STATE OF WASHINGTON

DEPARTMENT OF NATURAL RESOURCES

BERT L. COLE, Commissioner of Public Lands

DON LEE FRASER, Supervisor

DIVISION OF MINES AND GEOLOGY

MARSHALL T. HUNTTING, Supervisor

Bulletin No. 60

CENOZOIC VOLCANISM IN THE CASCADE MOUNTAINS OF SOUTHERN WASHINGTON

By

WILLIAM S. WISE

STATE PRINTING PLANT OLYMPIA, WASH., 1970

1970

For sale by Department of Natural Resources, Olympia, Washington.
Price, $1.50.

FOREWORD

The southern Cascade Mountains in Washington are of particular interest because they contain the most complete stratigraphic section of Tertiary and Quaternary volcanic rocks in the state. Strata cones, cinder cones, and shield volcanoes are all present; lava tubes are numerous, and some of the lava flows are so recent that trees growing on their surfaces are only a few inches in diameter.

Relatively little has been published on the geology of the southern Cascades in Washington, and the Division of Mines and Geology is fortunate in being able to publish this report on the Wind River area. Although the report covers a relatively small area, the geology is fairly representative of the southern Cascades, and rocks from every Tertiary and Quaternary Epoch are present.

The author, Dr. William S. Wise, who is currently on the staff of the University of California at Santa Barbara, has spent several years working on the rocks of the Wind River area, and received a Ph.D. degree from The Johns Hopkins University as a result of his studies. This report presents some of the conclusions that resulted from his work.

MARSHALL T. HUNTTING, Supervisor
Division of Mines and Geology

November 15, 1970

CONTENTS

	Page
Foreword	III
Abstract	1
Introduction	2
Acknowledgments	2
Previous work	2
Geologic setting	4
Early to middle Tertiary rocks	5
Stratigraphic and rock terminology	5
Ohanapecosh Formation	5
Extent and age	6
Petrology	8
Interbedded flows	8
Volcaniclastic rocks	14
Eagle Creek Formation	19
Extent and age	20
Petrology	20
Yakima Basalt	22
Extent	22
Petrology	22
Intrusive rocks	23
Diabase and gabbro plugs and dikes	23
Diorite and quartz diorite sills and plugs	25
Diorite sills	25
Quartz diorite plug	26
Hornblende diorite plugs	28
Deformation of early to middle Tertiary rocks	28
Quaternary lavas	29
Descriptions of the volcanoes and their lavas	29
Pre-Red Mountain flows	31
Red Mountain volcano	31
Post-Red Mountain flows	32
Trout Creek Hill volcano	32
East Crater	32
Flows of the Big Lava Bed	32
Other Quaternary flows of undetermined stratigraphic sequence	33
West Crater volcano	33
Rock Creek lavas	33
Red Bluffs volcano	33
Hornblende andesite	33
Petrology of the Quaternary lavas	36
Chemistry of the Quaternary lavas	38
Summary of volcanic history	41
References cited	44

ILLUSTRATIONS

		Page
PLATE	1. Geologic map and sections of the Wind River area, Washington	In pocket
FIGURE	1. General geology of the central Cascade Range	3
	2. Distribution of the Ohanapecosh Formation in the Wind River area	7
	3. Photomicrographs of Ohanapecosh lavas	9
	4. Total iron-magnesia-alkali plot of the Ohanapecosh lavas	11
	5. Detailed description of a tuff breccia section in Bear Creek canyon	15
	6. Photomicrographs of Ohanapecosh volcaniclastic rocks	16
	7. Eagle Creek Formation exposure in the east end of the Red Bluffs	19
	8. Distribution of intrusive rocks in the Wind River area	24
	9. Photomicrograph of a diorite sill in the streambed of the Wind River	25
	10. Distribution of the three Quaternary basalt compositions in the Wind River area	30
	11. Photomicrographs of Quaternary basalts	35
	12. Plagioclase and olivine compositional variations of the Quaternary basalt groups	38
	13. Nepheline-olivine-quartz plot of the analyzed Quaternary basalts	39
	14. Columnar summary of the geologic history of the Wind River area	42

TABLES

TABLE	1. Chemical analyses of lavas from the Ohanapecosh Formation	12
	2. Modal analyses of lavas interbedded in the Ohanapecosh Formation	13
	3. Chemical analyses of volcaniclastic rocks from the Bear Creek section of the Ohanapecosh Formation	18
	4. Chemical analyses of intrusive rocks from the Wind River area	27
	5. Modal analyses of the Quaternary lavas from the Wind River area	34
	6. Summary of the mineralogy of the Quaternary lavas	37
	7. Chemical analyses of Quaternary lavas from the Wind River area	40

CENOZOIC VOLCANISM IN THE CASCADE MOUNTAINS OF SOUTHERN WASHINGTON

By William S. Wise

ABSTRACT

The Cascade Mountains in the Wind River area of southern Washington are built of extensive deposits of Cenozoic lavas and volcaniclastic debris, all having calc-alkaline compositions. These rocks are divided into four units—Ohanapecosh Formation, Eagle Creek Formation, Yakima Basalt, and Quaternary basalt flows.

The oldest unit, which is correlated with the Eocene Ohanapecosh Formation of the Mount Rainier region, is nearly 19,000 feet thick and is composed entirely of volcanic detritus and lavas. The lower two-thirds of this unit is composed mostly of andesitic pyroclastic debris in tuff breccias, tuffs, and reworked tuffs and breccias containing a few interbedded flows of basalt. The upper 6,000 feet of the formation, which may have been deposited during the Oligocene Epoch, is composed of about equal amounts of epiclastic debris (conglomerates and sandstones) and tuffs and pyroclastic breccias. Interbedded tholeiitic basalt flows from sources to the west occur near the top of the section. One volcanic center, built of gently dipping beds of breccia and flows of andesite, is exposed within the Ohanapecosh Formation.

Following gentle folding and uplift, during which the top of the Ohanapecosh Formation was deeply weathered, andesitic gravels and sands of the Eagle Creek Formation were deposited locally during early Miocene time. These in turn were later eroded, and the resulting topography was inundated by Yakima Basalt flows from the east during late Miocene time. The deposits of the Eagle Creek Formation north of the Columbia River were of limited extent and had thicknesses of as much as 1,300 feet. Yakima Basalt flows in the area probably accumulated to thicknesses of as much as 2,000 feet.

Gentle folding during the Pliocene Epoch was accompanied by the eruption of several andesitic and basaltic volcanoes; however, succeeding erosion has stripped away the lava flows, leaving only scattered plugs of diorite and diabase.

Quaternary volcanism has been limited to the extrusion of numerous basalt flows from at least ten different vents. The lavas are compositionally grouped into olivine basalts, platy olivine basalts, and low-alumina basalts. The olivine basalts are high-alumina basalts, which upon differentiation give rise to the slightly more silicic platy olivine basalts. Two of the Quaternary volcanoes erupted unusual lavas, which are poorer in alumina than the olivine basalts.

INTRODUCTION

The Columbia River Gorge has long held the interest of geologists as well as sightseers. High cliffs of Columbia River Basalt and younger olivine basalt flows along the Oregon side contrast with low, hummocky landslide areas and intracanyon flows of olivine basalt on the Washington side. Exposed in the gorge are rock units representing volcanism throughout most of Tertiary and Quaternary time.

The volcaniclastic rocks of the Eagle Creek Formation (lower Miocene) have long been considered the oldest rocks in the gorge. In 1955-56, however, A. C. Waters found the unconformable base of the Eagle Creek conglomerates, and thereby separated them from an older, early Tertiary unit of volcanic breccias.

Products of Cenozoic volcanism in southern Washington are especially well displayed along the Wind River valley, which lies just west of the Cascade Crest and opens into the Columbia River Gorge. This bulletin describes the volcanic history and growth of the southern Cascade Mountains, based on the petrologic and stratigraphic relations exposed in the Wind River area.

The geology of the Wind River area, which is covered by the Wind River quadrangle and part of the Bonneville Dam quadrangle (15-minute series) issued by the U.S. Geological Survey, was mapped during the summers of 1959, 1960, and 1962.

ACKNOWLEDGMENTS

Some of the work reported in this paper is extracted from a Ph.D. dissertation submitted by the author to The Johns Hopkins University. I am greatly indebted to Aaron C. Waters for his guidance during most of the study. Aaron C. Waters, Donald A. Swanson, and Richard S. Fiske have critically read this and earlier manuscripts, leading to improvements in presentation. To them I give my thanks. I am also grateful to Ivan Donaldson for his assistance in the field on various occasions.

PREVIOUS WORK

Parts of the Wind River area have been previously mapped only in reconnaissance, for although the Columbia River Gorge has long attracted geologic interest, lack of access roads deterred detailed work to the north. Williams (1916) and Chaney (1918) concentrated on the south wall of the gorge, and named the main stratigraphic units exposed there. They defined the Eagle Creek

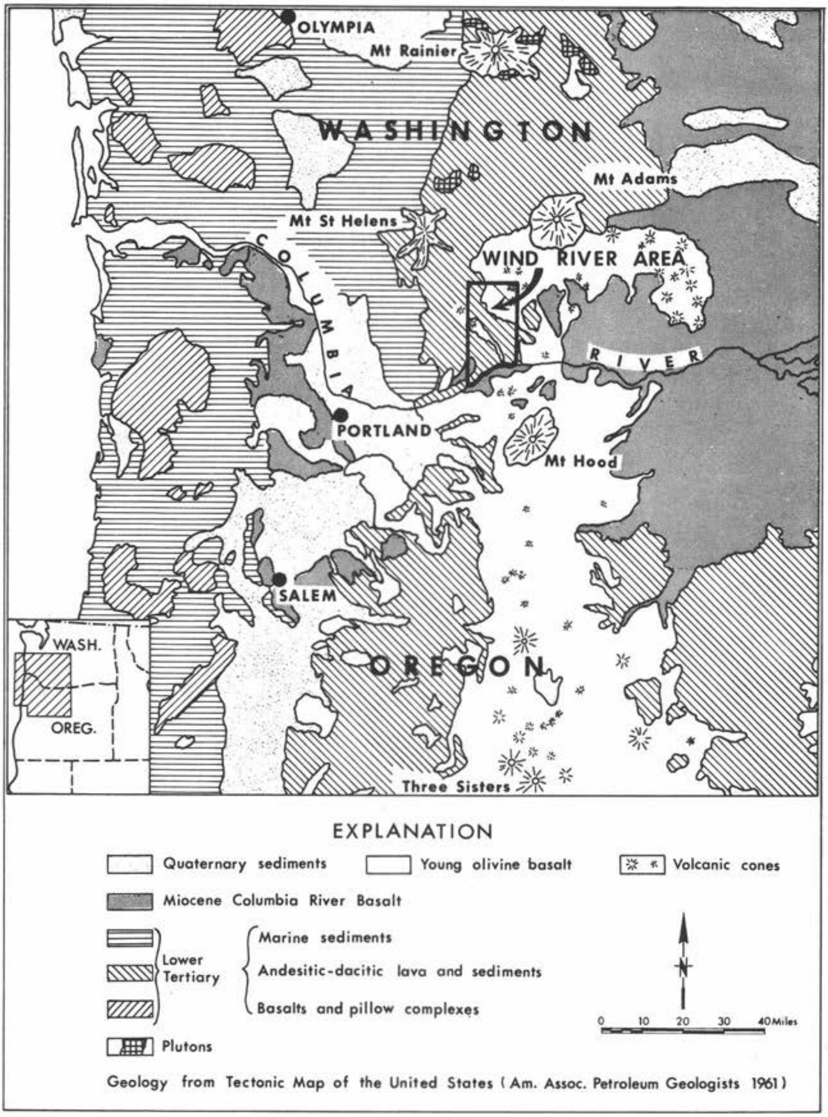


Figure 1. GENERAL GEOLOGY OF THE CENTRAL CASCADE RANGE.

Formation to include *all* sedimentary rocks and interbedded lavas underlying the Columbia River Basalts. Allen (1932) reconnoitered an area that extends 8 or 9 miles north and south of the Columbia River Gorge and grouped all rocks older than the Columbia River Basalt into the Warrendale Formation (a name incorrectly used in place of Eagle Creek Formation, Wilmarth, 1938). Allen considered all dips of the sedimentary rocks to be primary, therefore the beds were thought to show the original slopes of "Miocene volcanoes." The younger Columbia River Basalt and Quaternary intracanyon flows were mapped by Allen with much the same structural interpretation as in this report, although he thought some of the interbedded flows and sills were steptoes rising above the younger valley-filling lavas.

A. C. Waters made a brief four-week reconnaissance of the area 5 or 6 miles north of the Columbia River in 1955-56. He was the first to recognize a major unconformity within the Eagle Creek Formation, and he noticed that two periods of folding had deformed the pre-Pliocene rocks. He also discovered that the young olivine basalt in the Wind River valley had once dammed the Columbia River.

GEOLOGIC SETTING

During the early part of the Tertiary Period the Cascade volcanic belt in Oregon and Washington was mostly submerged, and was possibly a landward extension of the Coast Range eugeosyncline. Debris from numerous volcanoes, many of which were also submerged (Fiske, 1963; Peck and others, 1964), accumulated in a shallow basin. These volcanoes erupted andesitic material for the most part, whereas tholeiitic basalt poured into the eugeosyncline 100 miles to the west. The oldest rocks of the Wind River area are subaqueous accumulations of volcaniclastic debris (Pl. 1).

The Cascade belt became emergent by Oligocene time (Snavely and Wagner, 1963). Volcanism at that time is recorded by terrestrial lavas and epiclastic sediments. During late Miocene time a broad low gap existed in the then-emerging belt in northern Oregon. This gap permitted the west-flowing tholeiitic Yakima Basalt, a formation of the Columbia River Group, to cover that part of the belt. Its northern limit is exposed in the Wind River area (Fig. 1).

Volcanic activity during Pliocene time was extensive south of the Columbia River, in Oregon, but nearly nonexistent to the north, in Washington. During the Quaternary Period, however, activity was widespread, including the eruption of huge andesitic stratovolcanoes and of relatively small olivine basalt volcanoes that built cinder cones or lava shields. The Wind River area lies between three of the big andesitic stratovolcanoes—Mount Hood, Mount St. Helens, and Mount Adams. Lava fields of high-alumina olivine basalt, which erupted from numerous centers, coalesce to cover about a third of the Wind River area.

EARLY TO MIDDLE TERTIARY ROCKS

STRATIGRAPHIC AND ROCK TERMINOLOGY

The early to middle Tertiary rocks of the Wind River area have been divided into three formations, from oldest to youngest: Ohanapecosh Formation, Eagle Creek Formation (redefined), and Yakima Basalt. Intrusive into these three formations are a variety of plugs, dikes, and sills, recording several different igneous episodes.

The sedimentary units of the Wind River area are composed entirely of fragments of volcanic rocks. Therefore, the classification of volcaniclastic sediments of Fisher (1960) is used. Although Fisher's classification is clear and unambiguous, several points need emphasis.

Epiclastic terms (conglomerate, sandstone, etc.) are used only where it is fairly certain that the clasts have been derived by the weathering and erosion of older, indurated rock. Pyroclastic terms are used for deposits resulting from the direct deposition of material ejected from a volcanic vent and also for sediments formed as a result of the immediate reworking of unindurated pyroclastic accumulations. The only departure from Fisher's classification is in the use of the term "tuff breccia." It is here used to refer to the thick layers composed of a mixture of angular lapilli and ash and deposited massively from a pyroclastic flow, whether subaerial or subaqueous.

OHANAPECOSH FORMATION

In this report the thick section of volcaniclastic rocks (pre-Columbia River Basalt) has been divided into the Ohanapecosh Formation and the Eagle Creek Formation. These rocks in the Wind River area and surrounding region have been called the Skamania Series by Felts (1939a, 1939b), the Warrendale Formation by Allen (1932), and the Eagle Creek Formation by Williams (1916) and Chaney (1918). However, Waters discovered an unconformity within this unit, and he suggested (Waters, oral communication, 1959) that the conglomeratic sediments exposed along Eagle Creek in Oregon (Pl. 1) extend north across the Columbia River, where their unconformable base is exposed.

The following features were used as field evidence for the mapping of the unconformity:

1. The younger conglomerates have boulders that are still hard and easily separated from the matrix. The older rocks generally have fewer conglomerate beds, and in these the boulders are altered to the point that they break as a unit with the matrix.

2. The unconformity is marked in most places by a thick saprolite (deeply weathered) zone.

3. Definite angular discordance can be seen at some localities outside the map area. Within the Wind River area, only a slight angular discordance can be seen, and this only at one locality near the town of Stevenson.

The older rocks, underlying the unconformity, are correlative with the Ohanapecosh Formation of Mount Rainier National Park.

Extent and Age

The Ohanapecosh Formation, as defined by Waters (1961a, p. 48) and described by Fiske and others (1963), comprises about 10,000 feet of Eocene volcaniclastic and flow rocks, cropping out near and in Mount Rainier National Park. Similar rocks in the Wind River area are tentatively correlated with those near Mount Rainier. This correlation is based chiefly on the lithologic similarities of the rocks in the two areas, and the reconnaissance tracing of the Ohanapecosh rocks southward from Mount Rainier by R. S. Fiske and A. C. Waters (oral communication, 1962). In the area between the Wind River and Mount Rainier many exposures of the Ohanapecosh Formation were found, although between Mount St. Helens and Mount Adams the Ohanapecosh Formation is covered by younger rocks.

An Eocene age was assigned to the Ohanapecosh Formation by Fiske and others (1963), based on fosil leaves found by them and by Fisher (1957). However, the age of the Ohanapecosh in the Wind River area could not be determined with any certainty. Fossils from only one locality, Nelson Creek (roadcut on west side of Nelson Creek, N½ sec. 36, T. 3 N., R. 7½ E.), were sufficiently well preserved for identification. The Nelson Creek locality (Fig. 2) is near the top of the formation and yielded the following genera, which were identified by the late Dr. Roland Brown (oral communication, 1961):

Liquidamber sp.
Magnolia sp.
Acer sp., possibly *A. glabroides*
Platanus sp.

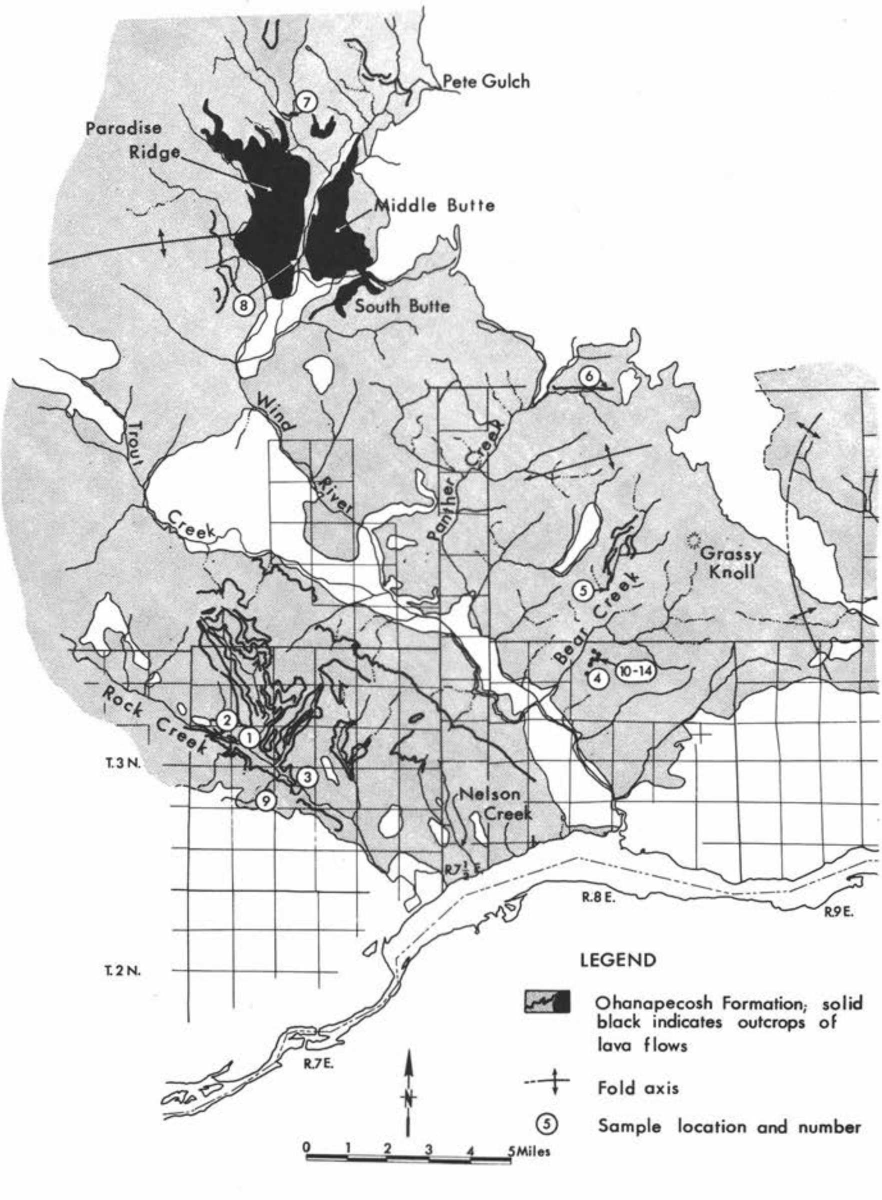


Figure 2. Distribution of the Ohanapecosh Formation in the Wind River area.

No characteristic Eocene genera are present in this small assemblage. All four are typical of Oligocene fossils, especially those from the Bridge Creek locality in the John Day basin (Chaney, 1927).

A more satisfactory age determination awaits field work west of the Wind River area, where the Ohanapecosh may interfinger with marine Eocene units, such as the Cowlitz Formation (Wilkinson and others, 1946). The only rocks suitable for radiometric dating are flows in the uppermost part of the section; the others have been too extensively zeolitized.

The Ohanapecosh Formation in the Wind River area is nearly 19,000 feet thick, if there is no repetition of the section by faulting. The stratigraphically highest part, near Greenleaf Peak, is unconformably overlain by the Eagle Creek Formation. The base is not exposed where the stratigraphically lowest part of the section crops out in the core of an anticline east of Grassy Knoll (Pl. 1). Some small faults have been noted, but no repetition of beds was found.

The slight angular unconformity with the overlying Eagle Creek Formation is characterized by a deeply weathered zone. Below the contact, Ohanapecosh rocks to a depth of 30 to 50 feet have been weathered to a soft, clay-rich saprolite, in which the original textures are still preserved. A red, more massive weathered zone as much as 10 feet in thickness generally overlies the saprolite, but it was locally removed before deposition of the Eagle Creek conglomerates.

Petrology

The lower two-thirds of the Ohanapecosh Formation is composed chiefly of pyroclastic debris and rare interbedded lavas. The upper part contains as much as 50 percent epiclastic debris and more lava flows.

Outcrops are abundant, but a complete section is not exposed. Two areas were studied in detail, the canyons of Rock Creek and Bear Creek (Fig. 2); each contain exposures of a substantial part of the formation. The Rock Creek canyon section is characterized by basalt flows interlayered with the volcaniclastic rocks of the upper 5,000 feet of the formation. The 10,000-foot Bear Creek section, well exposed in roadcuts, has very few lava flows and is predominantly thick tuff breccia units and intercalated thin-bedded sediments. The following descriptions of the clastic rocks and interbedded lavas are based chiefly on exposures in these localities.

Interbedded Flows

The basalt and andesite flows that are interbedded with the volcanic sedimentary rocks of the Ohanapecosh Formation stand

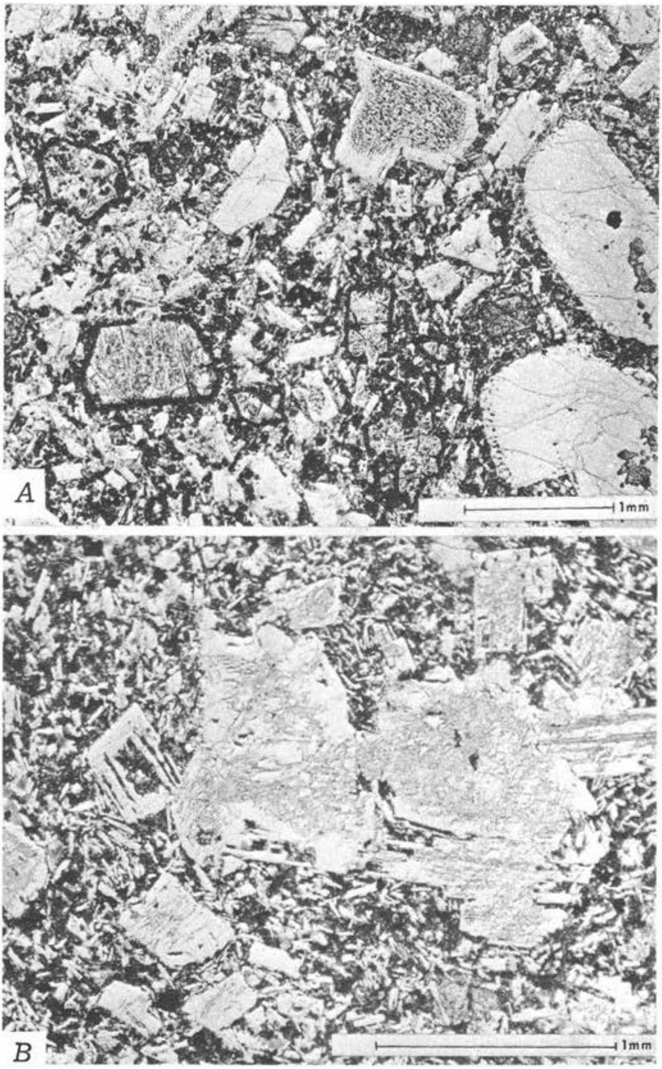


Figure 3. PHOTOMICROGRAPHS OF OHANAPECOSH LAVAS. (*A*) Olivine basalt (Table 1, no. 7, and Figure 2) from Paradise Creek. The blotchy grain with a dark border is probably a remnant of olivine, which has been replaced by calcite, quartz, chlorite, and hematite. A glomeroporphyritic clot of plagioclase and pyroxene (augite) is in the lower right corner; (*B*) A highly altered basalt from Panther Creek canyon (Table 1, no. 6, and Figure 2). The plagioclase has been altered to celadonite and laumontite. Plain light; length of bars = 1 mm.

out as resistant outcrops that contrast with the more subdued outcrops of the volcaniclastic rocks. Seven or eight such flows occur within the 5,000 feet of the Rock Creek section, and only three flows crop out within the 10,000-foot section of the formation in Bear Creek canyon. Flows are much more abundant in the northwest corner of the Wind River area, where 2,000 to 3,000 feet of andesitic breccias and flows are exposed in the canyon between Middle Butte and Paradise Ridge.

Single flows are 50 to 75 feet thick, and a few can be traced as far as 7 miles. Most of the flows overlie a red clay zone 2 to 10 feet thick. Because pillow structures were not found, most of the flows are interpreted as being subaerial.

Most of the outcrops on Middle Butte and Paradise Ridge are predominantly shallow-dipping porphyritic andesite flows and breccias. They are less common in the surrounding areas. On Middle Butte the massive outcrops of andesite cut by dikes and hydrothermally altered fracture zones are interpreted as representing the core of an Ohanapecosh volcano. The gentle slopes of the flows and the complete lack of epiclastic sediments suggest that this volcano may have been submerged (Fiske, 1963, p. 395).

On South Butte and in Pete Gulch, tuff breccias and tuffs, overlying the flows reaching out from Middle Butte, are similar to those in Ohanapecosh rocks farther south (Fig. 2). Therefore, this lava complex is not of Eagle Creek age but is the remnant of a major eruptive center that was active during late Ohanapecosh time.

Most Ohanapecosh flow rocks are hypocrystalline and have porphyritic or glomeroporphyritic textures. The groundmass textures are intersertal, tending toward intergranular in flows of low glass content.

Plagioclase phenocrysts are mostly labradorite, but in a few flows they are calcic andesine. The groundmass plagioclase ranges from sodic labradorite (in basalts) to andesine (in Middle Butte andesites). Pyroxene phenocrysts are uncommon in flows from the southern part of the area, but hypersthene makes up 7 to 11 percent of the Middle Butte andesites. The groundmass pyroxene is granular augite. Remnants of olivine were found in only one flow, cropping out in Paradise Creek, where the olivine was altered mostly to hematite and saponite and is surrounded by rims of magnetite and pyroxene (Fig. 3, *A*).

Alteration affected all the flows, but the minerals and glass in the flows cropping out east of Wind River have undergone the most extensive changes. Glass has devitrified to celadonite, zeolites (mostly laumontite), and montmorillonite. Plagioclase phenocrysts are extensively zeolitized and albitized. The mafic grains show only minor replacement by montmorillonite (Fig. 3, *B*).

Eight samples of Ohanapecosh lavas were chemically analyzed (Table 1, on p. 12, and Fig. 2, on p. 7). The analyses plotted on Figure 4 show several interesting features. The basalts from deep in the pile (Table 1, nos. 4, 5, and 7) are similar to many high-alumina basalts of the calc-alkaline series. The Rock Creek canyon lavas (Table 1, nos. 1, 2, and 3; Table 2, no. 9) are much richer in iron and resemble upper Eocene to lower Oligocene lavas of the Oregon Coast Range (Snavely and others, 1965). Figure 4 shows the total iron-magnesia-alkali trend of one group of these Coast Range lavas (Snavely, oral communication, 1966).

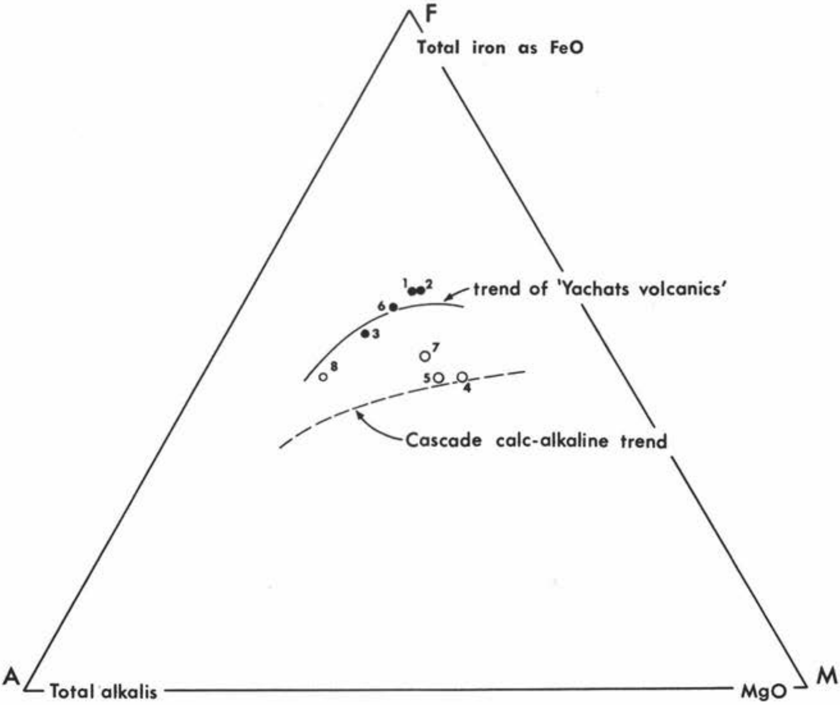


Figure 4. TOTAL IRON-MAGNESIA-ALKALI PLOT OF THE OHANAPECOSH LAVAS. Trends of the Cascade calc-alkaline suite and an upper Eocene to lower Oligocene suite of lavas ("Yachats Volcanics") from the Oregon Coast Range (Snavely, oral communication, 1966) are plotted to illustrate compositional similarities of these two suites. Numbered points refer to analyses in Table 1 and locations in Figure 2. Open circles represent samples from lower part of formation, and solid circles represent samples from upper part.

TABLE 1.—*Chemical analyses of lavas from the Ohanapecosh Formation*

	Sample number							
	1	2	3	4	5	6	7	8
SiO_2	47.74	49.93	53.74	48.43	54.23	51.76	53.40	57.72
TiO_2	1.20	2.4	1.59	1.70	0.87	1.53	0.89	1.03
Al_2O_3	18.1	16.3	17.28	16.7	17.4	17.41	18.7	16.34
Fe_2O_3	5.45	5.5	5.02	4.05	3.30	4.73	2.88	3.34
FeO	6.09	6.0	4.13	5.05	5.09	4.73	5.65	4.20
MnO	0.18	0.18	0.14	0.22	0.19	0.15	0.19	0.13
MgO	3.87	4.07	3.05	6.34	5.36	3.45	4.58	2.43
CaO	9.37	9.21	8.13	6.60	7.76	8.55	7.72	5.18
Na_2O	3.52	2.9	3.72	3.15	3.48	3.68	2.84	3.98
K_2O	0.31	0.7	1.15	0.85	0.76	0.54	1.12	1.99
P_2O_5	0.34	0.65	0.27	0.35	0.22	0.22	0.19	0.21
CO_2	0.10	0.00	0.34	0.00	0.00	0.00	0.00	0.34
H_2O+	1.85	0.98	0.27	5.33	0.67	0.54	0.45	1.78
H_2O-	1.74	1.02	1.24	1.27	0.39	0.00	0.77	1.35
Total	99.75	99.84	100.07	100.04	99.72	100.54	99.38	100.25
	Molecular norms							
Quartz	1.5	7.5	8.5	2.9	5.8	6.9	6.7	11.8
Orthoclase	1.9	4.3	7.0	5.4	4.6	3.3	6.8	12.2
Albite	33.2	27.2	34.3	30.3	31.7	34.3	26.1	37.0
Anorthite	34.3	30.7	27.8	31.0	30.0	30.5	35.8	22.2
Diopside	9.2	10.1	7.7	1.3	6.0	9.6	1.7	0.6
Hypersthene	11.1	9.2	5.7	21.3	16.7	6.6	18.1	9.7
Magnetite	6.0	6.0	5.4	4.5	3.5	6.2	3.1	3.6
Ilmenite	1.8	3.5	2.3	2.5	1.2	2.2	1.3	1.5
Apatite	0.7	1.4	0.6	0.8	0.5	0.5	0.4	0.5
Calcite	0.3	..	0.9	..	..	..	..	0.9
Composition of norm plagioclase	50.8	53.0	44.8	50.6	48.7	47.1	57.8	37.5

Locations of samples:

Sample no.

1 Basalt, along streambed of Rock Creek; NW¼ sec. 17, T. 3 N., R. 7 E. Bonneville Dam quadrangle.

2 Basalt, along streambed of Rock Creek (underlies sample no. 1); NE¼ sec. 18, T. 3 N., R. 7 E. Bonneville Dam quadrangle.

3 Basalt, along streambed of Rock Creek (overlies samples no. 1 and no. 2); center of sec. 21, T. 3 N., R. 7 E. Bonneville Dam quadrangle.

4 Zeolitized basalt (albite, laumontite, quartz, chlorite), Bear Creek section; along Bear Creek road, ½ mile east of canyon mouth on 1,600-foot contour. Wind River quadrangle.

5 Altered basalt, upper Bear Creek canyon; on west side of canyon 4½ miles from canyon mouth. Wind River quadrangle.

6 Altered basalt, north slope of Big Huckleberry Mountain; along Mouse Creek road in Panther Creek canyon about ¾ mile northeast of Big Huckleberry Creek. Wind River quadrangle.

7 Olivine basalt, Paradise Creek; 1½ miles northwest from junction with Wind River. Wind River quadrangle.

8 Andesite, west side of upper Wind River canyon, along road directly west of Middle Butte. Wind River quadrangle.

Locations of analyzed samples are shown on Figure 2.

Analyists: Sample 3, S. Imai; sample 6, H. Asari; sample 8, T. Asari; samples 1, 2, 4, 5, and 7, W. S. Wise.

TABLE 2.—*Modal analyses of lavas interbedded in the Ohanapecosh Formation*

	Sample number						
	1	2	3	5	6	7	9
Phenocrysts:							
Plagioclase	19.0	14.5	15.8	3.2	26.0	20.6	11.4
Orthopyroxene	..	..	..	..	..	..	3.2
Clinopyroxene	..	..	1.0	1.2	..	7.2	1.2
Groundmass:							
Plagioclase	37.2	44.3	39.2	58.2	37.0	35.8	42.8
Clinopyroxene	21.0	26.5	19.0	27.0	25.0	21.0	14.0
Magnetite	5.2	5.3	4.6	5.4	5.8	2.0	5.0
Apatite	tr.	tr.	0.8	tr.	tr.	0.4	0.2
Glass	12.4	1.1	11.0	5.0	6.2	..	6.4
Alteration products*	5.2	8.3	8.4	..	..	13.0	5.8

*Alteration products are mostly those replacing mineral grains, such as serpentine pseudomorphs after olivine. Montmorillonite has replaced all glass. Even though no glass remains, it is listed where identifiable by texture.

Sample no. Locations of samples:

1 Basalt, along streambed of Rock Creek; NW¼ sec. 17, T. 3 N., R. 7 E. Bonneville Dam quadrangle.

2 Basalt, along streambed of Rock Creek (underlies sample no. 1); NE¼ sec. 18, T. 3 N., R. 7 E. Bonneville Dam quadrangle.

3 Basalt, along streambed of Rock Creek (overlies samples no. 1 and no. 2); center of sec. 21, T. 3 N., R. 7 E. Bonneville Dam quadrangle.

5 Altered basalt, upper Bear Creek canyon; on west side of canyon 4½ miles from canyon mouth. Wind River quadrangle.

6 Altered basalt, north slope of Big Huckleberry Mountain; along Mouse Creek road in Panther Creek canyon about ¾ mile northeast of Big Huckleberry Creek, Wind River quadrangle.

7 Olivine basalt, Paradise Creek, 1½ miles northwest from junction with Wind River. Wind River quadrangle.

9 Andesite, south side of Rock Creek canyon (50 feet below contact with Eagle Creek Formation); SE¼ sec. 20, T. 3 N., R. 7 E. Bonneville Dam quadrangle.

Locations of analyzed samples are shown on Figure 2.

The Middle Butte complex is composed largely of andesite; it may have contributed andesitic debris to the upper part of the formation to the south.

Volcaniclastic Rocks

Beds of volcanic conglomerate, though rare, are widely distributed in the Ohanapecosh Formation. They contain pebbles and cobbles of porphyritic and aphanitic basalt and andesite. Lapillistone composed of coarse, well-sorted pumice lapilli and rock fragments is common, and occurs as beds up to a few inches in thickness. Pumice-rich beds are extensive and of constant thickness, but deposits poor in pumice are lenticular and are interbedded with coarse-grained tuffs. The pumice-poor beds consist of reworked debris, whereas the pumice-rich beds are primarily pyroclastic deposits.

Tuff breccias.—Tuff breccia units are abundant in the Ohanapecosh Formation, but are least common in the stratigraphically highest part. These massive bedded rocks show little or no stratification and are composed of angular fragments of andesite and pumice (Fig. 6, *A*, on p. 16). Tuff breccias are especially abundant in exposures east of the Wind River, where the beds range in thickness from 5 to 75 feet, averaging 40 feet in thickness.

The tuff breccias are similar to those exposed in Mount Rainier National Park, first described and interpreted by Fiske (1963) as subaqueous pyroclastic flows. In the less zeolitized rocks of the Wind River area, a few features were observed that were not reported by Fiske.

The basal 10 feet of many of the thick tuff breccia units, along with several feet of the underlying sedimentary rocks, show evidence of baking. An example is illustrated in Figure 5, where the uppermost zone is loose and friable and contains nearly equidimensional pumice clasts in contrast to a more compact and tougher middle zone. The lowest 10 feet of the tuff breccia, commonly containing charred wood fragments, is dark colored and very hard. The pumice fragments in the lower zones are flattened parallel to the base of the unit. Several feet of the upper part of the sedimentary rocks underlying the tuff breccia unit have been baked and are much harder than the lower unbaked part, although the present textures and mineralogy are identical.

The upper part of nearly every tuff breccia unit exhibits features suggesting that the debris has been reworked. The clasts in the upper 3 feet are relatively well sorted. The fragmental material is similar to that comprising the entire tuff breccia bed, except that pumice is rare or absent. Wispy layers of fine ash and accretionary lapilli are commonly interlayered with coarser, poorly sorted debris.

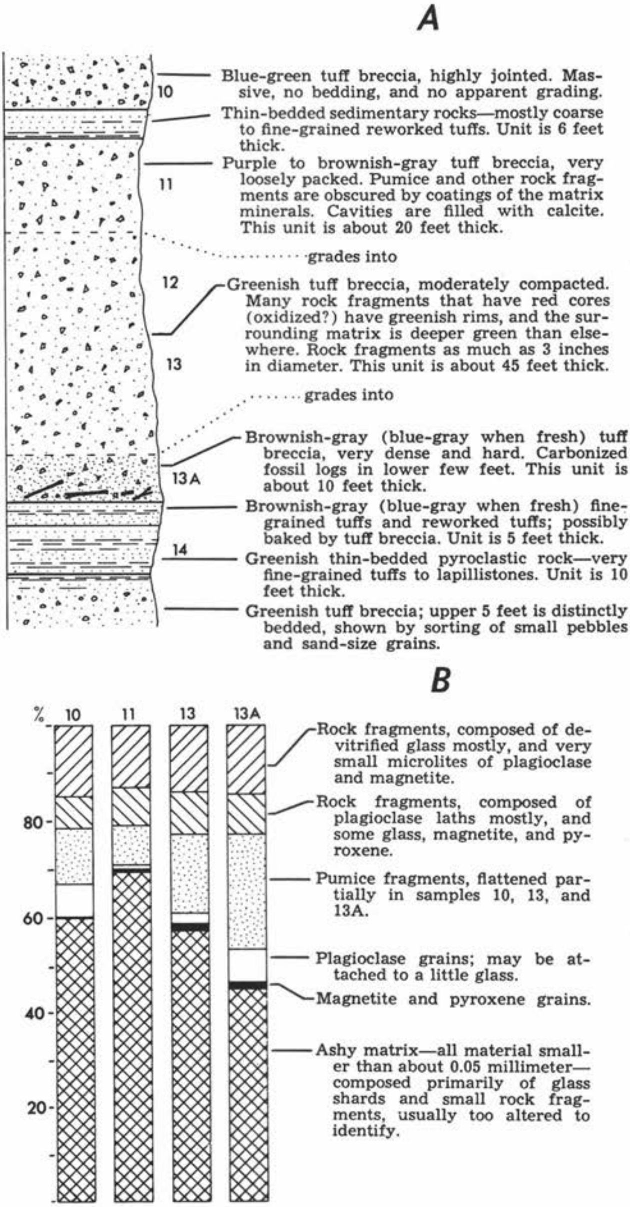


Figure 5. DETAILED DESCRIPTION OF A TUFF BRECCIA SECTION IN BEAR CREEK CANYON. *(A)* Description of a measured tuff breccia section; *(B)* Modal analyses of tuff breccia samples from the section (excludes grains larger than 4 millimeters).

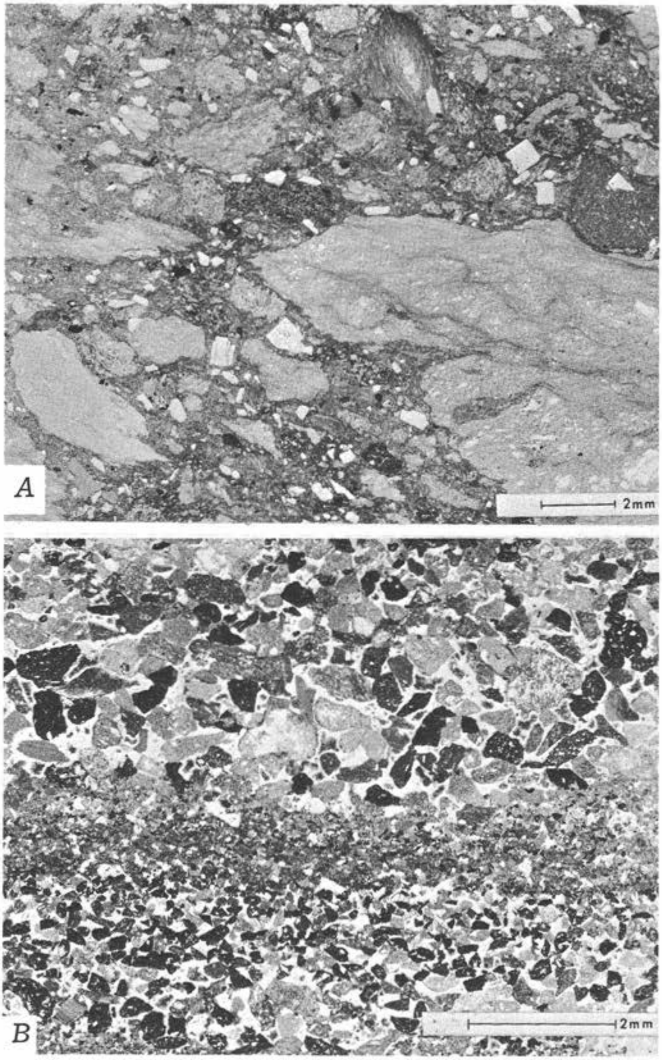


Figure 6. PHOTOMICROGRAPHS OF OHANAPECOSH VOLCANICLASTIC ROCKS. (*A*) Tuff breccia, composed of angular fragments of plagioclase and andesite with abundant pumice. Some pumice, wholly replaced by heulandite and celadonite, appears to be partially collapsed; (*B*) A reworked tuff, exhibiting graded bedding, Bear Creek canyon. The fragments are mostly lithic grains with some plagioclase. The cement is heulandite with celadonite in the center of cavities. Plain light; length of bars = 2 mm.

Well-bedded layers of reworked, well-sorted, sand-size tuff are interbedded with the tuff breccias. These beds are easily recognized by their better sorting and lateral continuity.

The tuff breccia units were deposited from subaqueous pyroclastic flows, as envisioned by Fiske (1963). Reworking of the top parts and of the interbedded stratified tuffs clearly indicates a subaqueous environment of deposition. In apparent contradiction, the baked zones indicate that at least the largest pyroclastic flows were not completely cooled by the surrounding water (Fiske, 1963, p. 404). Retention of heat was necessary to cause baking and pumice collapse near the base of the tuff breccia beds.

Tuffs and volcanic sandstones.—Throughout the Ohanapecosh Formation there are numerous thinly bedded layers of sand-size volcanic detritus. In the lower two-thirds of the section these layers are largely tuffs, or reworked pyroclastic debris, deposited from subaqueous ash falls, turbidity flows, and other currents. They are similar in most respects to the rocks described by Fiske (1963) in the vicinity of Mount Rainier.

The predominant detritus in these tuffs is composed of basaltic and andesitic rock fragments (Fig. 6, *B*) and pumice shreds. The amount of pumice is greatest in the tuffs and least in the reworked debris. Less abundant clasts are crystals of plagioclase and pyroxene. The ratio of rock fragments to plagioclase crystals is about 9 to 1 in most of the samples examined.

Epiclastic volcanic sandstones occur most commonly in the upper one-third of the section. Zeolitization has obscured most of the textural features that might serve to distinguish the sandstones from the reworked tuffs. An epiclastic origin is assumed for a sandstone bed if it is associated with conglomerate, or has fossil leaf horizons, and has sedimentary structures, such as channeling, that imply deposition from streams.

Only a small part of the volcaniclastic rocks are unaltered. Glass shards and pumice clasts, most rock fragments, and much of the plagioclase have been replaced by zeolites or clay minerals. This alteration is discussed in a separate paper (Wise and Fisher, in preparation). Many plagioclase clasts in the tuff breccia units and tuffs are partially replaced by zeolite, but enough of the original plagioclase remains for approximate composition determinations by universal stage techniques. Plagioclases from the rocks of the Bear Creek section range from An_{40} to An_{28}; most are between An_{36} and An_{32}. The structural state of all crystals measured is disordered. Calcic andesine was found in tuffs and breccias underlying South Butte, where the volcaniclastic debris was derived from a local andesitic volcano.

Relict pyroxene clasts can be found in any bed. Most are clinopyroxenes with high $2V_z$ (55° to 60°). Hypersthene and hornblende, though generally rare throughout the formation, are abundant in a few tuff beds of the Rock Creek section.

Rock particles vary widely in glass content, giving the illusion of a variety of lava types. Most of the fragments are small, contain few phenocrysts, and are composed of glass and microlites of plagioclase (sodic andesine) (Fig. 6, *B*).

TABLE 3.—*Chemical analyses of volcaniclastic rocks from the Bear Creek section of the Ohanapecosh Formation*

	Sample number				
	10	11	12	13	14
SiO_2	59.60	49.70	52.48	53.64	52.38
TiO_2	0.62	1.21	1.11	0.92	0.80
Al_2O_3	13.63	15.9	15.6	15.6	17.1
Fe_2O_3	5.04	5.35	5.00	5.06	5.06
FeO	0.74	2.88	2.86	1.77	3.00
MnO	0.10	0.18	0.18	0.21	0.14
MgO	1.49	2.20	2.18	1.47	2.47
CaO	4.50	6.75	5.71	6.49	4.93
Na_2O	1.59	3.80	2.80	1.63	3.40
K_2O	1.90	1.20	1.46	1.70	1.68
P_2O_5	0.14	0.38	0.41	0.52	0.24
CO_2	0.01	1.12	0.25	0.28	0.01
H_2O+	6.73	5.04	6.42	8.42	5.93
H_2O-	4.36	4.26	3.69	2.60	2.26
Total	100.44	100.01	100.25	100.30	100.46

Descriptions of samples:

Sample no.

10 Tuff breccia, replaced by celadonite, montmorillonite, heulandite, and quartz.

11 Top part of tuff breccia unit, replaced by analcime, quartz, montmorillonite, and calcite.

12 Near top of tuff breccia unit, replaced by heulandite, quartz, and montmorillonite (minor calcite and analcime).

13 Near middle of same unit as no. 11, replaced by celadonite, heulandite, quartz, and montmorillonite.

14 Reworked tuff, interbedded between tuff breccia units, replaced by heulandite, quartz, and montmorillonite.

All samples were collected along Bear Creek road ½ mile east of canyon mouth. Wind River quadrangle. (See Figures 2 and 5.)

Analysts: Sample 10, T. Asari; samples 11-14, W. S. Wise.

Five specimens of volcaniclastic rocks from the Bear Creek section were analyzed (Table 3). Three samples from different levels within a single tuff breccia unit (Fig. 5, on p. 15) are listed in Table 3 (nos. 11, 12, and 13). They show an increase of Na_2O and a decrease of K_2O from the base toward the top. The alkali ion migration may have occurred after deposition and during zeolitization. The original overall composition of these rocks ranged from andesite to rhyodacite.

EAGLE CREEK FORMATION

Because an unconformity has been found within the unit previously called the Eagle Creek Formation, the formation is herein redefined as the sequence of volcanic conglomerates, sandstones, and tuffs that are typically exposed south of the Columbia River along Eagle Creek and adjacent parts of the Columbia River Gorge in Multnomah County, Oregon.

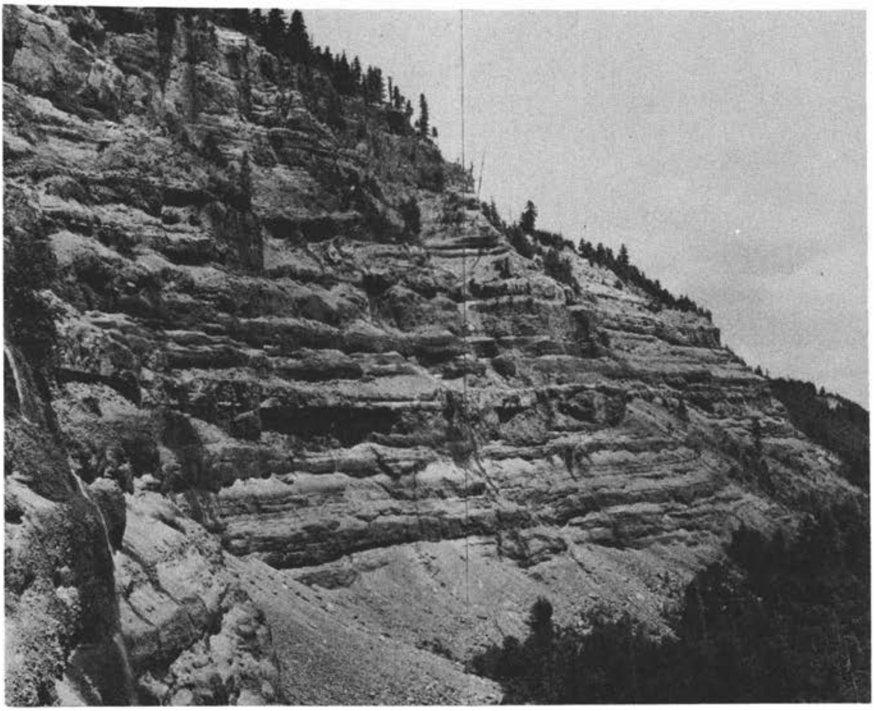


Figure 7. EAGLE CREEK FORMATION EXPOSURE IN THE EAST END OF THE RED BLUFFS.

Extent and Age

In the Wind River area (Pl. 1) the Eagle Creek Formation is best exposed around Table Mountain and Greenleaf Peak and along Hamilton Creek. The northernmost exposure is on the south side of Rock Creek canyon. Four thin patches of Eagle Creek sedimentary rocks that cover small areas occur north and northeast of Stevenson.

The Eagle Creek Formation rests unconformably upon the Ohanapecosh Formation and is unconformably overlain by the Yakima Basalt. The upper surface had been deeply eroded and had a relief of several hundred feet at the time of lava inundation. The overall attitude of the Yakima Basalt parallels that of the Eagle Creek sedimentary rocks, indicating a lack of intervening deformation.

The thickness of the section measured in the upper part of Hamilton Creek is about 1,300 feet. Nearly 1,200 feet of sedimentary rocks are exposed on the north and northeast slopes of Greenleaf Peak. The uppermost 800 feet of this section is exposed in the Red Bluffs (Fig. 7).

Only 500 feet of section is exposed in the original type locality in Eagle Creek, south of the Columbia River in Oregon. Moreover, cores from near the bottom of test holes drilled 200 feet deep on Bradford Island at Bonneville Dam are very similar to Ohanapecosh rocks exposed north of the river. This indicates that the base of the Eagle Creek Formation is not far below the river level, and therefore the formation thins southward from Hamilton Creek (about 1,300 feet) to Eagle Creek (about 500 feet).

A careful review of Chaney's (1920) fossil localities strongly suggests that he obtained all his fossils from outcrops above the unconformity with the Ohanapecosh Formation. All but two of his localities are from exposures in the type area south of the Columbia River. The other two were from blocks that had slumped from the face of the Red Bluffs.

In a general paper on the Miocene flora of the Columbia Plateau, Chaney (1959, p. 124) lists the Eagle Creek flora as lower Miocene.

Petrology

More than 800 feet of the Eagle Creek Formation is continuously exposed in the Red Bluffs (Pl. 1, southwestern part, and Fig. 7).

Following is a summary of the kinds of rocks exposed in the Red Bluffs. The sedimentary rocks there are typical of the Eagle Creek Formation elsewhere in the Wind River area as well as in the type area.

Boulder and cobble conglomerates, which compose about 10 percent of the exposures, are characterized by their channeling into underlying beds, by lenses of sand, and by boulders that are fairly well rounded and sorted. The lateral extent of all conglomerate beds 10 to 15 feet thick is less than 100 feet.

Nearly 60 percent of the Red Bluffs beds are paraconglomerates. They are very poorly sorted and contain angular to subrounded boulders and cobbles in a white or buff matrix containing pumice fragments. Single beds are as much as 20 feet thick and rarely have internal structures. They were probably deposited by mudflows, because sorting and rounding are poor (which indicate apparent rapid deposition). The paraconglomerates on the face of the Red Bluffs have a lateral extent of more than 1 mile.

Thin-bedded sandstones and pebble conglomerates (25 percent of the section) are interbedded with conglomerates, but also form extensive sequences in which large boulders are scarce. They contain little matrix and are fairly well sorted, and single beds rarely extend more than a few tens of feet. Channeling and crossbedding indicate generally south-flowing streams.

Tuffaceous sandstones, forming 5 percent of the section, have been extensively altered to montmorillonitic clay. Originally the sands were mostly glassy ash mixed with some epiclastic debris, such as rounded rock fragments. They form thin beds that have greater lateral extent than the other sandstones described above. Several of these beds may have formed from ash falls; others are ash, reworked and mixed with weathered debris.

Several soil zones can be recognized by the concentration of clayey material and the fossilization of roots. Most of the zones are less than a few feet thick and may contain silicified tree stumps.

An andesite flow overlies some conglomerates in Rock Creek, west of Stevenson, and another is exposed 2 miles north of the mouth of Hamilton Creek. The Rock Creek flow is columnar, and the Hamilton Creek flow shows structures interpreted as spiracles. Bending of spiracle tops indicates flow toward the south.

The porphyritic textures and mineralogy of these two flows are similar to those of most clasts in the conglomerates. Plagioclase phenocrysts are 2 or 3 millimeters across, twinned, and complexly zoned. The cores range from An_{55} to An_{47}, and the outer zones approach An_{40}. The groundmass laths are andesine. Both flows contain pyroxene phenocrysts. The Hamilton Creek flow has augite and hypersthene, but only augite occurs in the Rock Creek flow. Individual augites are similar in size to the plagioclase, but in places they occur in clots. The groundmass pyroxene in both lavas is augite, occurring as small grains between plagioclase laths. This mineralogy is typical of calc-alkalic pyroxene andesites.

The only known plugs of Eagle Creek age are to the northwest, in the north-central part of the Bridal Veil quadrangle.

The deposits composing the Eagle Creek Formation are interpreted as being a debris fan extending south and southeast from one or more andesite volcanoes. The general position of the source volcano (15 to 20 miles west of the present Cascade Crest), the age of the debris fan, and the composition of the volcanic rocks are all similar to the Little Butte Volcanic Series (Peck and others, 1964). This series is exposed the entire length of the western Cascade Range in Oregon. Similar rocks to the north are the Fifes Peak Formation, typified by the Tieton volcano (Swanson, 1967).

YAKIMA BASALT

Extent

The basalt flow immediately above the Eagle Creek Formation in the Wind River area is Yakima Basalt. At Augspurger and Dog Mountains, the basalt covers an area of about 9 square miles. Another 2 square miles of basalt crops out in the southwestern part of the Wind River area (Pl. 1). Across the Columbia River, in Oregon, the basalt covers wide areas and exceeds 3,500 feet in thickness.

The thickest sections in the Wind River area (as much as 2,000 feet) are at Augspurger Mountain, Table Mountain, and Greenleaf Peak (Pl. 1).

The contact between the Yakima Basalt and the Eagle Creek Formation is irregular and disconformable. The basal flows contain abundant palagonite and pillow structures, especially where lava entered canyons in which were streams. Contacts are obscured by extensive landslides north of Wind Mountain and on the west and north slopes of Augspurger Mountain. No rocks overlie the Yakima Basalt in any part of the Wind River area.

Petrology

In decreasing order of abundance, plagioclase, glass, pyroxene, magnetite, ilmenite, chlorophaeite, opal, celadonite, and apatite are the components of the Yakima Basalt. The main minerals—plagioclase, pyroxene, and magnetite—form an intersertal to intergranular texture.

The pyroxene is a pale-brown, non-pleochroic augite. A few crystals are as much as 1 millimeter long and are prismatic. Most occur as small stubby grains interstitial to the plagioclase. Almost 20 percent of the pyroxene grains are twinned.

The plagioclase occurs mostly as twinned laths about 0.5 millimeter long. Late-formed microlites are interstitial and are charged with inclusions of magnetite and glass. The plagioclase is sodic labradorite zoned to sodic andesine.

Glass fills the interstices and during chilling had partly crystallized to acicular plagioclase, pyroxene, and skeletal grains of magnetite. Chlorophaeite fills many interstitial cavities and vesicles, and some of it is cracked because of desiccation and recrystallization. Weakly birefringent opal occurs in the same cavities, but formed later. Celadonite crystallized later than chlorophaeite and opal in vesicles of basalt exposed north of Stevenson.

The mineralogy of the Yakima Basalt in the Wind River area is similar to that of most Yakima Basalt flows in other areas, in that these basalts lack the olivine that is found in Picture Gorge Basalt flows (Waters, 1961b).

INTRUSIVE ROCKS

Sills, plugs, and dikes (Pl. 1 and Fig. 8), intruding primarily into the Ohanapecosh Formation, form prominent outcrops in the Wind River area. The intrusives are grouped into diabase and gabbro plugs and dikes, diorite and quartz diorite sills and plugs, and hornblende diorite plugs and stocks.

Diabase and Gabbro Plugs and Dikes

Plugs of diabase and gabbro cut the Ohanapecosh Formation at Bunker Hill and to the west and north of Augspurger Mountain. A large dike intrudes the Eagle Creek Formation about a mile south of Table Mountain. The outer part of the Bunker Hill plug and most of the Table Mountain dike are slightly altered diabases, but the core of Bunker Hill is fresh gabbro. The volcanic sediments at Bunker Hill are hornfelsed out about 300 feet from the contact, and the aureole at the Table Mountain dike is about 50 feet wide. The contact relations of three plugs near Augspurger Mountain are obscured by landslides and poor exposures.

These gabbros or diabases are composed of plagioclase (An_{52}) and augite, and minor amounts of potash feldspar, magnetite, and apatite. The cores of some plagioclase phenocrysts are partially replaced by laumontite. Veinlets of calcite are abundant, and celadonite and montmorillonite have replaced some of the potash feldspar, plagioclase, and augite.

The Bunker Hill plug is younger than the middle part of the Ohanapecosh Formation, and the dike south of Table Mountain is younger than the Eagle Creek Formation. The outer margins of the

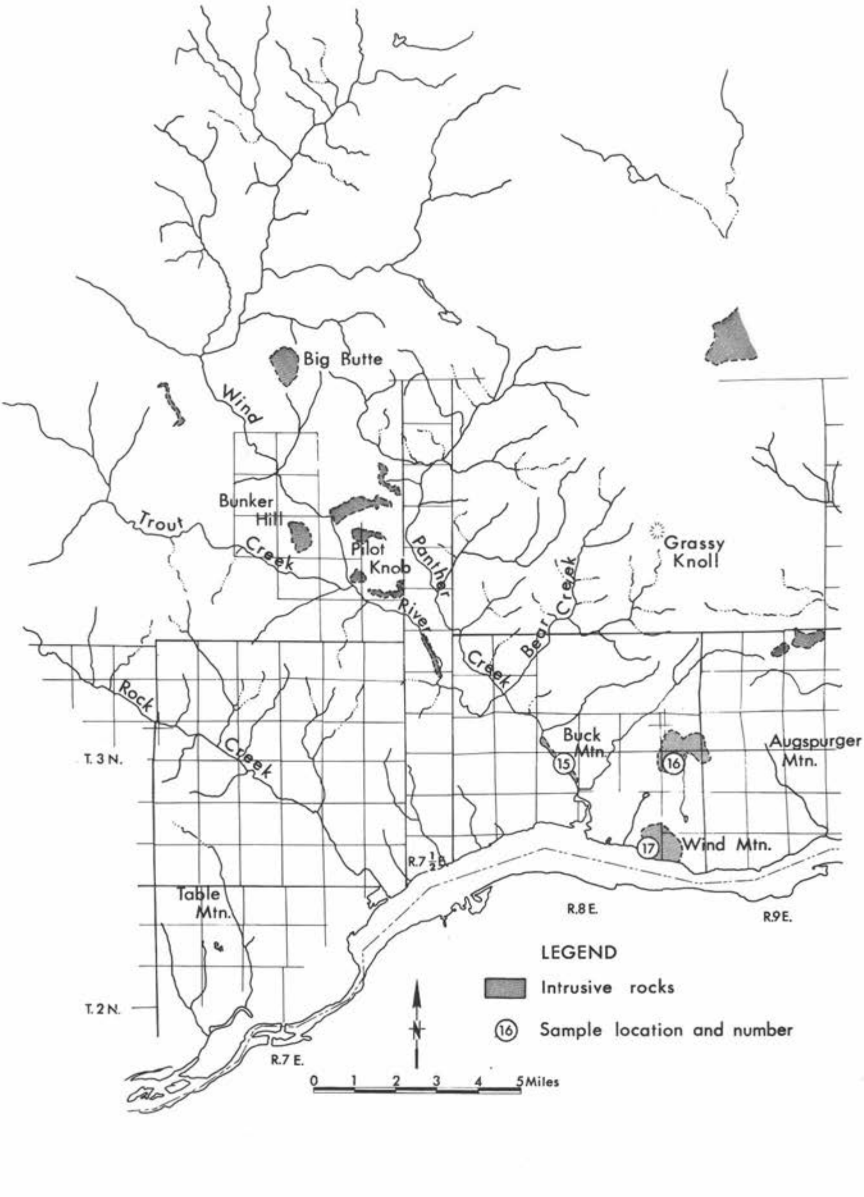


Figure 8. DISTRIBUTION OF INTRUSIVE ROCKS IN THE WIND RIVER AREA.

Bunker Hill plug are not as strongly altered as some of the flows in the upper part of the Ohanapecosh, therefore it may be post-Ohanapecosh in age.

Diorite and Quartz Diorite Sills and Plugs

Diorite Sills

Pyroxene-bearing diorite sills in the Ohanapecosh Formation compose a remarkably linear series of outcrops along the Wind River valley from its mouth to Big Butte (Pl. 1). A sill is exposed for 2 miles along the bottom of the Wind River gorge southwest of Buck Mountain, and another crops out on the south flank of Buck Mountain. Yet another sill is exposed along the Wind River south of Pilot Knob. Pilot Knob has three large exposures of diorite, and Warren Ridge (north of Warren Gap) is underlain by a single sill of diorite. The summit of Big Butte is underlain by similar diorite, but the intrusion may be a plug rather than a sill. A small sill occurs across the Wind River from Big Butte.

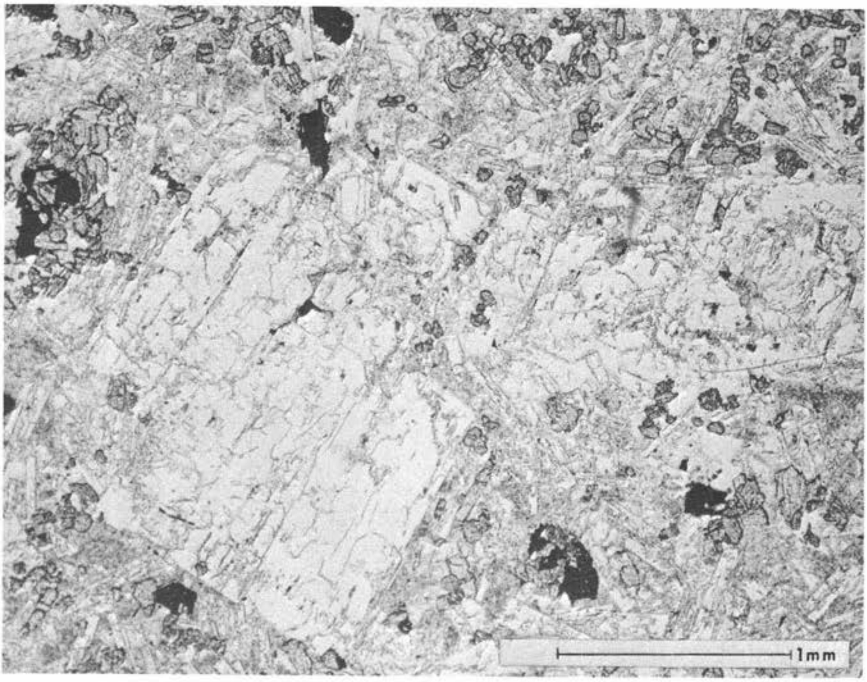


Figure 9. Photomicrograph of a diorite sill in the streambed of the Wind River. Plagioclase phenocryst is partially replaced by laumontite and albite (Table 4, no. 15, and Figure 8). Plain light; bar is 1 mm.

All these intrusions except Big Butte show evidence that they are sills. Bedding of the sedimentary rocks lying conformably above and below the sill is particularly well-exposed in the gorge south of Pilot Knob. The sills are rarely more than 200 feet thick, and some of the thinner ones, such as the one west of Big Butte, show crude columnar jointing.

The sedimentary rocks within at least 100 feet of each sill are slightly baked and are always purple, in contrast to the greens and browns seen elsewhere.

The sills are holocrystalline, but in hand specimen they have the appearance of porphyritic andesite. The bases and tops of many of the sills contain amygdules of stilbite. Plagioclase is the most abundant mineral, occurring as phenocrysts and as laths in the groundmass (Fig. 9). The phenocrysts occur in clusters or as single grains as much as 3 millimeters across. Zoning is pronounced; the cores are calcic andesine or sodic labradorite, and the rims are sodic andesine. Hypersthene and augite are abundant (Fig. 9). Augite occurs as phenocrysts, occasionally intergrown with magnetite, in most sills. Interstitial quartz and a potassic feldspar occur in small amounts.

An analysis of the sill exposed in the streambed of the Wind River west of Buck Mountain (Fig. 8) is given in Table 4 (No. 15). Compared with the calc-alkaline series (Turner and Verhoogen, 1960, p. 285), this sample is slightly deficient in alkali and has an excess of iron and calcium.

All the sills are moderately altered. Celadonite and montmorillonite commonly replace the pyroxene and the feldspars. Plagioclase grains are partially replaced by laumontite and albite (Fig. 9).

These sills intrude the Ohanapecosh Formation, but there is no other evidence to indicate their age. Their alteration may have occurred in either of two ways. Perhaps they were emplaced early, and were later regionally altered along with the Ohanapecosh Formation, or perhaps the diorite was deuterically or hydrothermally altered—aided by intrastratal solutions in the sedimentary rocks—during and after intrusion.

Quartz Diorite Plug

Wind Mountain, in the southeastern corner of the area (Fig. 8, on p. 24), is composed of a light-gray quartz diorite. Large talus slopes mantle much of the base of the mountain, but on the northern edge intrusive contact relations with the Yakima Basalt can be seen. The age of the plug is, therefore, post-late Miocene.

TABLE 4.—*Chemical analyses of intrusive rocks from the Wind River area*

	Sample number		
	15	16	17
SiO_2	62.28	63.86	65.71
TiO_2	0.57	0.56	0.77
Al_2O_3	16.1	17.3	17.4
Fe_2O_3	0.83	3.01	1.92
FeO	4.81	1.33	2.01
MnO	0.14	0.04	0.03
MgO	2.27	2.22	2.14
CaO	5.85	4.20	3.40
Na_2O	3.26	4.40	4.53
K_2O	0.82	1.12	1.14
P_2O_5	0.16	0.25	0.28
CO_2	0.00	0.00	0.00
H_2O+	2.61	0.99	0.40
H_2O-	0.58	1.05	0.00
Total	100.28	100.09	99.73
Molecular norms			
Quartz	20.8	21.2	23.6
Orthoclase	5.0	6.6	6.5
Albite	30.5	40.2	40.7
Anorthite	28.0	19.6	15.2
Corundum	0.0	2.0	3.6
Diopside	0.9	0.0	0.0
Hypersthene	12.6	6.2	6.7
Magnetite	0.9	2.0	2.0
Ilmenite	0.8	0.8	1.1
Apatite	0.3	0.5	0.6

Locations of samples:

Sample
no.

15 Diorite sill exposed in streambed of the Wind River west of Buck Mountain; sec. 21, T. 3 N., R. 8 E. Bonneville Dam quadrangle.

16 Hornblende diorite plug 2 miles north of Wind Mountain; sec. 24, T. 3 N., R. 8 E. Hood River quadrangle.

17 Quartz diorite plug, Wind Mountain; sec. 35, T. 3 N., R. 8 E. Bonneville Dam quadrangle.

Locations of samples are shown on Figure 8.

Analyst: W. S. Wise.

The plug rock has a texture and mineralogy somewhat distinct from the diorite sills, though broadly similar. It contains phenocrysts of plagioclase 2 millimeters across and ghost grains with broad reaction rims set in a groundmass of quartz, plagioclase, and pyroxene. The plagioclase phenocrysts are somewhat altered to clay in their cores and are highly zoned, but their compositions are approximately calcic andesine. The groundmass pyroxene is probably an orthopyroxene. Magnetite, plagioclase, pyroxene, and biotite aggregates completely replace phenocrysts that originally may have been hornblende.

The groundmass quartz is reflected by the high silica content (Table 4, no. 17). The analysis is similar to that of rocks of the calc-alkaline magma series (Turner and Verhoogen, 1960, p. 285).

Hornblende Diorite Plugs

Large plugs of hornblende diorite crop out 2 miles north of Wind Mountain and at Little Huckleberry Mountain (Pl. 1 and Fig. 8). The plugs intruded and baked the adjacent Ohanapecosh volcanic sedimentary rocks.

The dominant mineral is plagioclase, which occurs as phenocrysts about 0.5 millimeter long and in glomerocrysts as much as 3 millimeters across. The crystals are oscillatory zoned from cores of calcic andesine (An_{45}) to rims of sodic andesine (An_{37}). Apatite needles stud the outer rims. The groundmass plagioclase occurs as laths and short prisms, and its composition is near An_{35}. None of the plagioclase is altered.

Quartz and potash feldspar occur sparsely in the groundmass. Hornblende forms phenocrysts as much as 5 millimeters long that have an alteration rim of montmorillonite and magnetite. The hornblende is strongly pleochroic with:

$$X = \text{pale green-brown}$$
$$Y = \text{green-brown}$$
$$Z = \text{olive-green}$$
$$Z > Y > X$$

Montmorillonite is a very common alteration product of the groundmass. It surrounds practically every grain and partially replaces the borders of all hornblende phenocrysts.

The analysis (Table 4, no. 16) shows that these hornblende diorites are similar to the hornblende andesites of the present Cascade Range (Turner and Verhoogen, 1960, p. 285).

DEFORMATION OF EARLY TO MIDDLE TERTIARY ROCKS

Rocks in the Wind River area show no evidence of marked orogenic movements. Faults are common but have little displacement, and the folds are best described as gentle warps. Unconformities apparently followed periods of folding or uplifting.

Dips in the Ohanapecosh and Eagle Creek Formations are less than 27°. Correspondingly, the folds are broad, and the fold axes are difficult to find. The Ohanapecosh Formation exposed in Bear Creek is in the southwestern limb of an anticline, but traced to the north these same beds undergo a 90° change in strike. The axis of this fold trends almost east-west and plunges about 20° westward (Pl. 1). The volcanic sediments a few miles north and south of Howe Ridge dip in opposite directions, suggesting a very broad anticline whose axis trends east-west and may plunge eastward.

Many normal faults are exposed in roadcuts in the Ohanapecosh Formation, but most cannot be traced to any other exposures. Displacements are seldom more than a few feet. The faults in the Bear Creek area are nearly vertical, the east blocks being down thrown.

Linear alignment of the scarplike west slope of the Wind River valley with the Trout Creek Hill volcano suggests a northwest-trending fault, but definite evidence is lacking. The six or seven flows and the low degree of alteration of the section west of the valley are not repeated to the east. Only three extensively altered flows were found along Bear Creek.

Unconformities or disconformities exist between the Ohanapecosh and Eagle Creek Formations and between the Eagle Creek and the Yakima Basalt. The Ohanapecosh-Eagle Creek unconformity is slightly angular, suggesting that some folding took place before deposition of the Eagle Creek sediments. The irregular surface at the base of the Yakima Basalt flows means that a period of erosion preceded the basalt flows.

The Yakima Basalt exposed along the Columbia River east of the Wind River area is distinctly folded, therefore the latest folding that affected the Wind River area was probably post-late Miocene. It is not known whether the lower part of the Ohanapecosh Formation at Grassy Knoll was uplifted at that time.

QUATERNARY LAVAS

DESCRIPTIONS OF THE VOLCANOES AND THEIR LAVAS

About 100 square miles of the Wind River area is covered by olivine-bearing lava flows (Pl. 1 and Fig. 10) from volcanoes that probably began erupting early in the Pleistocene. Most of the activity was post-glacial, and a few flows have been extruded within the past 1,000 years. Although vents are scattered throughout the area, they are more numerous toward the northeast.

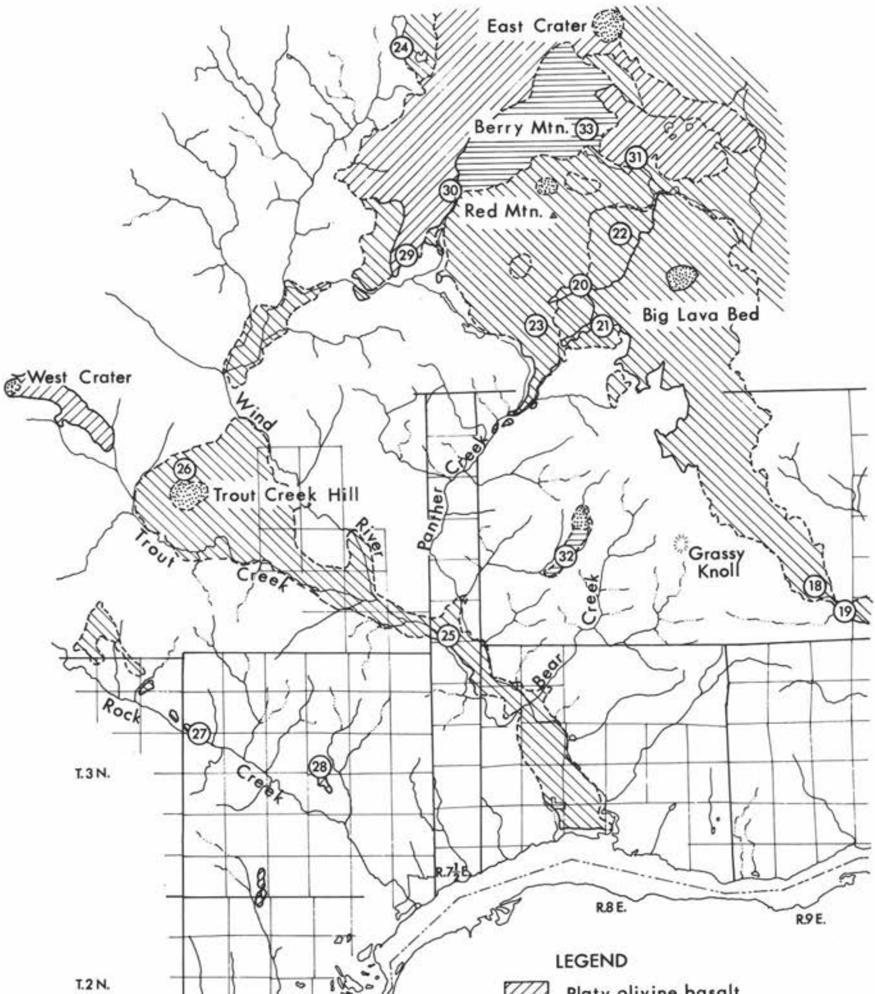


Figure 10. DISTRIBUTION OF THE THREE QUATERNARY BASALT COMPOSITIONS IN THE WIND RIVER AREA.

The lavas and their vents have been grouped into seven volcanoes or groups of volcanoes and placed in an approximate age sequence (Pl. 1). The largest volcano is Red Mountain. As it is of intermediate age, the nearby lavas are dated relative to the Red Mountain flows. Several flows cannot be correlated directly with the northwestern group and are described separately.

Pre-Red Mountain Flows

Berry Mountain and Gifford Peak are remnants of the earliest volcanoes to erupt olivine basalt flows in the area. The western slopes of the two peaks suggest a shield 8 miles in diameter surmounted by a north-south row of composite and cinder cones. Glaciers, possibly during Frasier glaciation, cut a cirque about 4,000 feet across into the western slope of the ridge between Berry Mountain and Gifford Peak. There is no evidence of activity from this volcano during or after glaciation, in contrast to Red Mountain and other cones, which are post-glaciation in age.

The flows forming much of this lava shield are low-alumina, subalkaline olivine basalts and have a petrography and chemistry distinctive from that of all the other basalts. They look much the same in the field, however.

Several other exposures of lavas older than the Red Mountain flows are: three rounded hills along the Cascade Crest west of Big Lava Bed and north of Big Huckleberry Mountain; a large dike or plug near the junction of Panther Creek and Twelvemile Creek; and The Wart, on the southwestern slope of Red Mountain.

Red Mountain Volcano

Red Mountain is a shield volcano topped with two cinder cones, which rise about 1,000 feet above the shield. Flows from the volcano underlie an area of 17 square miles, which originally may have been as large as 20 square miles. The flows extend eastward at least to the western shore of Goose Lake. To the west, lava flowed 8 miles into the drainage of Falls Creek, over the bluffs, and down into the valley of the Wind River. Flows to the south entered the canyon of Panther Creek but did not extend beyond Twelvemile Creek, which is about 6 miles from Red Mountain. Individual flows of these dark-gray olivine basalts are 50 to 100 feet thick and have irregular, blocky jointing.

The summit cone of Red Mountain is composed of cinders and lava spatter, whereas the cone on the north slope is composed of loose cinders and bombs.

Post-Red Mountain Flows

Two small flows east of Berry Mountain originated from vents that lack cinder cones. The vent of the younger flow is occupied by two small lakes whose rims are free of cinders. The lava, a platy olivine basalt easily recognized by its sparse olivine content, extends to and underlies the area around Forlorn Lakes. This flow overlies a small flow of olivine basalt erupted from a vent now occupied by Lake Sahalee Tyee.

Trout Creek Hill Volcano

Trout Creek Hill is a small shield volcano surmounted by two closely adjacent cinder cones that were vents for several lava flows. The flows are dark-gray olivine basalt with glomeroporphyritic olivine clots. The lavas did not advance far westward, but they flowed southeastward around both sides of Bunker Hill and down the Wind River valley into the Columbia River. The intracanyon flows filled the Wind River valley to a depth of at least 325 feet near the junctions of Bear Creek, Panther Creek, and the Wind River. Flows that moved westward from the vent are probably more than 200 feet thick, but only 1½ miles long.

East Crater

East Crater is a cinder cone rising 400 feet above the adjacent lavas. Its crater is about 150 feet deep. Irregularities in the shape of the western slope of the cone mark the vent from which platy olivine basalt flowed to the southeast and southwest. The southeastward flow extended to the Black Creek swamp east of Middle Butte, filling the old Falls Creek drainage that had become readjusted on the surface of the Red Mountain flows.

The flow that advanced southwestward is probably more than 100 feet thick near its terminus, but is thinner in its middle part. Lava tubes—now collapsed—testify to the fluidity of these lavas. The flows crop out mainly as piles of light-gray platy debris; solid outcrops are uncommon.

Flows of the Big Lava Bed

The east edge of the Wind River area is largely underlain by a young sequence of dark-gray to black olivine basalt flows, which were erupted from the base and west side of an 800-foot-high cinder cone in the northwestern part of the lava field. The vent and directions of flow are shown on Plate 1. No attempt was made to map the several distinguishable flows of the Big Lava Bed, which extend down the valley east of Big Huckleberry Mountain to the Columbia River Gorge, 16 miles away.

The Big Lava Bed has very little soil cover, and the flows are so young that northwest of the crater their surfaces are cluttered with rubble and pressure ridges about 30 feet high. Trunks of trees growing on the flow rarely are greater than 3 or 4 inches in diameter, whereas the presence of a soil layer and large trees accurately delimits the older flows.

Other Quaternary Flows of Undetermined Stratigraphic Sequence

West Crater Volcano

Two Recent flows, each about 2 miles long, emerged from West Crater, a small cinder cone 4 miles northwest of Trout Creek Hill. The flows partially fill the two canyons on each side of the crater and are so young that the displaced streams have just begun downcutting at the flow margins. The rubbly flow surfaces support only sparse vegetation. The gray lava is a platy olivine basalt with small, scattered olivine phenocrysts.

Rock Creek Lavas

Small remnants of an intracanyon dark-gray olivine basalt flow occur on the north side of Rock Creek (southwest and south of Mowich Butte), where they form low bluffs. The flow may have originated from a vent along the ridge southwest of Mowich Butte.

Rock Creek Butte is a small pluglike body of platy olivine basalt that may have fed a flow southward, but the flow has very little extent.

Red Bluffs Volcano

Platy olivine basalt and a part of a cinder cone cutting and overlying the Eagle Creek Formation occur along the eastern margin of Greenleaf Basin in the Red Bluffs. These are remnants of a small volcano, most of which has slumped southeastward on the large Bonneville landslide, southeast of the Red Bluffs (Pl. 1). Red Bluffs volcano erupted within the valley of upper Greenleaf Creek, damming the stream with lava and forming Greenleaf Basin.

Hornblende Andesite

Only a small amount of hornblende andesite occurs in the area. It is situated along the extreme west edge of the area near West Crater northwest of Trout Creek Hill. Although this small patch of andesite was mapped, it is not described in the text.

TABLE 5.—*Modal analyses of the Quaternary lavas from the Wind River area*

	Olivine basalts										Platy olivine basalts				Low-alumina olivine basalts	
	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Phenocrysts:																
Plagioclase	...	...	7.5	0.2	6.6	7.1	...	1.3	0.8	...	...	...	...	...	...	...
Orthopyroxene	...	...	...	...	...	...	...	...	...	...	...	...	0.8	...	...	...
Clinopyroxene	...	...	...	3.6	...	...	...	...	...	1.0	...	...	...	...	...	2.2
Olivine	1.6	7.5	4.3	6.1	6.4	1.2	7.4	7.2	5.3	7.5	4.8	3.6	2.5	tr.	5.5	11.2
Magnetite (microphenocrysts)	...	...	...	...	...	...	...	...	...	...	1.5	1.3	1.1	tr.	...	...
Groundmass:																
Plagioclase	57.0	47.4	51.0	49.8	50.6	50.8	56.2	56.2	51.0	52.6	56.0	64.8	57.8	63.5	42.1	40.8
Orthopyroxene (reaction rims)	...	...	...	...	...	...	...	...	...	...	2.5	2.6	2.8	0.8	...	...
Clinopyroxene	24.0	23.3	24.4	27.2	20.4	15.5	15.4	13.0	17.6	18.1	23.6	22.0	23.1	28.3	31.6	21.9
Olivine	12.8	9.4	5.0	4.6	6.6	6.8	17.5	11.6	8.4	3.1	1.2	...	0.3	tr.	2.8	0.5
Magnetite	2.6	6.3	4.8	6.4	4.4	5.7	2.3	1.1	8.0	7.3	3.5	1.5	2.0	3.0	4.4	3.8
Apatite	tr.	2.1	0.1	0.4	1.3	1.7	1.1	tr.	0.8	0.7	1.4	0.5	0.7	tr.	0.6	tr.
Alkali feldspar	...	...	...	...	...	...	...	...	...	...	...	...	...	...	8.0	18.5
Biotite	...	...	...	0.9	...	...	...	...	...	...	tr.	tr.	tr.	...	1.2	...
Amphibole	...	...	...	0.2	...	...	...	...	...	...	...	...	0.3	...	3.3	1.1
Glass	2.0	4.0	2.8	...	3.7	11.2	0.0	9.6	4.6	7.1	5.1	3.7	8.9	2.3	...	...
Alteration (deuteric) products	...	...	...	0.4	...	1.0	...	...	3.3	2.6	0.3	...	...	...	0.5	...

Locations of samples are shown on Figure 10.

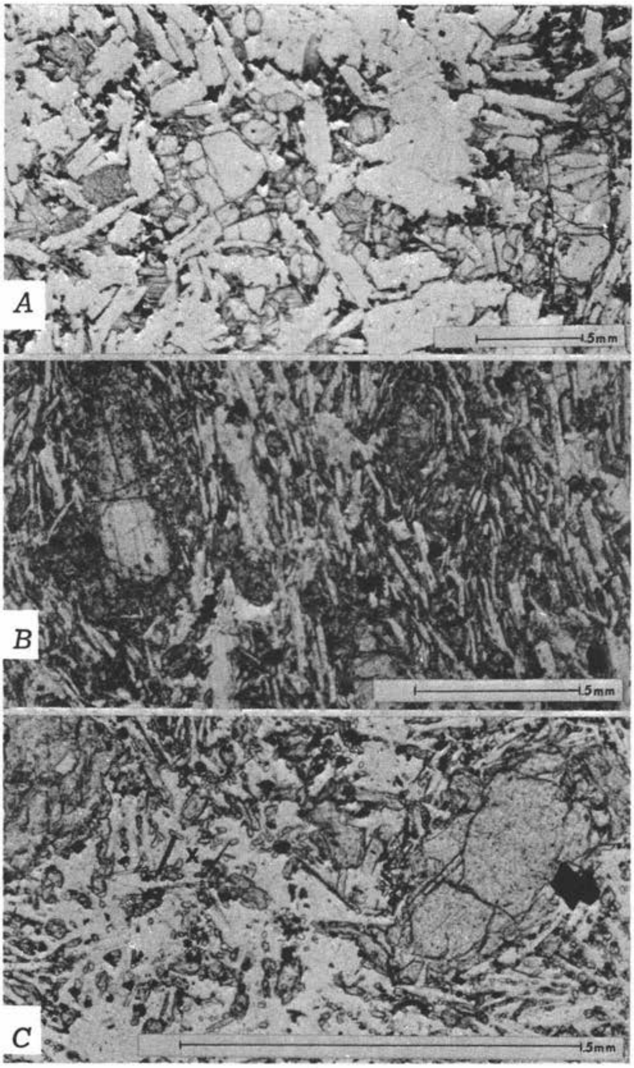


Figure 11. PHOTOMICROGRAPHS OF QUATERNARY BASALTS. (*A*) High-alumina basalt of the Big Lava Bed. Olivine phenocrysts are surrounded by plagioclase and light-brown augite. Small magnetite grains and glass fill remaining interstices; (*B*) Platy olivine basalt from East Crater. Small plagioclase laths, showing flow alignment, are wrapped around olivine phenocrysts, which have reaction rims of hypersthene; (*C*) Low-alumina olivine basalt from Berry Mountain. Very small grains of plagioclase and pyroxene surround much larger augite and olivine phenocrysts. Alkali feldspar occurs in ill-defined patches, which also contain tiny amphibole grains (X). Plain light; length of bars = 0.5 mm.

PETROLOGY OF THE QUATERNARY LAVAS

The Quaternary volcanic rocks of the Wind River area are divided into three groups based on mineralogy and chemical composition (Fig. 10, on p. 30, and Tables 5, on p. 34; 6, on p. 37; and 7, on p. 40).

Olivine basalts are dark gray and blocky and compose most of the lavas in the area. They are extensive; some flowed 15 to 20 miles from their vents. They commonly built shield volcanoes, such as Trout Creek Hill and Red Mountain. The Big Lava Bed volcano has only a low shield, however, because the numerous lava flows that erupted from it moved rapidly away from the vent. This type of lava has been erupted from the oldest as well as the youngest volcanoes.

Of a second type are the light-gray **platy olivine basalts.** Three of the flows are short, but one extended nearly 8 miles from its vent at East Crater. The vents are near the bases of cinder cones. Both platy and nonplaty types were probably fluid when they were extruded, as both types developed lava tubes. Platy olivine basalts are among the youngest flows in the Wind River area.

Of a third type, not easily distinguished in the field from the olivine basalts, are subalkaline, **low-alumina olivine basalts.** These lavas are dense and dark gray, and contain abundant alkali feldspar in the groundmass.

The olivine basalts are porphyritic, rarely glomeroporphyritic, and the groundmass has an intergranular texture and contains some glass (Fig. 11, *A*). The plagioclase occurring as glomerocrysts is An_{70}, and that occurring in the groundmass is zoned from An_{60} to An_{40}. Olivine phenocryst compositions are in the Fo_{90-80} range; most groundmass olivines are more iron-rich than Fo_{80}. Augite, magnetite, and rare ilmenite and apatite complete the groundmass.

The texture of the platy olivine basalts is characteristically intergranular. A subparallel arrangement of the plagioclase laths accounts for the common platy jointing (Fig. 11, *B*). Platy olivine basalts contain little or no groundmass olivine, and the olivine phenocrysts are surrounded by reaction rims of hypersthene and magnetite. Plagioclase occurs only in the groundmass and is zoned from An_{60} to An_{40}. Magnetite is present in all samples as microphenocrysts. Phlogopite occurs near olivine and magnetite grains as a reaction product between these two minerals and the potash-silica-rich residual melt. Granular augite, magnetite, and apatite complete the groundmass.

Most of the low-alumina basalts examined are holocrystalline and have olivine phenocrysts and an intergranular groundmass (Fig. 11, C). The amount (near 40 percent) and composition (An_{50-35}) of the plagioclase reveals higher alkali content and lower alumina content than that in the other basalts. The olivine phenocryst cores are near Fo_{95} and are zoned to Fo_{80}. The rest of the groundmass contains augite, an alkali-feldspar, apatite, rare phlogopite, and very small crystals of a yellow-brown amphibole.

For comparative purposes, the mineralogy of the Quaternary basalts is summarized in Table 6 and the compositional variations of plagioclase and olivine are graphed in Figure 12.

TABLE 6.—*Summary of the mineralogy of the Quaternary lavas*

	Olivine basalts	Platy olivine basalts	Low-alumina olivine basalts
Plagioclase	Groundmass, rarely as glomerocrysts An_{70-40}	Groundmass An_{60-40}	Groundmass An_{50-35}
Olivine (all olivines contain between 1% and 3% Ca_2SiO_4)*	Phenocrysts and groundmass Fo_{90-65}	Phenocrysts only Fo_{90-65}	Phenocrysts and groundmass Fo_{95-78}
Clinopyroxene	Augite in groundmass; rare as phenocrysts	Augite in groundmass	Augite in groundmass; some phenocrysts
Orthopyroxene	None	As reaction rims around olivine phenocrysts	None
Magnetite	Groundmass	Microphenocrysts and groundmass	Groundmass
Apatite	Groundmass	Groundmass	Groundmass
Alkali feldspar	None	None	Groundmass, between plagioclase laths
Phlogopite (occurs only near olivine and magnetite grains)	Rare in groundmass	Trace	Rare
Amphibole	None	None	As very small crystals associated with alkali feldspar

*Determined by combining data obtained through the methods of Poldervaart (1950), Smith and Stenstrom (1965), and Yoder and Sahama (1957).

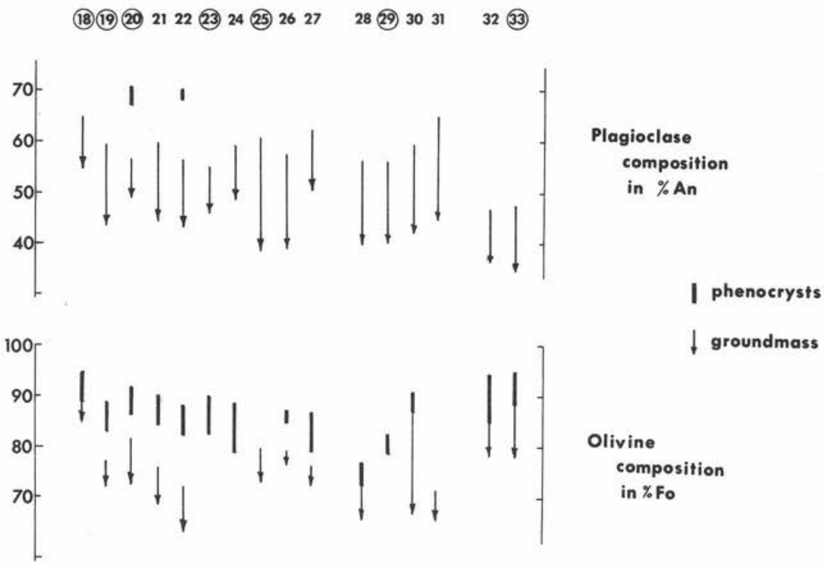


Figure 12. PLAGIOCLASE AND OLIVINE COMPOSITIONAL VARIATIONS OF THE QUATERNARY BASALT GROUPS. Sample numbers are located on Figure 10, and circled sample numbers refer to analyzed rocks (Table 7).

CHEMISTRY OF THE QUATERNARY LAVAS

Analyses of seven Quaternary basalts are presented in Table 7. All the lavas, with the exception of that from Berry Mountain, are high-alumina basalts as defined by Kuno (1960). The earliest flow from the Big Lava Bed (Table 7, no. 18) contains the least alkalies and the most lime and alumina of all the Wind River lava samples. In this respect it is similar to the Warner Basalt of northern California (Table 7, WB), which was considered by Yoder and Tilley (1962, p. 362) to be a typical high-alumina basalt.

All the other samples analyzed have more silica and alkalies, and less alumina, magnesia, and lime than the first flow of the Big Lava Bed. That these samples represent differentiated magma is supported by the Big Lava Bed samples in age sequence (Table 7, nos. 18, 19, and 20). Although no cognate xenoliths were found in the younger flows, these lavas do contain abundant phenocrysts (Table 5, on p. 34). Separation of these phenocrysts of olivine and calcic plagioclase can yield magma compositions similar to those of nos. 19, 23, and 29 in Table 5, on p. 34.

This differentiation trend is illustrated in the composition plot of Quaternary basalts (Fig. 13), which shows directly the effects of olivine separation and only indirectly the effects of plagioclase separation. Variants from this trend result from a lack of, or an overabundance of, phenocrysts of either olivine or plagioclase. For example, in Figure 13, sample no. 20 from the Big Lava Bed contains many more plagioclase phenocrysts than do the earlier flows. These phenocrysts cause the analysis to have higher lime and alumina values.

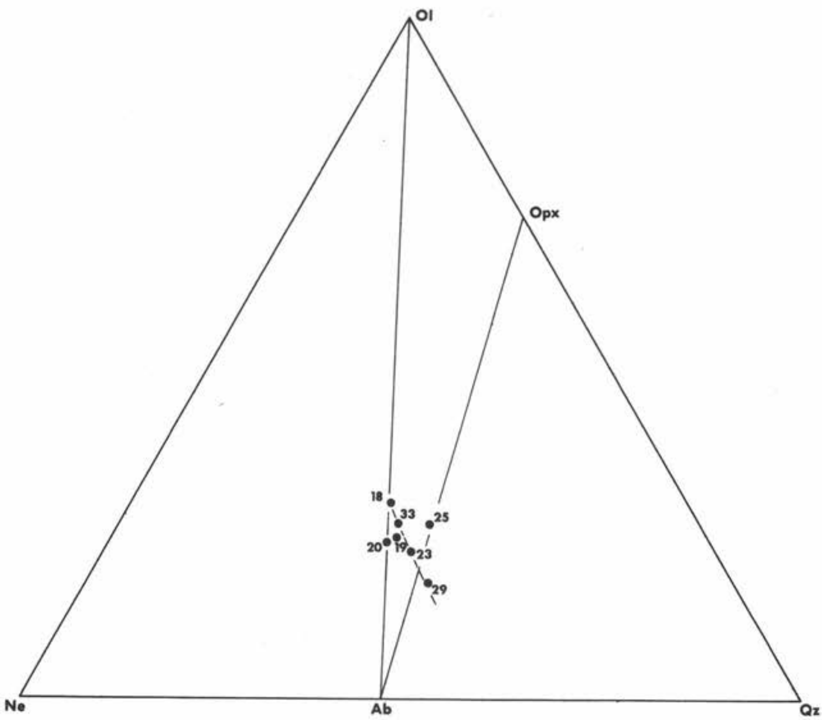


Figure 13. NEPHELINE-OLIVINE-QUARTZ PLOT OF THE ANALYZED QUATERNARY BASALTS. Point coordinates are calculated from weight percent normative minerals (Poldervaart, 1964, p. 231). Dashed curve represents trend, resulting from crystal fractionation of olivine and calcic labradorite.

The platy olivine basalts (for example, no. 29 in Fig. 13) appear to be the end result of this differentiation in the Wind River area. Several of these flows are not directly associated with olivine basalts and are probably from magma chambers that differentiated to this extent before eruption.

TABLE 7.—*Chemical analyses of Quaternary lavas from the Wind River area*

	Sample number							
	18	19	20	23	25	29	33	(WB)
SiO_2	48.0	49.4	49.2	50.44	49.95	53.97	49.91	48.27
TiO_2	0.99	1.37	1.45	1.51	1.20	1.06	1.30	0.89
Al_2O_3	18.6	16.9	17.15	17.96	16.81	17.35	14.53	18.28
Fe_2O_3	2.62	2.82	2.52	2.40	3.39	2.67	5.34	1.04
FeO	7.13	7.67	6.89	7.10	6.72	5.28	4.88	8.31
MnO	0.17	0.17	0.15	0.13	0.16	0.11	0.13	0.17
MgO	8.15	7.54	7.92	6.50	8.60	6.68	9.10	8.96
CaO	11.13	10.56	10.68	8.38	8.79	8.03	9.33	11.32
Na_2O	2.88	3.25	3.44	3.57	3.01	3.80	3.26	2.80
K_2O	0.25	0.41	0.45	0.93	0.49	0.73	1.07	0.14
P_2O_5	0.15	0.17	0.26	0.39	0.17	0.27	0.32	0.07
CO_2	...	...	...	0.05	0.02	0.00	0.09	...
H_2O+	...	...	...	0.32	0.38	0.37	0.21	0.15
H_2O-	...	...	...	0.59	0.22	0.24	0.24	0.07
Total	100.07	100.28	100.11	100.27	99.92	100.56	99.71	100.47
Molecular norms								
Quartz	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0
Orthoclase	1.5	2.4	2.6	5.5	2.9	4.3	6.3	0.6
Albite	25.7	29.0	30.4	32.1	27.1	33.9	29.3	23.6
Anorthite	36.8	30.2	29.8	30.3	30.9	27.9	21.9	37.0
Diopside	13.6	16.7	16.9	6.8	9.2	7.9	17.4	15.2
Hypersthene	1.7	4.4	0.0	12.9	9.7	19.3	11.0	0.0
Olivine	16.4	12.2	15.2	6.9	4.6	0.0	5.7	20.6
Magnetite	2.7	2.9	2.6	2.5	3.5	2.8	5.6	1.4
Ilmenite	1.4	1.9	2.0	2.1	1.7	1.5	1.8	1.7
Apatite	0.3	0.4	0.5	0.8	0.4	0.6	0.7	0.2
Calcite	...	...	...	0.1	0.1	...	0.2	...

Locations of samples:

Sample no.

18 High-alumina basalt, Big Lava Bed, oldest flow near Lost Creek. Willard quadrangle.

19 High-alumina basalt, Big Lava Bed, young flow filling shallow canyon cut in earlier flow; near Lost Creek. Willard quadrangle.

20 High-alumina basalt, Big Lava Bed, youngest flow; in notch along Carson-Guler road. Wind River quadrangle.

23 Porphyritic high-alumina olivine basalt, Red Mountain lavas; along Panther Creek road ½ mile south of junction with Carson-Guler road. Wind River quadrangle.

25 High-alumina olivine basalt; Trout Creek Hill along Wind River valley (Waters, 1961b). Wind River quadrangle.

29 High-alumina platy olivine basalt flow from East Crater; on Falls Creek at end of Panther Creek road. Wind River quadrangle.

33 Olivine basalt of Berry Mountain; along ridge at north end of Berry Mountain. Wind River quadrangle.

(WB) Warner Basalt of northern California (Yoder and Tilley, 1962).

Locations of analyzed samples are shown on Figure 10.

Analysts: Samples 18, 19, and 20, W. S. Wise; samples 23 and 29, H. Asari; sample 25, V. C. Smith; sample 33, T. Asari.

The basalts of Berry Mountain and the Cedar Creek flow are chemically different from the other lavas, for they contain less alumina (Table 7, no. 33). The chemical differences are reflected in the amount of normative diopside and alkali feldspars. On the basis of the one analysis presented here (Table 7, no. 33), a genetic connection with high-alumina basalt is not apparent.

SUMMARY OF VOLCANIC HISTORY

The history of volcanism, sedimentation, and intrusive igneous activity, as recorded in the rocks of the Wind River area, is summarized in Figure 14.

The oldest exposed rocks of the Wind River area show that by early Tertiary time the area of the present Cascade Mountains was occupied by a submerged trough. Vast amounts of pyroclastic debris, mostly andesitic and dacitic in composition, were deposited by explosive volcanoes erupting mostly within the trough. Subaqueous pyroclastic flows, ash falls, and reworked pyroclastic deposits and a few high-alumina basalt flows accumulated to a thickness of more than 10,000 feet. Scattered lenses of conglomerate indicate that the basin occasionally filled when the deposition rate exceeded that of the subsidence.

In late Eocene or early Oligocene time, more of the pyroclastic debris was deposited, mostly on emergent surfaces. Tholeiitic basalt flows from volcanoes to the west occasionally covered parts of the land surface. When volcanic activity ceased, gentle warping and minor faulting uplifted much of the area to form low rolling hills bordering the shallow shelf area to the west.

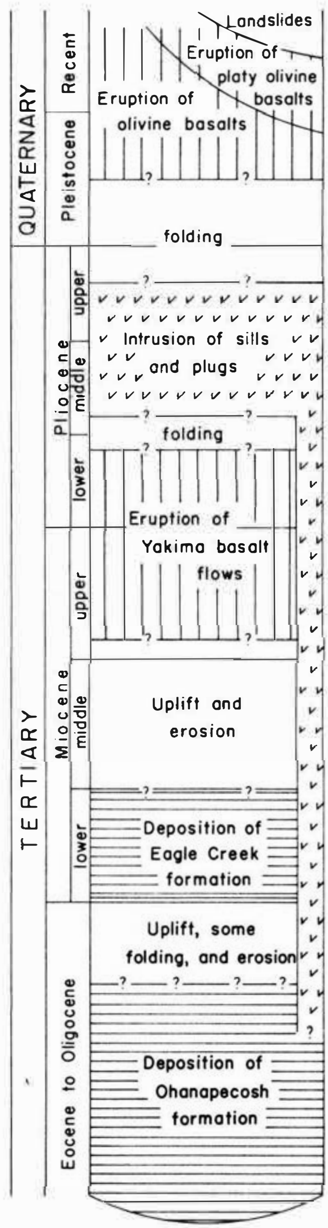


Figure 14. Columnar summary of the geologic history of the Wind River area.

The surface of the Ohanapecosh Formation was eroded and deeply weathered, and a saprolitic soil zone was formed during early Miocene time, before deposition of the andesitic detritus of the overlying Eagle Creek Formation. Eagle Creek conglomerates and sands were deposited by swiftly running streams pouring into what may have been a broad, nearly flat valley or basin. A few lava flows and mudflows entered the valley. Interruptions in deposition were sufficiently long for soil zones and a forest to develop locally. Most of the material came from volcanoes a short distance to the north and northwest, and it is composed of a remarkably homogeneous assemblage of rock fragments. Erosion of the Ohanapecosh rocks contributed little to the detritus. Folding after cessation of volcanic activity and deposition of sediments was very minor. Canyons of post-Eagle Creek age were carved to depths of several hundred feet, indicating that some uplift took place.

During late Miocene time, Yakima Basalt flows flooded the eroded surface underlain by the Eagle Creek Formation, covering rough topography that had a relief of as much as 1,500 feet. The northernmost extent of the Yakima flows is unknown, but basalt accumulated to a thickness of more than 1,000 feet in the southern part of the Wind River area. More folding and possibly faulting, which is best shown east of the Wind River area, followed extrusion of the lava.

During or soon after the folding, a few volcanoes erupted through the Yakima Basalt, leaving small stocks, plugs (such as Wind Mountain), and dikes as their only remnants. Diorite sills were intruded into the Ohanapecosh Formation either much earlier, or at about the same time that the Wind Mountain plug was emplaced. These diorite sills were altered either during regional zeolitic metamorphism or as they reacted with intrastratal solutions in the sediments into which they intruded.

Extensive uplift and erosion took place before the beginning of the Pleistocene Epoch. Volcanoes in the northeastern part of the area probably began erupting olivine basalt lavas early in the Pleistocene. The earliest activity built a long shield cone (Gifford Peak and Berry Mountain), which was glaciated during late ice advances. Since then, numerous vents have extruded olivine-rich lava flows. Red Mountain was formed from a shield volcano, topped with two cinder cones. Another shield with cinder cones (Trout Creek Hill) was built west of Wind River valley, and extensive flows from it poured down the valley and flowed into the Columbia River. East Crater is a cinder cone and vent for platy olivine basalts that covered the western part of the earlier olivine basalts from Red Mountain. A cinder cone emitted a small flow within the canyon of Greenleaf Creek. Most of that cinder cone and the lava were later pulled apart by continued landslide movement to the south. Great quantities of olivine basalts poured from a vent at the base of a large cinder cone east of Red Mountain. These flows, some extending as far as the Columbia River Gorge, formed what is now called the Big Lava Bed.

REFERENCES CITED

Allen, J. E., 1932, Contributions to the structure, stratigraphy, and petrography of the lower Columbia River Gorge: Univ. of Oregon M.S. thesis, 96 p.

Chaney, R. W., 1918, The ecological significance of the Eagle Creek flora of the Columbia River Gorge: Jour. Geology, v. 26, no. 7, p. 577-592.

Chaney, R. W., 1920, The flora of the Eagle Creek Formation [Washington and Oregon]: Univ. of Chicago Walker Museum Contr., v. 2, no. 5, p. 115-181.

Chaney, R. W., 1927, Geology and paleontology of the Crooked River basin, with special reference to the Bridge Creek flora: Carnegie Inst. Washington Pub. 346, p. 45-138.

Chaney, R. W., 1959, Miocene floras of the Columbia Plateau: Carnegie Inst. Washington Pub. 617, 237 p.

Felts, W. M., 1939a, A granodiorite stock in the Cascade Mountains of southwestern Washington: Ohio Jour. Science, v. 39, no. 6, p. 297-316.

Felts, W. M., 1939b, Keechelus andesitic lava flows of Washington in southward extension: Pan-Am. Geologist, v. 71, no. 4, p. 294-296.

Fisher, R. V., 1957, Stratigraphy of the Puget Group and Keechelus Group in the Elbe-Packwood area of southwestern Washington: Univ. of Washington Ph.D. thesis, 157 p.

Fisher, R. V., 1960, Proposed classification of volcaniclastic rocks [abs.]: Geol. Soc. America Bull., v. 71, no. 12, pt. 2, p. 1864-1865.

Fiske, R. S., 1963, Subaqueous pyroclastic flows in the Ohanapecosh Formation, Washington: Geol. Soc. America Bull., v. 74, no. 4, p. 391-406.

Fiske, R. S.; Hopson, C. A.; Waters, A. C., 1963, Geology of Mount Rainier National Park, Washington: U.S. Geol. Survey Prof. Paper 444, 93 p.

Kuno, Hisashi, 1960, High-alumina basalt: Jour. Petrology [Oxford, England], v. 1, no. 2, p. 121-145.

Peck, D. L.; Griggs, A. B.; Schlicker, H. G.; Wells, F. G.; Dole, H. M., 1964, Geology of the central and northern parts of the western Cascade Range in Oregon: U.S. Geol. Survey Prof. Paper 449, 56 p.

Poldervaart, Arie, 1950, Correlation of physical properties and chemical composition in the plagioclase, olivine, and orthopyroxene series: Am. Mineralogist, v. 35, nos. 11-12, p. 1067-1079.

Poldervaart, Arie, 1964, Chemical definition of alkali basalts and tholeiites: Geol. Soc. America Bull., v. 75, no. 3, p. 229-232.

Smith, J. V.; Stenstrom, R. C., 1965, Chemical analysis of olivines by the electron microprobe: Mineralog. Mag., v. 34, no. 268, p. 436-459.

Snavely, P. D., Jr.; Wagner, H. C., 1963, Tertiary geologic history of western Oregon and Washington: Washington Div. Mines and Geology Rept. Inv. 22, 25 p.

Snavely, P. D., Jr.; Wagner, H. C.; MacLeod, N. S., 1965, Preliminary data on compositional variations of Tertiary volcanic rocks in the central part of the Oregon Coast Range: The Ore Bin, v. 27, no. 6, p. 101-117.

Swanson, D. A., 1966, Tieton volcano, a Miocene eruptive center in the southern Cascade Mountains, Washington: Geol. Soc. America Bull., v. 77, no. 11, p. 1293-1314.

Turner, F. J.; Verhoogen, John, 1960, Igneous and metamorphic petrology, 2nd edition: McGraw-Hill, New York, 694 p.

Waters, A. C., 1955, Volcanic rocks and the tectonic cycle. *In* Crust of the earth: Geol. Soc. America Special Paper 62, p. 703-722.

Waters, A. C., 1961a, Keechelus problem, Cascade Mountains, Washington: Northwest Science, v. 35, no. 2, p. 39-57.

Waters, A. C., 1961b, Stratigraphic and lithologic variations in the Columbia River Basalt: Am. Jour. Science, v. 259, no. 8, p. 583-611.

Waters, A. C., 1962, Basalt magma types and their tectonic associations—Pacific Northwest of the United States. *In* The crust of the Pacific Basin: Am. Geophys. Union Geophys. Mon. 6, p. 158-170.

Wilkinson, W. D.; Lowry, W. D.; Baldwin, E. M., 1946, Geology of the St. Helens quadrangle, Oregon: Oregon Dept. Geology and Mineral Industries Bull. 31, 39 p.

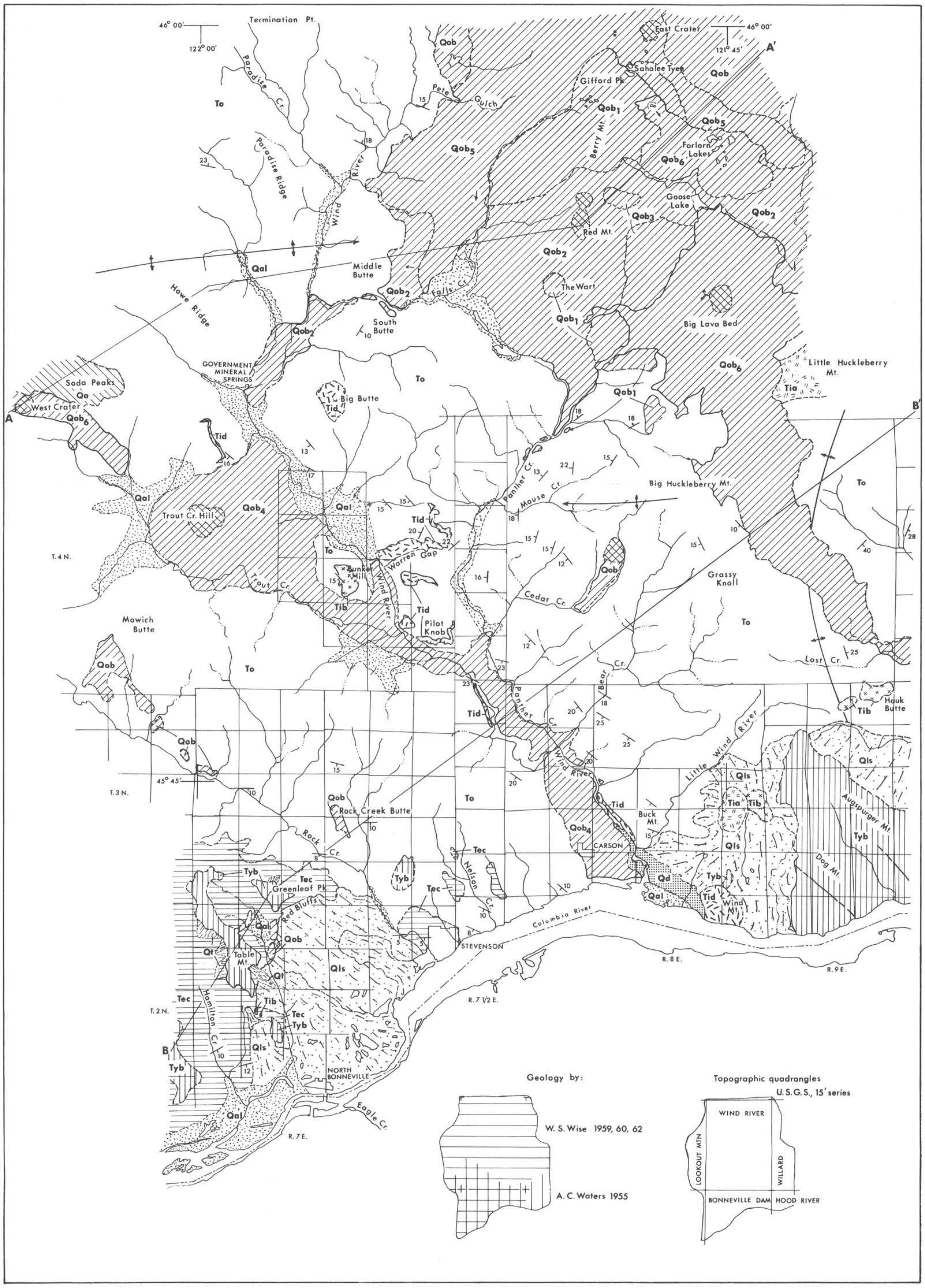
Williams, I. A., 1916, The Columbia River Gorge—its geologic history interpreted from the Columbia River Highway: Oregon Bureau of Mines and Geology, Mineral Resources of Oregon, v. 2, no. 3, 130 p.

Wilmarth, M. G., 1938, Lexicon of geologic names of the United States: U.S. Geol. Survey Bull. 896, 2 volumes, 2396 p.

Wise, W. S.; Fisher, R. V., in preparation, Equilibrium in zeolite assemblages.

Yoder, H. S.; Sahama, T. G., 1957, Olivine X-ray determinative curve: Am. Mineralogist, v. 42, nos. 7-8, p. 475-491.

Yoder, H. S.; Tilley, C. E., 1962, Origin of basalt magmas—an experimental study of natural and synthetic rock systems: Jour. Petrology [Oxford, England], v. 3, pt. 3, p. 342-532.



Base from U.S. Geological Survey topographic quadrangles

Scale in miles

Geology by W. S. Wise (north part) and A. C. Waters (south part)

EXPLANATION

PLEISTOCENE AND RECENT

Qal — **Alluvium**
Flood plain and stream deposits
(Thin alluvium on intracanyon lavas omitted)

Qt — **Extensive talus cones**
Yakima Basalt debris

Qls — **Landslides**
Debris derived chiefly from Yakima Basalt and Eagle Creek Formation

Qd — **Deltaic deposits**
formed behind lava dams

Qob — **Olivine basalt**
Lava flows and cinder cones

Numbered in probable relative age
6. Big Lava Bed
5. East Crater flows
4. Trout Creek Hill flows
3. post-Red Mountain flows (?)
2. Red Mountain flows
1. pre-Red Mountain flows

Qa — **Hornblende andesite**
Lavas from Soda Peaks volcano

UNCONFORMITY

MIOCENE

Tyb — **Yakima Basalt**
Dark, fine-grained lavas in flows 40 to 100 feet thick

UNCONFORMITY

Tec — **Eagle Creek Formation**
Volcanic conglomerates and sandstones with some tuffs

UNCONFORMITY

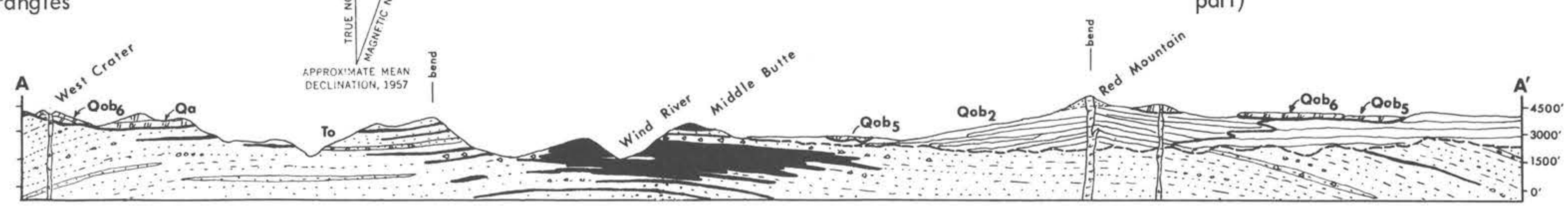
EOCENE TO OLIGOCENE

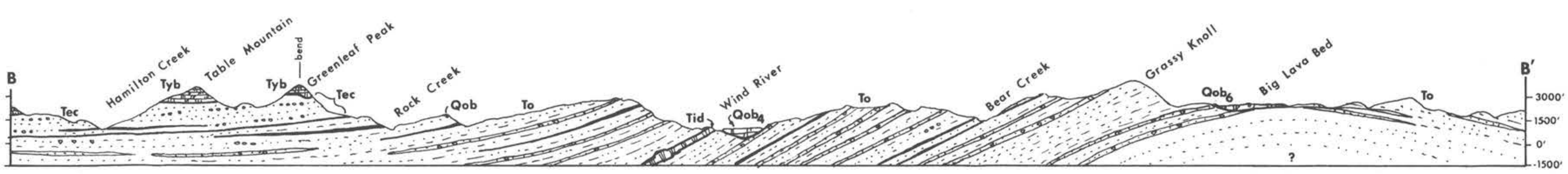
To — **Ohanapecosh Formation**
Largely andesitic to rhyodacitic pyroclastic rocks (primary and reworked tuffs and lapillistones, and tuff breccias) having interbedded basaltic flows

Tia, Tib, Tid — **Intrusives**
Tia: Augite-hornblende diorite; Tib: Gabbro, diabase, microgabbro; Tid: Augite-hypersthene diorite dikes, sills, and plugs

SYMBOLS

23 — Strike and dip of bedded rocks
Flow direction in lavas
Contact; dashed where approximate
Anticline
Fault





GEOLOGIC MAP AND SECTIONS OF THE WIND RIVER AREA, SKAMANIA COUNTY, WASHINGTON