
Enstatite	10.70	11.50	24	8.2	12.80	11.20	9.4	8.9	10.30	6.90	8.6	6.8
Ferrosilite	15.97	14.52	7.2	7.4	7.26	6.47	4.0	5.7	6.20	8.98	2.8	2.2
Forsterite	-----	-----	.10	-----	-----	-----	-----	-----	-----	-----	-----	-----
Fayalite	-----	-----	.07	-----	-----	-----	-----	-----	-----	-----	-----	-----
Magnetite	3.25	2.55	5.1	5.3	4.18	4.41	4.2	5.8	4.64	3.02	3.5	4.0
Ilmenite	5.32	3.80	2.1	2.7	1.98	2.43	2.0	3.0	2.89	3.04	1.5	1.4
Hematite	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Apatite	1.34	.84	.3	.3	.34	.34	.3	.3	.34	.67	.3	.3
Calcite	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

Modes

[Figures in

	3	4	7	8	11	12	[1] 13	15
Phenocrysts:								
Quartz	0	0	0	0	0	0	1	0
K-feldspar	0	0	0	0	0	0	0	0
Or:AbAn	-----	-----	-----	-----	-----	-----	-----	-----
Plagioclase	0	32	23	3	22	34	28.5	9
An	-----	60–85(80)	65–85(75)	70	50–65(60)	45–50	-----	30–35
Clinopyroxene	16	0	2	Tr.	1	1	3.5	1
Wo:En:Fs	50:35:15	-----	40:25:35	-----	(2V=45°)	-----	-----	35:10:55
Orthopyroxene	Tr.	0	0	0	8	5	0	½
En	-----	-----	-----	-----	65	60	-----	30
Olivine (chrysolite)	6	Tr.	3	1	1	0	0	0
Fo	80	-----	80	-----	-----	-----	-----	-----
Hornblende	0	0	Tr.	0	0	0	0	0
Biotite	0	0	0	0	0	0	0	0
Magnetite and ilmenite	Tr.	0	0	0	1	1	1	½
Lithic inclusions	0	0	0	0	0	0	0	1
Groundmass:	78	68	72	96	67	59	66	88
Plagioclase	41	26	27	43	-----	-----	-----	0
An	(65)	(60)	(45)	(50)	(40)	(30)	-----	-----
Alkalic feldspar and silica minerals	0	1	0	1	-----	-----	-----	0
Glass	10	10	4	16	-----	-----	-----	[5] 38
Pigeonite	Tr.	} 25	{ 0	Tr.	} 8	{ 10	-----	0
Wo:En:Fs	-----	10:40:50	-----	-----			-----	-----
Augitic pyroxene	19		23	28			-----	0
Wo:En:Fs	30:30:40	30:30:40	(2V=40)	20:35:45			-----	-----
Orthopyroxene	0	Tr.	Tr.	0			-----	0
En	-----	65	-----	-----			-----	-----
Magnetite and ilmenite	4	4	5	7	2	2	-----	0
Alteration minerals	4	2	1	1	-----	-----	-----	0
Apatite	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	-----	0

[1] Modal analysis published by Buddington and Callaghan (1936).
[2] Includes intergrowths with plagioclase on rims of plagioclase grains.
[3] Augite, chlorite, and others.
[4] Augite, hornblende, chlorite, and other.
[5] Includes crystallites of unknown composition.

1. Black Stayton Basalt (S36); collected from flow of Columbia River Basalt 4 miles north of Stayton. A. Willman, analyst. (Thayer, 1937, p. 1622, col. 1.)

2. Gray Stayton Basalt (S28); collected from flow of Columbia River Basalt east of Oregon State Training School. A. Willman, analyst. (Thayer, 1937, p. 1622, col. 2.)

3. Olivine basalt (DLP–56–27); collected 2 feet below amygdaloidal top of flow in Little Butte Volcanic Series (overlain by leaf-bearing tuff) in bank of road 0.1 mile northeast of Hayden Bridge in center of SW¼ sec. 20, T. 17 S., R. 2 W. Sample is dark gray, microporphyritic (glomeroporphyritic in part) and intergranular; average diameter of phenocrysts is 2 mm; grain size of groundmass averages 0.1 mm. Analyzed by P. L. D. Elmore, S. D. Botts, H. H. Thomas, and M. D. Mack using rapid techniques.

4. Basaltic andesite (P–55–8–31A); collected from middle part of columnar-jointed amygdaloidal flow near base of Sardine Formation in roadmetal quarry on U.S. Highway 20, 1 mile west of Cascadia Ranger Station in NW¼SE¼ sec. 35, T. 13 S., R. 2 E. Sample is dark gray, porphyritic, and intergranular; average diameter of phenocrysts is 1 mm; grain size of groundmass average 0.2 mm. Analyzed by P. L. D. Elmore, S. D. Botts, H. H. Thomas, and M. D. Mack using rapid techniques.

5. Labradorite andesite; collected from Little Butte Volcanic Series near Grizzly Saddle, Bohemia District (sec. 7, T. 23 S., R. 2 E.). George Steiger, analyst. (Callaghan, 1933, p. 246, col. 4.)

6. Labradorite andesite; collected from flow in Sardine Formation(?) at top of Gold Hill, Blue River District (sec. 32, T. 15 S., R. 4 E.). George Steiger, analyst. (Callaghan, 1933, p. 246, col. 5.)

of rocks of the Western Cascade Range in Oregon

(weight percent)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
61.99	62.72	67.9	69.2	69.58	70.5	71.0	71.2	71.9	74.0	52.67	53.63	59.70	62.37	65.16	65.71	71.03	71.57
15.69	15.04	13.5	14.7	13.68	15.1	14.8	14.1	15.1	13.7	17.36	17.95	15.53	15.19	15.24	14.29	12.67	13.55
2.96	1.73	1.5	2.8	1.39	2.4	2.0	1.5	1.1	.8	3.37	3.24	3.57	2.13	2.08	2.44	2.03	1.55
2.85	4.44	2.6	1.3	1.88	.94	.49	.5	.67	.7	5.14	4.84	4.07	3.38	3.04	2.85	1.58	2.28
2.76	2.19	.16	.62	.63	.34	.40	.22	.10	.31	5.06	4.94	3.16	2.78	2.22	2.15	1.29	.53
4.62	3.83	2.0	2.1	2.68	2.1	1.8	1.6	1.1	1.1	8.80	7.88	6.17	5.06	4.69	4.13	2.66	1.52
3.52	4.18	4.8	4.9	3.66	5.0	3.8	3.8	4.5	3.5	3.06	2.25	3.65	3.39	3.62	3.55	2.47	4.75
1.60	2.26	2.7	2.6	3.22	2.5	3.6	3.3	3.8	3.2	.73	1.16	1.34	1.85	2.08	2.42	4.16	4.09
.13	.34	4.2	1.2	.45	.87	1.6	2.0	1.2	1.8	.18	1.10	.03	.11	.13	.11	.08	.02
1.83	1.91			1.46						2.15	1.12	.98	1.90	.77	.82	.84	.13
.73	.95	.31	.58	.44	.40	.38	.38	.18	.12	1.13	.91	1.13	.82	.74	.81	.50	----
.06	.10	.12	.08	.07	.08	.06	.01	.04	.06	.17	.11	.17	.11	.09	.18	.06	.03
.31	.21	.03	.09	.09	.06	.04	.04	.00	.01	.29	.72	.25	.24	.29	.20	.39	.03
.75	.38	.07	.14	1.38	.14	.06	<.05	.48	.55	.09	----	----	.32	.17	----	.05	----
99.80	100.28	100	100	100.61	100	100	99	100	100	100.20	99.85	99.75	99.65	100.32	99.66	99.81	100.05
----	----	2.47	2.64	----	2.63	2.58	2.60	2.52	2.59	----	----	----	----	----	----	----	----
----	----	1.512	1.505	----	1.503	1.502	1.499	1.494	1.490	----	----	----	----	----	----	----	----

(weight percent)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
23.76	17.28	24	25	32.82	26	32	32	29	38	6.72	11.22	16.14	20.40	23.16	23.94	34.02	23.
9.45	13.34	16	16	18.90	15.	21	20	22	19	3.89	7.23	7.78	11.12	12.23	14.46	24.46	24.
29.34	35.63	40	41	30.92	42	32	32	38	29	25.68	18.86	30.92	28.82	30.39	29.87	20.96	40.
16.40	15.29	7.2	9.7	3.61	11	8.9	8.1	5.6	5.6	31.97	34.73	21.96	20.57	19.18	15.85	10.56	3.34
2.24	----	----	0.2	2.86	0.2	1.4	1.3	1.5	2.4	----	.20	----	----	----	----	.30	----
----	----	1.2	----	----	----	----	----	----	----	3.94	----	3.36	.70	.58	1.51	----	1.74
6.90	5.50	.5	1.6	1.60	.85	1.0	.5	.25	.8	12.70	12.40	7.90	7.00	5.60	5.40	3.20	1.30
1.58	5.28	3.1	----	1.72	.40	----	----	----	.5	5.15	5.02	2.90	3.43	2.77	2.24	.53	2.90
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
4.41	2.55	2.1	2.6	2.09	1.9	.5	.5	1.6	1.2	4.87	4.64	5.34	3.02	3.02	3.48	3.02	2.32
1.37	1.82	.6	1.2	.76	.8	.8	.8	.3	.2	2.13	1.67	2.13	1.52	1.37	1.52	.91	----
----	----	----	1.4	----	1.1	1.8	1.1	----	----	----	----	----	----	----	----	----	----
.74	.34	----	.3	.34	----	----	----	----	----	.67	1.68	.61	.57	.67	.47	.91	----
1.70	.90	----	----	3.20	----	----	----	----	----	.20	----	----	.70	.40	----	----	----

(volume percent)

parentheses are averages]

16	18	19	20	21	22	[1] 23	[1] 25	[1] 26	[1] 27	[1] 28	[1] 30
0	Tr.	2	0	4	13	1.0	19	0.5	0	18	31
0	0	0	0	0	4	Tr.	3	0	0	8	[2] 37
----	----	----	----	----	40:60	----	----	----	----	----	----
8⅓	27	14	13	8	12½	69	59.5	25.5	34.5	43.5	26
40–45	30–35	30-35	35–40	15–30(25)	15	----	----	----	----	----	----
Tr.	Tr.	0	1½	0	0	[3] 26	[3] 0	[3] 9.5	[3] 7	0	0
1	0	0	0	0	0	0	0	0	5.5	0	0
0	0	0	0	0	0	0	0	[4] 0	0	0	0
0	0	⅔	0	½	0	0	[4] 14	0	0	9.5	0
0	0	0	0	0	½	0	0	0	0	0	3
⅔	1	⅔	½	Tr.	1	3.5	4	1.5	2.5	2.5	3
0	2	⅔	1	½	Tr.	0	.5	0	.5	.5	0
90	70	82	84	87	68	5	0	63	50.0	----	0
----	----	----	----	----	----	0	0	----	----	0	0
----	----	----	----	----	----	0	0	----	----	18.0	0
----	----	----	----	----	----	0	0	----	----	0	0
----	----	----	----	----	----	0	0	----	----	0	0
----	----	----	----	----	----	0	0	----	----	0	0
----	----	----	----	----	----	0	0	----	----	0	0
----	----	----	----	----	----	0	0	----	----	0	0
----	----	----	----	----	----	----	0	----	----	0	0
----	----	----	----	----	----	.5	0	----	----	0	0

7. Basaltic andesite (DLP–56–115); collected from platy flow in upper part of Sardine Formation in bank of road 1 mile southwest of Sardine Butte in NE¼ sec. 54, T. 18 S., R. 4 E. Sample is medium dark gray, porphyritic and intergranular; average diameter of phenocrysts is 2 mm; groundmass is aphanitic (grain size approximately 0.025 mm). Analyzed by P. L. D. Elmore, S. D. Botts, H. H. Thomas, and M. D. Mack using rapid techniques.

8. Basaltic andesite (P–55–8–19D); collected from platy flow in lower part of Sardine Formation in bank of road 3 miles southwest of Mill City in NW¼SW¼ sec. 7, T. 10 S., R. 3 E. Sample is dark gray, sparsely porphyritic, and pilotaxitic; average diameter of phenocrysts is 1 mm; grain size of groundmass averages 0.1 mm. Analyzed by P. L. D. Elmore, S. D. Botts, H. H. Thomas, and M. D. Mack using rapid techniques.

9. Labradorite andesite; collected from Little Butte Volcanic Series on Bohemia Mountain, Bohemia District (sec. 14, T. 23 S., R. 1 E.). George Steiger, analyst. (Callaghan, 1933, p. 346, col. 6.)

10. Black labradorite andesite; collected from McNeil Creek, Jackson County. J. C. Fairchild, analyst. (Callaghan, 1933, p. 246, col. 3.)

11. Hypersthene andesite (P–55–6–25G); collected from platy flow in the Sardine Formation, in roadmetal quarry 5 miles south of Colton in NW¼NW¼ sec. 35, T. 5 S., R. 3 E. Sample is medium gray, porphyritic, and pilotaxitic; average diameter of phenocrysts is 1 mm; groundmass is aphanitic (grain size approximately 0.01 mm). Analyzed by P. L. D. Elmore, S. D. Botts, H. H. Thomas, and M. D. Mack using rapid techniques.

12. Hypersthene andesite (P–55–6–29A); collected from columnar-jointed and platy flow in Sardine Formation in bank of road 2 miles

south of Brightwood in E¼ sec. 36, T. 2½ S., R. 6 E. Sample is medium gray, porphyritic, and pilotaxitic; average diameter of phenocrysts is ½ mm; groundmass is aphanitic (grain size approximately 0.01 mm). Analyzed by P. L. D. Elmore, S. D. Botts, H. H. Thomas, and M. D. Mack using rapid techniques.

13. Augite dacite porphyry; collected from small plug in Little Butte Volcanic Series on southeast spur of Bohemia Mountain in sec. 14, T. 23 S., R. 1 E. R. B. Ellestad, analyst. (Buddington and Callaghan, 1936, p. 427 and 428, col. 3.)

14. Augite andesite; collected from Little Butte Volcanic Series on South Grouse Mountain, Bohemia District (sec. 13, T. 23 S., R. 1 E.). George Steiger, analyst. Callaghan, 1933, p. 246, col. 7.)

15. Dacite (DLP–56–17); collected from 10-foot-thick layer of black vitreous welded tuff, which is interbedded in nonwelded vitric tuff and pumice lapilli tuff in Little Butte Volcanic Series, in bank of road along North Fork of Winberry Creek 1.6 miles east of Forest Service boundary in NE¼SW¼ sec. 20, T. 19 S., R. 2 E. Sample contains sparse crystals in light brown glass (N=1.507±.003), which is made up of welded shards, fine ash, and less abundant flattened pumice lapilli and contains scattered crystallites. Analyzed by P. L. D. Elmore, S. D. Botts, H. H. Thomas, and M. D. Mack using rapid techniques.

16. Dacite (DLP–56–133); collected from columnar-jointed plug in Little Butte Volcanic Series in roadmetal quarry at east side of Stone Mountain along W edge SW¼NW¼ sec. 31, T. 22 S., R. 4 E. Sample is light gray, sparsely porphyritic, and pilotaxitic: average diameter of phenocrysts is ⅔ mm: groundmass is aphanitic (grain size approximately 0.01 mm). Analyzed by P. L. D. Elmore, S. D. Botts, H. H. Thomas, and M. D. Mack using rapid techniques.

17. Rhyolite; collected from Little Butte Volcanic Series in Vesuvius Mine in Bohemia District (SW¼ sec. 11, T. 23 S., R. 1 E.). George Steiger, analyst. (Callaghan, 1933, p. 246, col. 8.)

18. Dacite (ABG–54–55); collected from 30-foot-thick massive vitric welded tuff bed in Little Butte Volcanic Series in road bank of Oregon Route 22, 5.4 miles east of Idanha in SE¼NE¼ sec. 20, T. 10 S., R. 7 E. Sample is light brownish gray and finely banded and contains crystals (average diameter 1 mm) in a vitroclastic matrix that is altered mostly to very fine grained alkali feldspar and chalcedony. Analyzed by P. L. D. Elmore, S. D. Botts, H. H. Thomas, and M. D. Mack using rapid techniques.

19. Rhyodacite (DLP–56–128A); collected from massive vitric tuff in upper part of Little Butte Volcanic Series in bank of Fox Mill road 1.5 miles west of McCredie Springs in NW¼NE¼ sec. 34, T. 21 S., R. 4 E. Sample is pinkish gray and contains sparse crystals (average diameter ⅔ mm) in a nonwelded vitroclastic matrix that is mostly altered to a very fine grained chalcedony, alkali feldspar, and cristobalite. Analyzed by P. L. D. Elmore, S. D. Botts, H. H. Thomas, and M. D. Mack using rapid techniques.

20. Dacite (DLP–56–82); collected from welded vitric tuff in Little Butte Volcanic Series in bank of road ½ mile north of Pernot Mountain in NW¼ sec. 32, T. 17 S., R. 3 E. Tuff contains about 10 percent very light gray disk-shaped flattened pumice lapilli that range from 1 to 10 cm in diameter and 0.1 to 1.5 cm in thickness. Sample is medium gray and contains sparse crystals (average diameter 1 mm) in a vitroclastic matrix that is altered mostly to chalcedony, alkali feldspar, zeolite(?), and montmorillonitic clay; plagioclase is partly altered to zeolite and albite. Analyzed by P. L. D. Elmore, S. D. Botts, H. H. Thomas, and M. D. Mack using rapid techniques.

21. Rhyodacite (ABG–94–55); collected from finely banded flow in Little Butte Volcanic Series in bank of road along Canyon Creek in NE¼SW¼ sec. 20, T. 14 S., R. 4 E. Sample is very light gray and contains phenocrysts (average diameter ½ mm) in banded spherulitic groundmass that is divitrified chiefly to chalcedony, alkali feldspar, and tridymite. Analyzed by P. L. D. Elmore, S. D. Botts, H. H. Thomas, and M. D. Mack using rapid techniques.

22. Rhyodacite (DLP–57–55); collected from welded tuff at base of Little Butte Volcanic Series in bank of road along Little River, 12 miles east of Glide, in center sec. 9, T. 27 S. R. 2 W. Sample is light brownish gray to purplish gray, and contains about 5 percent flattened pumice lapilli as much as 2 cm in diameter and crystals (average diameter ½ mm) in devitrified matrix of welded shards and ash. Analyzed by P. L. D. Elmore, S. D. Botts, H. H. Thomas, and M. D. Mack using rapid techniques.

23. Augite diorite; collected from small plug ½ mile west of Peekaboo mine, in sec. 14, T. 23 S., R. 1 E., Bohemia District. T. Kameda, analyst. (Buddington and Callaghan, 1936, p. 427–428, col. 1.)

24. Quartz diorite; collected from plug at Steens Butte (Buck Mountain) in sec. 24, T. 23 S., R. 3 W. J. J. Fahey analyst. (Wells and Waters, 1935, p. 970, col. 5.)

25. Augite quartz diorite; collected from porphyritic border facies of small stock on the Champion trail, 1,600 feet north of Golden Curry Creek in sec. 1, T. 23 S., R. 1 E., Bohemia District. R. B. Ellestad, analyst. (Buddington and Callaghan, 1936, p. 427–428, col. 2.)

26. Augite granodiorite porphyry; collected from dike on trail to Grizzly Saddle, 300 yards west-southwest of Grizzly Peak in sec. 12, T. 23 S., R. 1 E., Bohemia District. R. B. Ellestad, analyst. (Buddington and Callaghan, 1936, p. 427–428, col. 4.)

27. Augite-hypersthene granodiorite porphyry; collected from core of dike on road to Champion Saddle, above Champion boarding house in sec. 13, T. 23 S., R. 1 E., Bohemia District. T. Kamada, analyst. (Buddington and Callaghan, 1936, p. 427–428, col. 5.)

28. Augite granodiorite; collected from small stock on Champion Creek road at first creek crossing north of Golden Curry Creek in sec. 36, T. 22 S., R. 1 E., Bohemia District. R. B. Ellestad, analyst. (Buddington and Callaghan, 1936, p. 427–428, col. 6.)

29. Aplite; collected from small dike in porphyritic granodiorite dike on trail to Champion Saddle above Champion boarding house in sec. 13, T. 23 S., R. 1 E., Bohemia District. T. Kamada, analyst. (Buddington and Callaghan, 1936, p. 426–427, col. 7.)

30. Granite; collected from stock at Nimrod, McKenzie River. A. H. Phillips, analyst. (Buddington and Callaghan, 1936, p. 426–427, col. 8.)

PETROLOGIC DATA

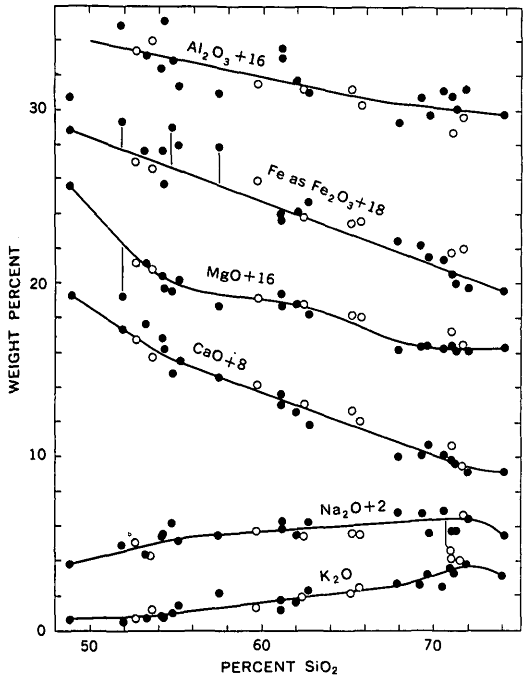
VARIATION IN CHEMICAL COMPOSITION

The volcanic rocks of the Western Cascade Range vary from olivine basalt through basaltic andesite and hypersthene andesite to dacite and rhyodacite. Chemical analyses and norms of 30 volcanic and intrusive rock samples from the Western Cascade Range in Oregon, all that are available, are given in table 7, together with the modes of 20 of the analyzed samples and the location and a brief description of each sample. The analyses include 13 previously unpublished analyses prepared by the Rapid Analysis Laboratory of the U.S. Geological Survey, as well as analyses published by Callaghan (1933), Buddington and Callaghan (1936), Wells and Waters (1935), and Thayer (1937). Analyses 3 through 30 are plotted against silica in figure 28; the smooth curves were drawn from inspection. Chemical analyses of rocks from the Western Cascade Range, excluding Columbia River Basalt, are similar to analyses of plutonic and volcanic rocks from elsewhere in the circumpacific belt and to Nockolds' (1954) average analyses of "central" basalt, andesite, dacite, rhyodacite, and dellenite. Nockolds' analyses are compared with the smoothed curves of analyses of Western Cascade rocks in the silica-variation diagram of figure 28.

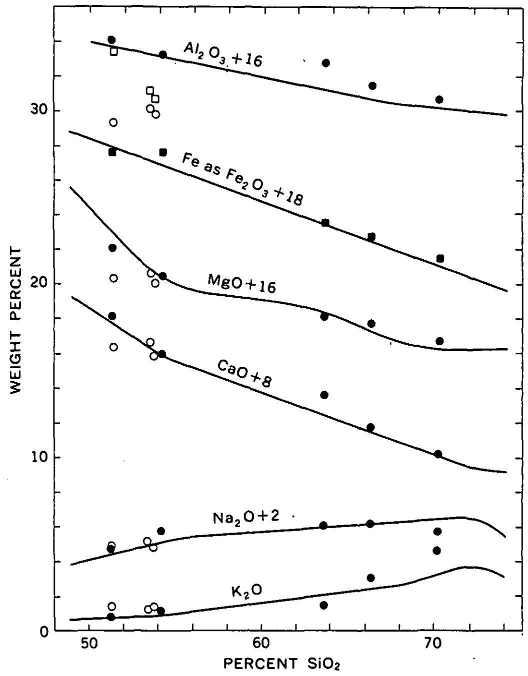
Analyzed samples of Columbia River Basalt from the Western Cascade Range (table 7, cols. 1, 2) contain less alumina and more iron oxide than other basalt and basaltic andesite in the range, as shown in figure 28. The analyses are similar to those of Columbia River Basalt elsewhere in Oregon and Washington (compare with Waters, 1961, tables 2, 3).

The volcanic rocks of the Western Cascade Range are similar to those of the High Cascade Range, but they contain more iron oxide and less alumina. The variation in chemical composition of rocks of the two suites are compared in the silica-variation diagram of figure 28.

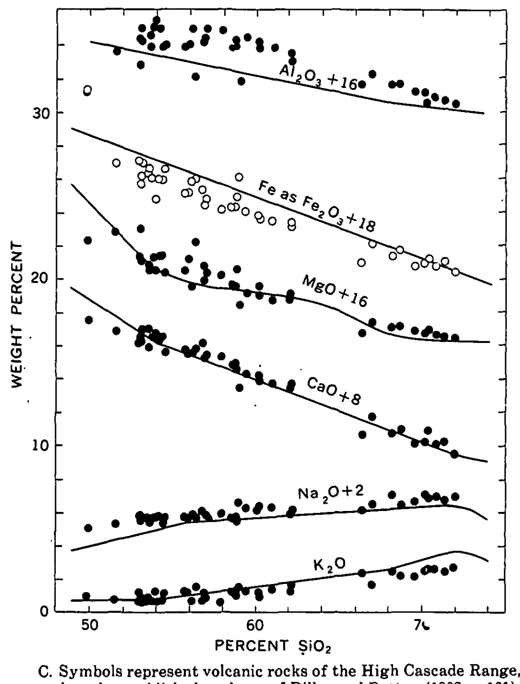
With one exception, the analyzed rocks of the Western Cascade Range contain normative quartz, as much as 38 percent in one sample. The mafic and intermediate rocks are subaluminous (molecular proportion of alumina equal to or only slightly greater than Na_2O+K_2O). The felsic rocks are meta-aluminous or peraluminous (molecular proportion of alumina greater than Na_2O+K_2O+CaO). The rocks are poor in K_2O in comparison with many other volcanic suites in western North America; the Niggli K value (molecular ratio of K_2O to K_2O+Na_2O) is 35 at 70 percent silica, 20 at 60 percent silica, and 8 at 50 percent silica. As a result of the relative paucity of K_2O, modal sanidine is rare, and the proportion of normative orthoclase is low compared to normative plagioclase (figs. 29, 30). The



A. Extrusive and intrusive rocks of the Western Cascade Range in Oregon. Dots represent volcanic and fine-grained intrusive rocks; circles represent medium-grained intrusive rocks



B. Solid symbols represent Nockolds' average "central" basalt, andesite, dacite, rhyodacite, and dellenite; open symbols represent Columbia River Basalt (table 7, col. 1 and 2, and Waters' (1961, table 3, col. B) average Yakima type). Curves represent analyses of rocks from the Western Cascade Range in Oregon (from fig. 28A). Squares are total iron as Fe_2O_3; circles and dots are other oxides



C. Symbols represent volcanic rocks of the High Cascade Range, based on published analyses of Diller and Patton (1902, p. 161), Moore (1937, p. 159), Thayer (1937, p. 1622-1623), and Williams (1942, p. 150-152). Curves represent analyses of rocks from the Western Cascade Range in Oregon. Circles are total iron as Fe_2O_3; dots are other oxides.

Figure 28.—Silica-variation diagrams of rocks from the Cascade Range and some other regions.

alkali-lime index (Peacock, 1921, p. 54–67), that is, the silica percent at which CaO equals Na_2O+K_2O, is about 60. Thus the rocks of the Western Cascade Range are calc-alkalic, as are the Tertiary volcanic rocks of central Oregon and the neovolcanic zone of Mexico (Williams, 1950, p. 265). In contrast, the volcanic rocks of the High Cascade Range and of the Aleutians are calcic, the alkali-lime index ranging from 62 to 64 (Williams 1942, p. 153; Mathews, 1957, p. 408; Snyder, 1959, p. 196).

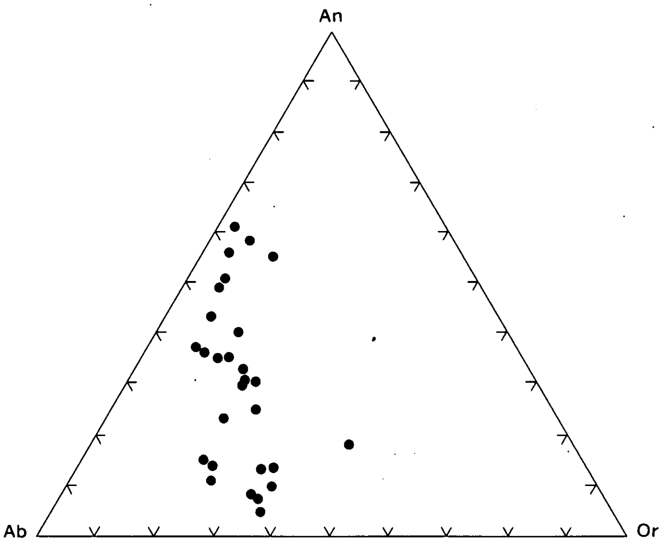


FIGURE 29.—Composition diagram of normative feldspar of chemically analyzed rocks from the Western Cascade Range in Oregon. Molecular ratios plotted.

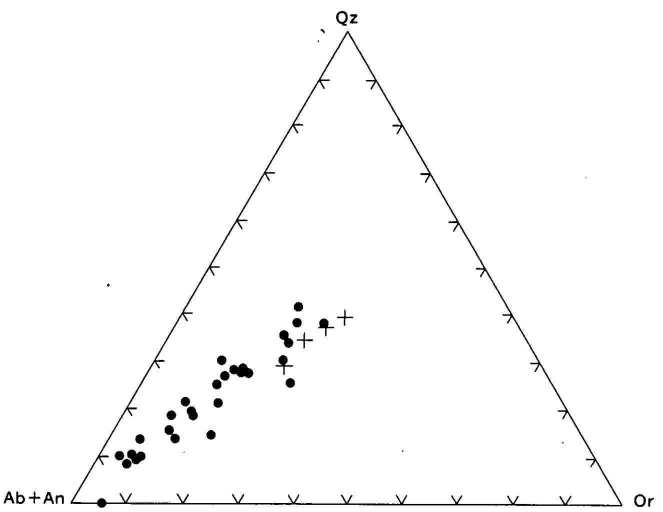


FIGURE 30.—Triangular diagram of normative quartz, plagioclase, and orthoclase of chemically analyzed rocks from the Western Cascade Range in Oregon (dots). Crosses represent isobaric minima in the system $NaAlSi_3O_8$–$KAlSi_3O_8$–SiO_2–H_2O between 500 and 4,000 kg per cm² water-vapor pressure (from Tuttle and Bowen, 1958, p. 75). Plotted in weight ratios.

TABLE 8.—*Average composition, in percent, of the volcanic rocks of the Western Cascade Range in Oregon*

[Based on the weighted average of 30 analyses]

SiO_2	60.7
Al_2O_3	16.6
Fe_2O_3	2.8
FeO	4.7
MgO	2.9
CaO	5.6
Na_2O	3.9
K_2O	1.5
TiO_2	1.0
P_2O_5	.1
MnO	.1
CO_2	.1

VOLUME AND AVERAGE COMPOSITION

The volume of volcanic rocks of late Eocene to late Miocene age in the Cascade Range in Oregon, including those buried by the volcanic rocks of the High Cascade Range, is estimated to be about 25,000 cubic miles, on the basis of an average thickness of 12,000 feet. The volcanic rocks of the High Cascade Range form an additional 5,000 cubic miles or so. The volcanic rocks of the Western Cascade Range in Oregon can be divided approximately as follows: 20 percent flows of basalt and basaltic andesite (including Columbia River Basalt), 20 percent flows of pyroxene andesite, 35 percent andesitic tuff, 20 percent dacitic tuff and flows, and 5 percent rhyodacitic tuff and flows. The flows of dacite and rhyodacite make up only 1 to 2 percent of the total, and Columbia River Basalt forms an equal amount. The average composition of the rocks of the Western Cascade Range is given in table 8; it corresponds to a silicic andesite or dark rhyodacite containing about 16 percent normative quartz, 9 percent normative orthoclase, and 56 percent normative plagioclase (about An_{40}). This average is more silicic than that of the volcanic rocks of the High Cascade Range, which is a basaltic andesite.

Although silicic andesite is the average rock type in the Western Cascade Range, it is not the most abundant rock type. The relative abundance of rocks of different composition seems to be distinctly bimodal, having a maximum at about 56 percent silica and a secondary maximum at about 70 percent silica, as shown by the curve in figure 31, in which relative abundance of volcanic rocks in the Western Cascade Range in Oregon has been plotted against silica content.

VARIATION IN MINERALOGICAL COMPOSITION

The volcanic rocks of the Western Cascade Range form a petrologic series containing a characteristic assemblage of minerals. The series ranges from olivine basalt through basaltic andesite and hypersthene andesite to dacite and rhyodacite. Gradational varieties are abundant, except for those containing 63 to 67 percent silica. Tholeiitic basalt is rare in the Western Cascade Range, excluding Columbia River Basalt; however, a few flows of tholeiitic basaltic andesite, which contain abundant pigeonitic pyroxene and basaltic glass and little or no olivine, occur in the upper part of the Little Butte Volcanic Series and the lower part of the Sardine Formation.

The nature and relative abundance of phenocrysts in volcanic rocks of different composition is shown in figure 32. This petrologic series is similar to that of the hypersthene or calc-alkaline series as defined by Kuno (1959, p. 44–45), who contrasted it with the pigeonitic or tholeiitic series and with the alkalic series. As in the Japanese rocks of the hypersthene series, described by Kuno (1950, 1959), the plagioclase phenocrysts in the rocks of the Western Cascade Range typically contain abundant blebs of glass and are conspicuously zoned in both normal progressive and oscillatory manners.

A sequence of crystallization is displayed in individual samples of the volcanic rocks by zoned and mantled crystals and by contrasting size and texture of mineral grains. The sequence as determined in a typical olivine basalt (the analyzed sample DLP–56–27) is shown in figure 33. In other samples of basalt, the olivine is rimmed by hypersthene instead of pigeonite, and the last phases to crystallize are andesine, cristobalite, and alkalic feldspar. The sequence in a typical hypersthene andesite (analyzed sample P–55–6–29A) is shown in figure 33. In other samples of andesite the groundmass pyroxene has been identified optically as ferrohypersthene and ferroaugite. In some samples ferrohypersthene is jacketed by pigeonitic pyroxene. As can be seen by comparing figures 32 and 33, the sequence of crystallization in individual rocks is similar to the change in mineralogic composition from less silicic to more silicic rocks in the petrologic series.

The difference in chemical composition between individual volcanic rocks and the groundmass constituents

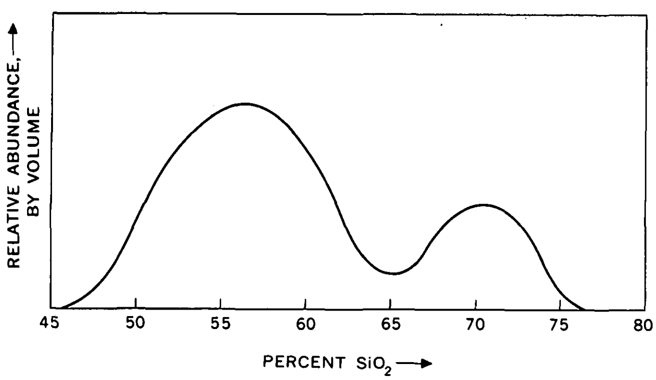


FIGURE 31.—Approximate relative abundance of volcanic rocks of different composition in the Western Cascade Range in Oregon.

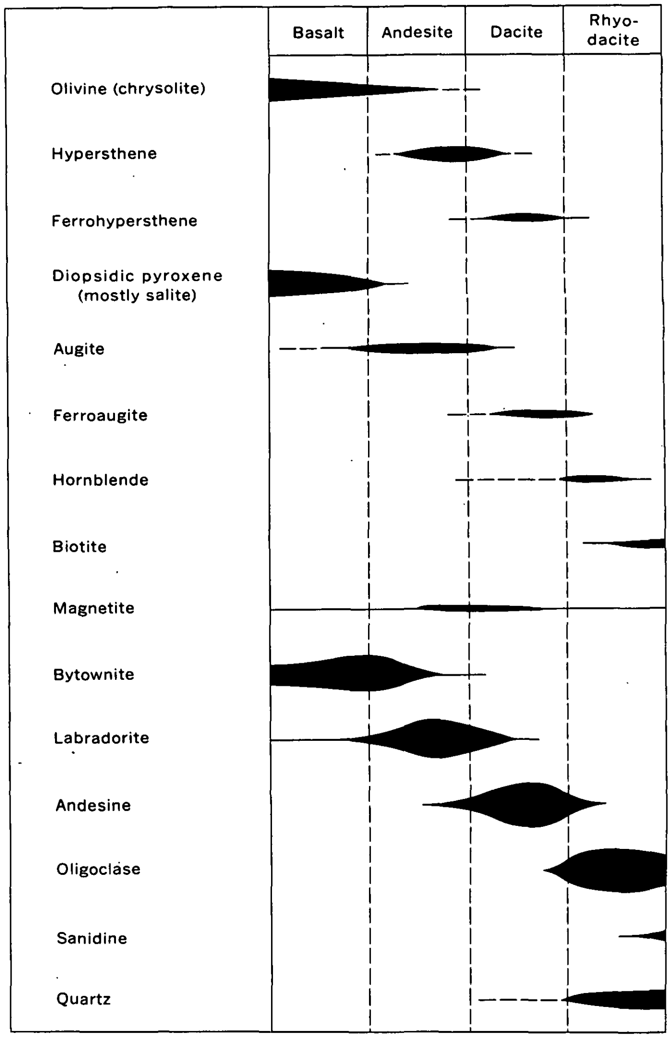


FIGURE 32.—Phenocrysts in volcanic rocks of the Western Cascade Range in Oregon.

of the rocks also is similar to the difference in chemical composition between less silicic and more silicic rocks. An estimate of this difference in composition was made for three analyzed rocks (an olivine basalt, a basaltic andesite, and a hypersthene andesite) by subtracting from each analysis the amount of material represented by phenocrysts in the rock, as determined from study of thin sections and grains in oil immersion. The calculated chemical and normative composition of the groundmass of each rock is given in table 9, and the chemical analyses, norms, and modes are given in table 7, columns 3, 7, and 10; the changes in composition between whole rock and groundmass are represented by arrows in the triangular FMA diagram (fig. 34). In this figure the composition of chemically analyzed volcanic and intrusive rocks from the Western Cascade Range in Oregon have been plotted using the variables MgO, $FeO+Fe_2O_3$, and K_2O+Na_2O, all in

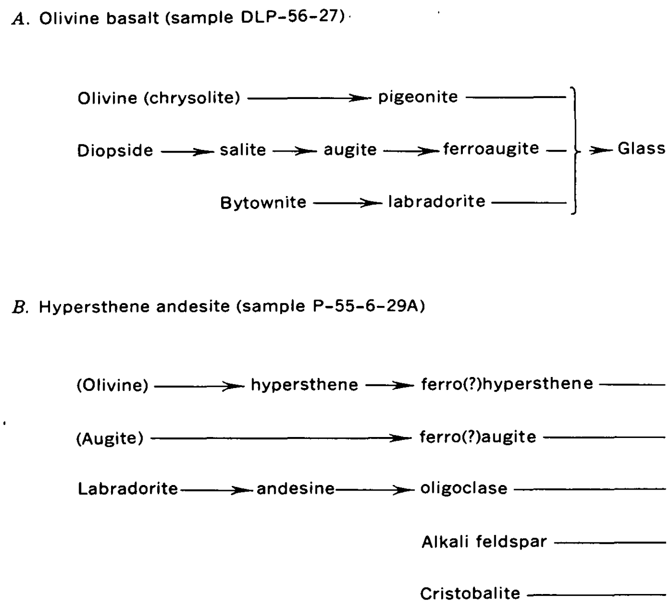


FIGURE 33.—Sequence of crystallization in an olivine basalt and a hypersthene andesite from the Western Cascade Range in Oregon.

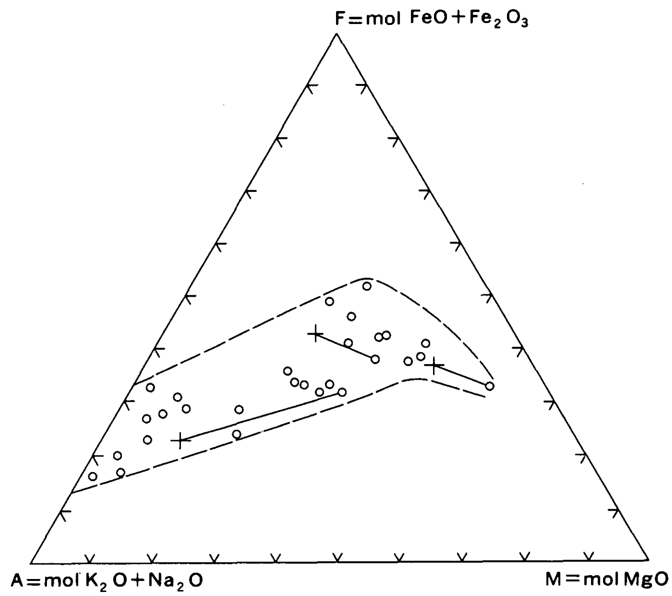


FIGURE 34.—Triangular FMA diagram of chemically analyzed rocks from the Western Cascade Range in Oregon. Circles bounded by dashed lines represent rocks from the Western Cascade Range; crosses represent calculated groundmass composition of three samples.

TABLE 9.—*Calculated chemical and normative composition, in percent of the groundmass of three volcanic rocks from the Western Cascade Range in Oregon*

Constituent	Field sample		
	DLP-56-27	DLP-56-115	P-55-6-25G
Chemical composition			
SiO_2	50	60	68.4
Al_2O_3	18.6	15.9	16.2
Fe_2O_3	4.9	4.3	2.9
FeO	5.2	4.6	.2
MgO	6.8	2.8	.9
CaO	9	6.4	3.5
Na_2O	2.2	4.1	4.5
K_2O	.9	1.1	2.8
TiO_2	1.8	1.4	.5
MnO	.3	.2	.1
P_2O_5	.3	.2	.2
Norms			
Quartz	4.7	15	23
Orthoclase	5.6	6.7	17
Albite	18	35	38
Anorthite	38	22	16
Wollastonite	2	3.8	.02
Enstatite	17	7	2.2
Ferrosilite	3.2	2.9	----------
Magnetite	7.2	6.3	----------
Hematite	----------	----------	2.9
Ilmenite	3.5	2.7	.6
Titanite	----------	----------	.4
Apatite	.7	.3	.3

DLP-56-27. Groundmass of olivine basalt; in calculations subtracted 15.3 percent pyroxene ($Wo_{50}En_{35}Fs_{15}$), 6.3 percent olivine (Fo_{80}), and 0.3 percent magnetite. Analysis of entire rock in table 7, column 3.
DLP-56-115. Groundmass of olivine andesite; in calculations subtracted 23 percent feldspar (An_{75}), 2 percent pyroxene ($Wo_{40}En_{25}Fs_{35}$), and 3 percent olivine (Fo_{80}) Analysis of entire rock in table 7, column 7.
P-56-6-25G. Groundmass of hypersthene andesite; in calculations subtracted 22 percent feldspar (An_{62}), 9 percent hypersthene (En_{65}), and 1 percent titaniferous magnetite. Analysis of entire rock in table 7, column 11.

molecular percent. The arrows lie in the band of points formed by the plotted analyses.

VARIATION IN COMPOSITION WITH TIME

A consistent variation in composition of the whole sequence of volcanic rocks of the Cascade Range with time has not been observed (fig. 35). Within some units, however, rocks containing progressively more silica are successively younger, as shown by Williams (1942, 1957) for the volcanic rocks of the High Cascade Range. In the volcanic rocks of the Western Cascade Range, crude sequences ranging upward from basalt to hypersthene andesite are exposed in the Coburg Hills (Little Butte Volcanic Series) and along the North Santiam River (Sardine Formation).

LOCATION OF VOLCANIC VENTS

The vents of the volcanic rocks of the Cascade Range in Oregon are distributed in several belts. The location of vents of different age is discussed on pages 21, 31, and 42; the vents are plotted on figures 15 and 21; dioritic and granitic intrusives, areas of propylitic alteration, and metalliferous deposits (all apparently associated with centers of volcanism) are plotted on figure 26. These data are summarized in figure 36, in which the center lines of each belt of vents has been plotted.

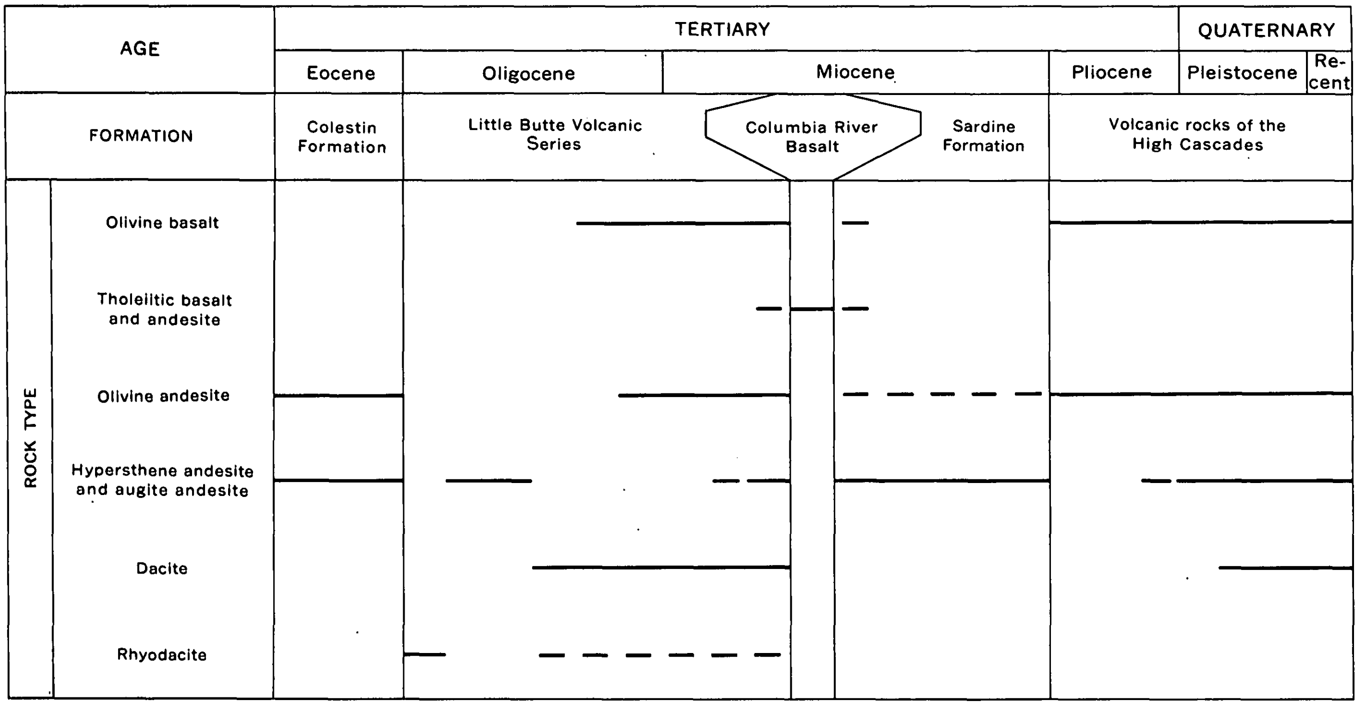


FIGURE 35.—Summary of the variation in composition with time of the volcanic rocks of the Cascade Range in Oregon.

No vents are known for the Colestin Formation. Only a few are known for the andesite flows in the lower part of the Little Butte Volcanic Series, and the location of line 1 of figure 36 is therefore uncertain.

The belts of vents of the Sardine Formation and of silicic rocks of the Little Butte Volcanic Series do not coincide exactly, but they differ to such a small extent that their center lines have been represented by a single line in figure 36 (line 3).

The data indicate that most of the volcanic activity in the Cascade Range in Oregon was concentrated in three and possibly four northward-trending belts during the Cenozoic. During early Oligocene, the vents may have been along the present western foothills. During the latter part of the Oligocene and the early Miocene, vents were alined in two separate belts lying farther east; vents in the western belt yielded mostly flows of olivine basalt and basaltic andesite, whereas contemporaneous vents in the eastern belt yielded mostly dacitic, andesitic, and rhyodacitic pyroclastic rocks. Volcanism continued in the middle and late Miocene along the eastern of these belts, but died out in the western belt. In the Pliocene, volcanic activity shifted to a belt lying still farther east. In a general way, thus, belts of active vents have shifted progressively eastward during the Cenozoic. The distribution of the vents in belts suggests that the vents are along deep fracture zones that channelled ascending magmas.

SPECULATION ON THE ORIGIN OF THE VOLCANIC ROCKS

For purposes of discussion, the origin of the volcanic rocks of the Cascade Range in Oregon can be divided into three separate but interrelated phases: (1) the composition of the source magma or magmas of the volcanic rocks, (2) the process of fractionation by which the variety of volcanic rocks were derived from the magma(s), and (3) the genesis of the magma(s). As a starting point, however, we need to consider the number of magmas involved, because several lines of evidence suggest that there were at least four and possibly five separate magmas or separate groups of similar magmas.

The Boring Lava and the volcanic rocks of the High Cascade Range differ consistently from the older volcanic rocks of the Western Cascade Range. (In this and following discussions, the Columbia River Basalt is not considered because it was derived from vents outside of the Cascade Range.) The older volcanic rocks of the Western Cascade Range are more silicic in average composition, for rocks of similar silica content, those of the Western Cascade Range contain less Al_2O_3 and more Fe_2O_3 (fig. 28); the basaltic rocks of the High Cascade Range typically are diktytaxitic rocks containing phenocrysts of olivine. In contrast, the basaltic rocks of the Western Cascade Range lack the diktytaxitic texture, and they contain phenocrysts of both the clinopyroxene salite and olivine. Further-

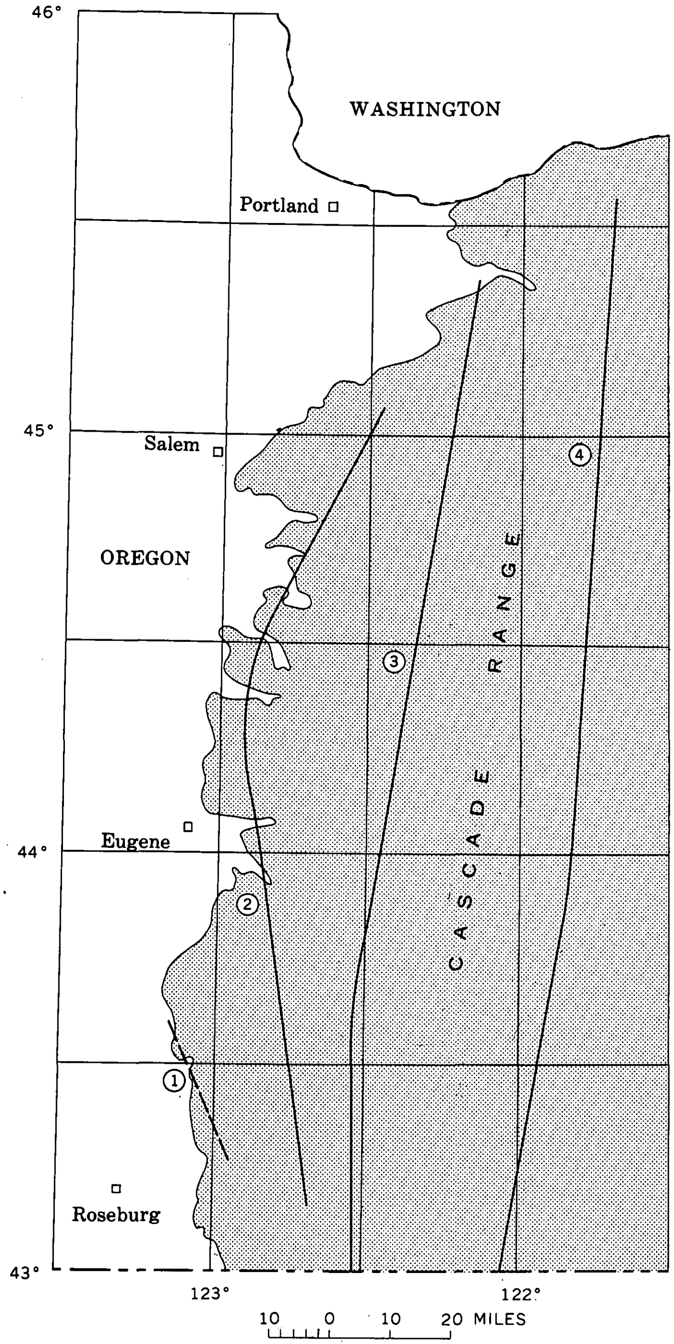


FIGURE 36.—Center lines of belts of vents of Cenozoic volcanic rocks in the Cascade Range in Oregon north of lat 43°. (1) Andesite flows of early Oligocene age (lower part of the Little Butte Volcanic Series); (2) basalt and basaltic andesite flows of middle Oligocene to early Miocene age (Little Butte Volcanic Series); (3) dacitic, andesite, and rhyodacitic pyroclastic rocks of Oligocene and early Miocene age (Little Butte Volcanic Series), and volcanic rocks of middle and late Miocene age (Sardine Formation); (4) volcanic rocks of the High Cascade Range of Pliocene and Quaternary age.

more, the two suites of rocks were erupted from vents that lay along separate belts. These differences strongly suggest that the Boring Lava and the volcanic rocks of the High Cascade Range form one magma series—that is, they were derived from a single magma (or a group of similar magmas)—and that the volcanic rocks of the Western Cascade Range were derived from other groups of magmas.

How many magmas were involved in the formation of the different volcanic rocks of the Western Cascade Range? The Little Butte Volcanic Series may have come from two or three magmas. The contrast in composition of the mafic flow rocks and the silicic pyroclastic rocks and their extrusion from separate belts of vents suggest that they were derived from separate magmas. Possibly the andesitic flows and pyroclastic rocks in the lower part of the series and the Colestin Formation were derived from a separate magma. The rocks of the Sardine Formation are similar chemically and petrographically to some of the mafic flow rocks of the Little Butte Volcanic Series; however, they are more silicic in composition on the average and were erupted from a separate belt of vents; accordingly, they also probably were derived from a separate magma. Thus the volcanic rocks of the Western Cascade Range apparently were derived from three or four separate magmas or separate groups of similar magmas.

The inferred composition and age of the magmas that yielded the volcanic rocks of the Cascade Range in Oregon are as follows (assuming, as discussed below, that crystal fractionation played a large role in the differentiation of the magmas): olivine basalt magmas of Pliocene and Quarternary age (source of the Boring Lava and the volcanic rocks of the High Cascade Range) and of Oligocene and early Miocene age (source of the basaltic rocks of the Little Butte Volcanic Series); andesitic magmas of middle and late Miocene age (source of the Sardine Formation) and possibly of late Eocene and early Oligocene age (source of the Colestin Formation and the andesitic volcanic rocks of the lower part of the Little Butte Volcanic Series); and dacitic or rhyodacitic magma of Oligocene and early Miocene age (source of the silicic volcanic rocks of the Little Butte Volcanic Series).

Each of these magmas produced a variety of volcanic rocks of different composition. The following relationships indicate that crystal fractionation could have produced much of the observed variation: (1) the time-sequence basalt-andesite-dacite that is apparent in the volcanic rocks of the High Cascade Range, in the Sardine Formation, and in the mafic flow of the Little Butte Volcanic Series, and (2) the similarity in the change in chemical and mineralogic composition between phenocrysts and groundmass in individual rocks on the one hand and between less and more silicic rocks on the other (compare figs. 32, 33). The small quantities of young silicic andesite and dacite present in the volcanic rocks of the High Cascade Range also indicate an origin by crystal fractionation, because crystal fractionation of basalt or basaltic andesite, the most abundant rock types in the High Cascade Range, should theoretically yield only small quantities of silicic rocks. Osborn (1959) has pointed out that in the volcanic rocks of the High Cascade Range, the ratio of total iron to magnesia varies in rocks of different silica content in a way similar to the variation in experimental melts that crystallized under constant oxygen pressure. The same relationship holds for analyzed rocks from the Western Cascade Range—a fact that suggests that both groups of rocks were derived from water-rich magmas that were crystallizing at approximately constant oxygen pressure.

Few conclusions can be drawn about the origin of the magmas that yielded the volcanic rocks of the Cascade Range. The dacitic or rhyodacitic magma that produced the silicic volcanic rocks of the Little Butte Volcanic Series may have formed by fusion of the crust. The relative abundance of these rocks is reflected in the secondary maximum in the frequency curve (fig. 31). These silicic rocks are close in composition to isobaric minima in the system $NaAlSi_3O_8$–$KAlSi_3O_8$–SiO_2–H_2O (fig. 36). Their extrusion was accompanied by little or no basalt or basaltic andesite, and rocks intermediate in composition between the silicic rocks and andesite (that is, in the interval 63–68 percent silica) are sparse in the Cascade Range. The genesis of these silicic rocks appears to be more closely related to the formation of the widespread silicic volcanic rocks of the same age in eastern Oregon (John Day Formation) than to the formation of the contemporaneous basaltic flows of the Little Butte Volcanic Series that occur farther west. The available evidence thus suggests that the silicic rocks were formed from silicic magma derived by partial fusion of part of the underlying sialic crust. Whether the other less silicic magmas were also formed by fusion of the crust, or whether they formed by differentiation of contaminated primary basalt magma, as suggested by Waters (1955b), is not known.

The Cenozoic volcanic rocks of the Cascade Range in Oregon apparently were derived principally by crystal differentiation of four or five magmas, or groups of similar magmas, that arose along a succession of north-trending fracture zones. It is tempting to speculate that these fracture zones were related to an underlying eastward-dipping master shear zone similar to the zones of deep-focus earthquakes described by Benioff (1949, 1955) from continental margins and island arcs elsewhere in the circumpacific area. Conceivably the magmas were generated in the crust or mantle along such a shear zone at times of greater stress.

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