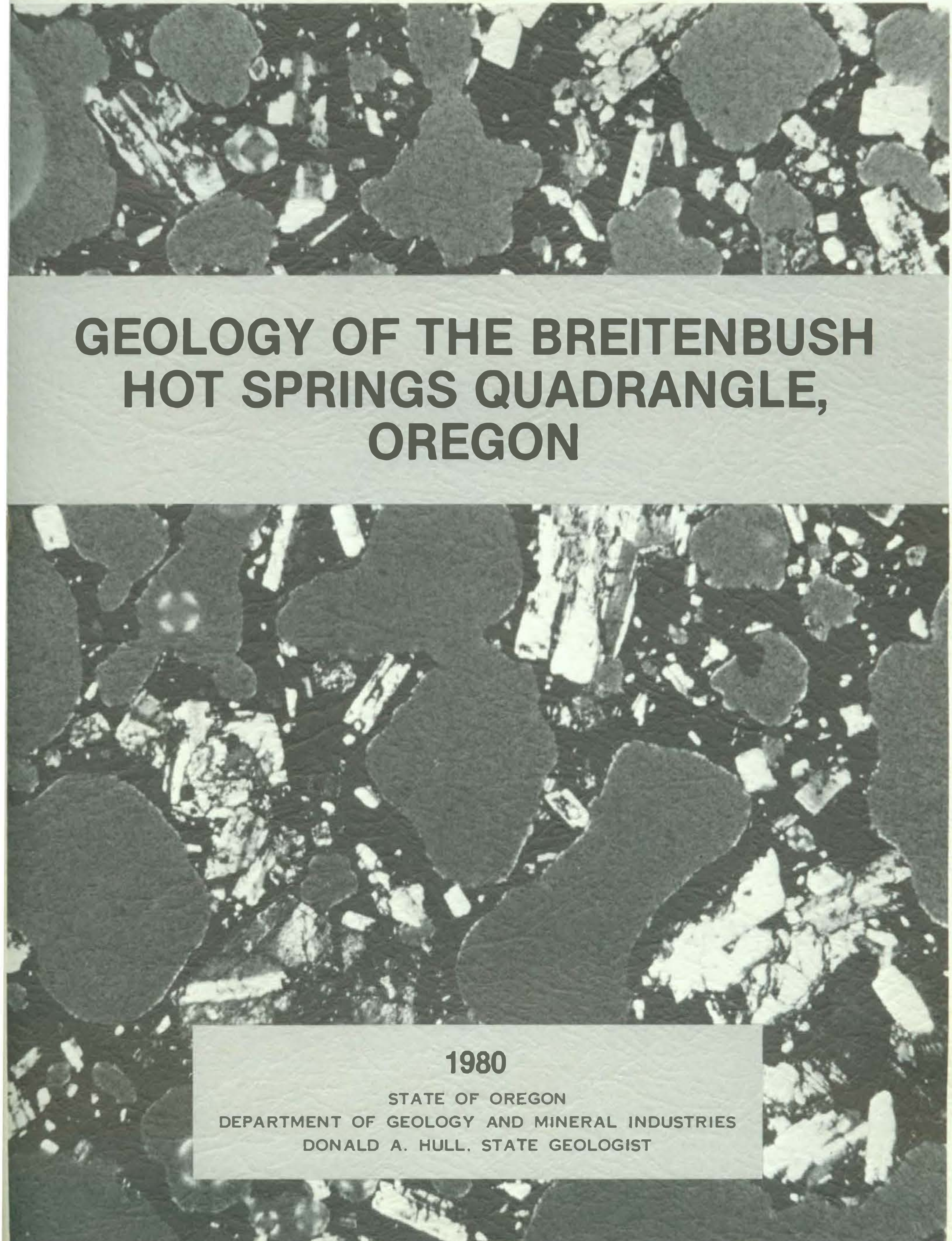

GEOLOGY OF THE BREITENBUSH HOT SPRINGS QUADRANGLE, OREGON

1980

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
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Special Paper 9

GEOLOGY OF THE BREITENBUSH HOT SPRINGS QUADRANGLE, OREGON

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1980

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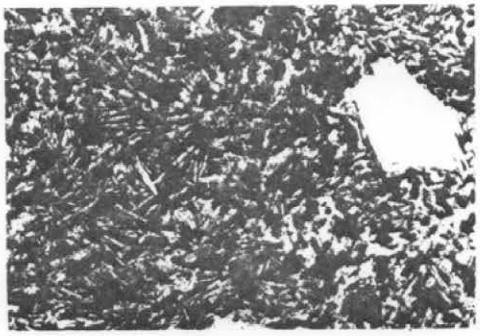
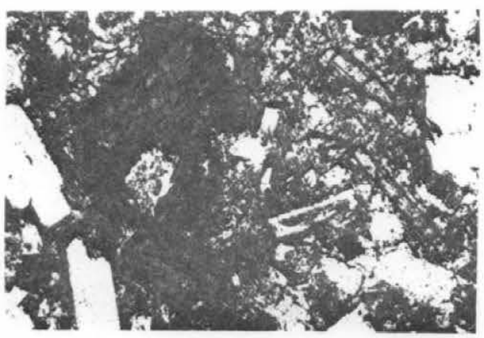
ERRATA SHEET: Photomicrographs on page 10 were reversed by printer and are printed in wrong order. This sheet shows correct placement of photos and captions.



a. Scorpion Mountain lava flow (CT-8); small plagioclase phenocryst in groundmass of plagioclase microlites, granular pyroxene, and opaque ore.

b. Elk Lake Formation, andesitic flow (CT-59); phenocrysts of plagioclase, hypersthene, and monoclinic pyroxene in a matrix of black glass and fine crystals



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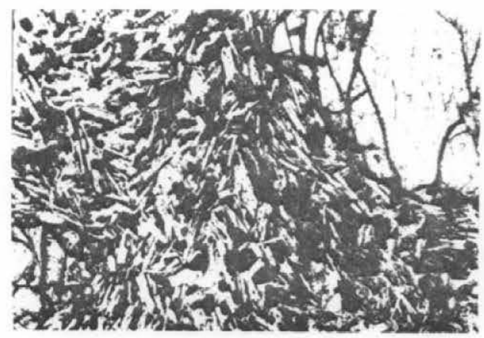
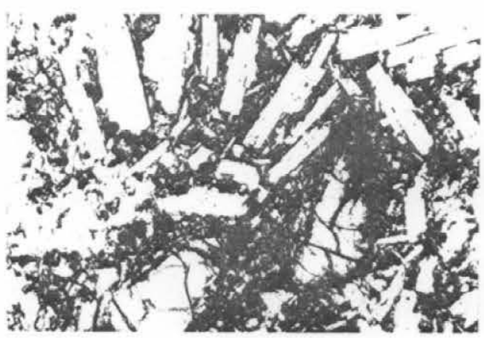


d. Outerson Formation, basaltic flow from the base of the formation; large olivine crystals in ophitic groundmass of olivine, plagioclase and optically continuous monoclinic pyroxene (CT-17).



e. Outerson Formation, basaltic andesite flow (CT-68); corroded olivine and small phenocrysts of plagioclase in groundmass of plagioclase, two pyroxenes, and ore.

f. High Cascade lava flow, middle Pleistocene basaltic andesite; small olivine phenocrysts in pilotaxitic groundmass of plagioclase and two pyroxenes (CT-51).

Figure 6. Photomicrographs of lavas from the Breitenbush Hot Springs quadrangle. All are at the same scale so that the height of each photo is equal to 1.6 mm.

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Photomicrograph of basaltic andesite bomb from the summit of Olallie Butte.

NOTICE

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GEOLOGY OF THE BREITENBUSH HOT SPRINGS QUADRANGLE, OREGON

INTRODUCTION

This report summarizes the results of a geological and geochemical study of the volcanic rocks in the Breitenbush Hot Springs 15-minute quadrangle. The map area is bounded by 44°45' and 45° N. latitudes and by 121°45' and 122° W. longitudes and is located wholly within the north-central part of the Oregon Cascade Range (Figure 1). It includes a part of the High Cascade platform north of Mt. Jefferson as well as the eastern edge of the Western Cascade Province. Rocks in this area range from late Oligocene to late Pleistocene in age and are almost entirely of volcanic origin.

The purpose of this study is to provide geological information that can be used in the evaluation of the Oregon Cascades as a potential geothermal resource. The Breitenbush Hot Springs area was selected because it includes the boundary between the Tertiary rocks of the Western Cascades and the Quaternary lavas of the High Cascade crest. The fact that the contact is marked by a line of hot springs along about 200 km of its length has led geologists to speculate that it may be the site of a major fault system. Allen (1966) suggested that this zone marks the western boundary of a north-south trending graben which has been filled by High Cascade lavas. A fault-controlled boundary for the eastern margin of this proposed structure has been identified by Taylor (1980), but faults along the western slope are obscured by vegetation and have been traced for no more than a few kilometers. In this terrain, the location and throw of major faults generally can be inferred only if stratigraphic relationships are well understood and large-scale displacements can be recognized. The stratigraphic data presented on the geologic map in Plate 1 and in the accompanying text provide new information on which to interpret structural relations in the Breitenbush Hot Springs quadrangle and in adjoining parts of the Cascade Range.

Field and Laboratory Procedures

Mapping was accomplished during the late summer and early autumn of 1979, and the preliminary map was revised and completed in June of the following year. Geological contacts are based primarily on the distribution of rock types exposed in road cuts along the extensive system of logging roads in the area. Large or critically located outcrops identified on aerial photographs were visited by foot.

Fifty-six samples were analyzed for major and selected trace elements on a Varian (AA-175 series) atomic absorption spectrometer. Ferrous iron analyses were made by titration, and the water contents of all samples were determined with a Du Pont electronic moisture analyzer. Analytical accuracy was checked by including two standard rocks with the analyzed specimens and by determining the major-element contents of four samples by both atomic absorption and X-ray fluorescence methods. The K/Ar ages of 11 whole-rock samples were determined in order to provide chronological control for stratigraphic and structural interpretations.

Acknowledgments

This project was carried out under a grant from the Oregon Department of Geology and Mineral Industries with funds provided in part by the United States Department of Energy. Gordon Goles and Alexander McBirney reviewed the text and contributed helpful suggestions. Julie White aided in preparation of the camera-ready copy.

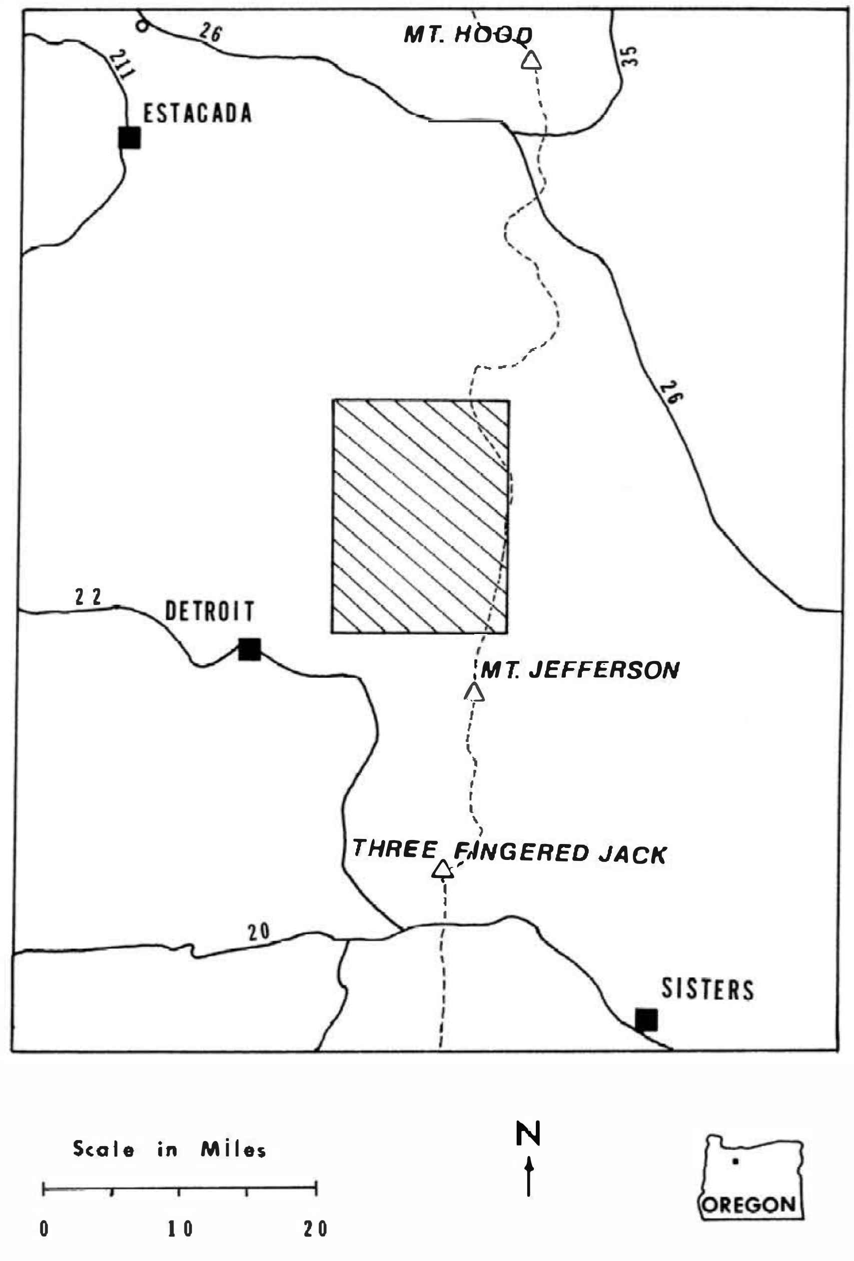


Figure 1. Index map showing the location of the Breitenbush Hot Springs quadrangle.

GENERAL STRATIGRAPHY OF THE NORTH-CENTRAL CASCADE RANGE IN OREGON

The Cascade Range in Oregon was divided by Callaghan (1933) into two major sequences on the basis of a marked structural and lithologic break. The Western Cascade Series consists of a structurally deformed and locally altered sequence of andesitic flows, andesitic to rhyodacitic pyroclastic rocks, and subordinate flows of basalt, dacite, and rhyolite. This sequence is overlain by the relatively undeformed and primarily basaltic lavas of the High Cascade Series.

Peck and his co-workers (1964) summarized previously published studies and their own reconnaissance mapping in a comprehensive report in which they subdivided the Western Cascade Series into three units: the Colestin Formation (late Eocene), the Little Butte Volcanic Series (Oligocene and early Miocene), and the Sardine Formation (middle and late Miocene). Field mapping and radiometric dating in recent years have shown that the stratigraphic relations in many areas of the Cascade Range do not readily conform to Peck's regional system. In this report I will follow a stratigraphic scheme based largely on the one suggested by McBirney and others (1974) for the north-central Cascades. The names and ages of units in this area are shown on the schematic column in Figure 2, along with the stratigraphic column of Peck and others (1964).

The revisions made by McBirney and his co-workers (1974) followed the recognition that radiometric ages of Western Cascade lavas erupted since middle Miocene time tend to cluster at intervals of roughly five million years. Additional ages of whole rocks from the north-central Cascades tend to confirm this trend (Figure 3). Because lavas of each age group represent a single widespread episode of volcanism, they have been assigned to four separate formations: the Sardine Formation (middle Miocene), the Elk Lake Formation (late Miocene), the Outerson Formation (Pliocene), and the High Cascade lavas (Quaternary). Radiometric ages of lavas erupted prior to middle Miocene time do not cluster at well-defined peaks; instead, the limited data indicate that volcanism was sporadically continuous throughout the interval between 19 and 30 m. y. Rocks erupted during this time have been subdivided into two interfingering units on the basis of their contrasting lithologic character.

Some specific features of the stratigraphy in the north-central Cascade Range are discussed below. Detailed lithologic and petrographic descriptions of many units are presented in previously published reports (Thayer, 1937, 1939; Peck and others, 1964), and for this reason the present discussion is confined primarily to new interpretations or recently acquired data.

Rocks of Late Oligocene and Early Miocene Age

The oldest rocks exposed in the north-central Cascades consist of pyroclastic flows, volcanic breccias, and basaltic to rhyodacitic lavas. Hammond (1979) applied the name "Breitenbush Formation" to these rocks where they crop out in the upper Breitenbush and Collawash river valleys. They are equivalent to the Breitenbush Tuff of Thayer (1939) and are similar in stratigraphic position and lithology to parts of the Little Butte Volcanic Series of Peck and others (1964). The age of the ignimbrites and breccias that comprise the lower part of the formation is not well known owing to the difficulty of determining radiometric ages for altered pyroclastic rocks; however, lavas overlying these units consistently yield K/Ar ages between 20 and 27 m. y.

Intercalated within the tuffs and tuffaceous sediments in the middle and upper parts of the Breitenbush Formation is a distinctive sequence of flows that I have informally named the Scorpion Mountain lavas. These rocks are exposed in the Calapooya, Middle Santiam, North Santiam, and upper Collawash drainage systems as well as in the

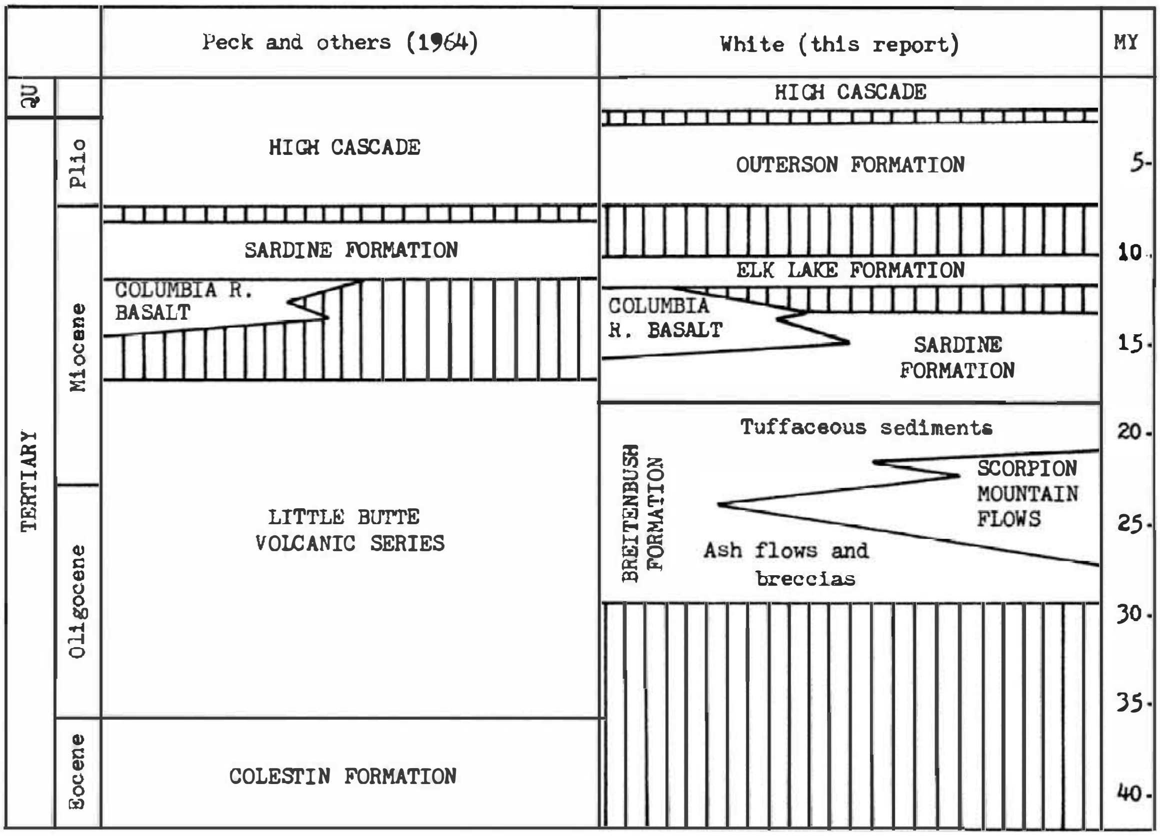


Figure 2. Correlation chart of formations in the north-central Cascade Range in Oregon

Western Cascade foothills near Eugene. They have been mistakenly identified as part of the Columbia River Group but yield late Oligocene and early Miocene K/Ar ages and were vented locally within the Western Cascade region. Lavas in this unit are invariably dark colored and generally appear aphanitic in hand specimen; despite their uniform appearance, however, they range in composition from basalt through dacite. In thin section, most samples contain a few phenocrysts of plagioclase and clinopyroxene, but only the most mafic specimens have modal olivine.

The Scorpion Mountain lavas have been shown to represent a geochemically distinct rock series that differs markedly from the calc-alkaline associations generally thought to be typical of Cascade lavas (White and McBirney, 1979). This trend can be clearly seen when analyses of lavas from the north-central Cascades are plotted on a ternary AFM diagram (Figure 4). The Scorpion Mountain lavas define a trend of iron-enrichment that is characteristic of the tholeiitic rock series, whereas middle and late Miocene lavas from the Sardine Formation display little or no iron enrichment. The dashed line in Figure 4 serves to separate the compositional fields of "classic" tholeiitic and calc-alkaline suites (Irvine and Baragar, 1971).

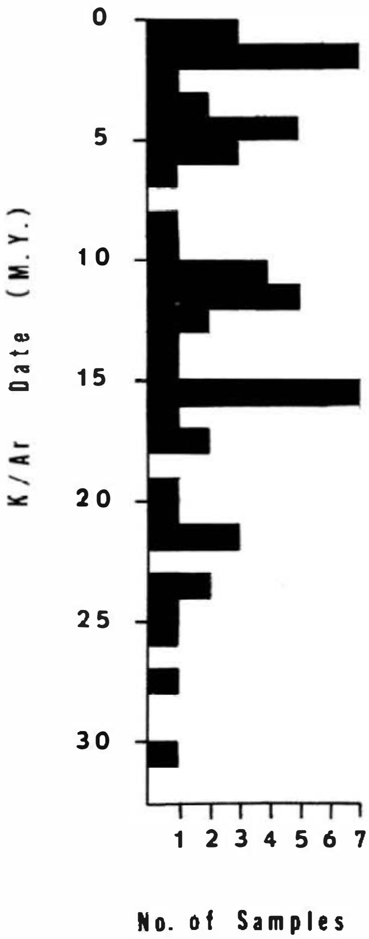


Figure 3. Histogram of K/Ar ages of volcanic rocks in the north-central Cascade Range in Oregon. Data are from Sutter (1978), Hammond and others (1980), and White (this report).

In addition to the contrasting trends in iron enrichment, the Scorpion Mountain lavas differ compositionally from younger Cascade lavas by having generally lower contents of MgO, CaO, Al_2O_3, Sr, Ni, and Cr, and higher contents of TiO_2, K_2O, Rb, Zr, Ba, and Sc. These differences are especially striking for rocks with compositions of basaltic andesite and andesite. Although several models have been proposed to explain geochemical differences between tholeiitic and calc-alkaline rock suites (e. g., Kuno, 1966; Ringwood, 1974), the contrasting trends observed in Cascade lavas can be explained best by a shift in the assemblage of early-stage phenocryst phases. The trends in the Scorpion Mountain lavas are consistent with early fractionation of olivine + plagioclase + Cr-rich spinel ± clinopyroxene, whereas the compositions of the younger calc-alkaline rocks indicate early removal of amphibole ± clinopyroxene ± olivine. The shift from an olivine-dominated fractionation scheme to one controlled by amphibole may indicate a change in the water content of the parental magmas or an increase in the depth of primary magma reservoirs, either of which could serve to stabilize amphibole in basaltic magmas.

Rocks of Middle and Late Miocene Age

Thayer (1937, 1939) first applied the name "Sardine lavas" to the flows and pyroclastic rocks of middle and late Miocene age that cap the ridges and peaks near an eroded vent complex at Sardine Mountain, northwest of Detroit. Peck and his co-workers (1964) re-defined the Sardine Formation to include all Western Cascade lavas that

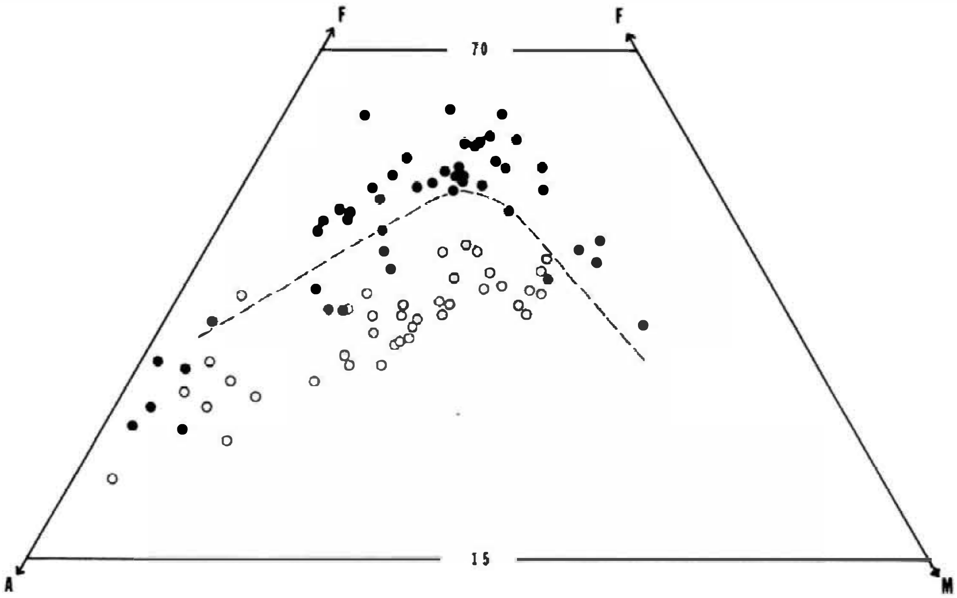


Figure 4. AFM {($Na_2O + K_2O$) : MgO : FeO(total)} relations for lavas of late Oligocene and Miocene age in the north-central Cascade Range in Oregon. Solid circles represent analyses of late Oligocene and early Miocene Scorpion Mountain lavas, open circles represent analyses of middle and late Miocene lavas of the Sardine and Elk Lake Formations. Data are from unpublished sources and are on computer file at the University of Oregon Center for Volcanology.

occupy a stratigraphic position between the dominantly pyroclastic rocks of the Little Butte Volcanic Series and the lava flows of the High Cascade Series. In the north-central Cascades, the Sardine Formation consists of andesitic flows and lahars interbedded with subordinate volumes of basalt and tuffaceous rocks. Most lavas in this unit are noticeably porphyritic and contain abundant phenocrysts of plagioclase. Olivine and clinopyroxene are common phases in Sardine basalts but give way to hypersthene as the most abundant mafic mineral in the andesitic and dacitic lavas. The textures and mineral contents of these rocks serve to distinguish them from the aphyric and hypersthene-free lavas of the Scorpion Mountain sequence.

McBirney and his co-workers (1974) divided the Sardine lavas into two formations. They retained the name "Sardine Formation" for the voluminous rocks of middle Miocene age, but recognized a less voluminous sequence of late Miocene lavas which they named the Elk Lake Formation. At its type locality about 10 km north of Detroit, the Elk Lake Formation consists of a sequence of rhyodacitic flows and tuffs and subordinate flows of hornblende andesite that unconformably overlies folded rocks of the Sardine and Breitenbush Formations. South and east of Detroit, rocks of Elk Lake age include dark-colored flows of olivine basalt. The Elk Lake Formation is probably equivalent to the pyroclastic rocks and andesitic flows of the Rhododendron Formation which overlie the Columbia River Basalt in the region west of Mt. Hood.

Rocks of Pliocene and Quaternary Age

The relatively unaltered basalts and basaltic andesites that unconformably overlie Miocene and Oligocene rocks of the Western Cascade Range were defined by Callaghan (1933) and later by Peck and others (1964) as the High Cascade Series. Thayer (1937, 1939) divided the High Cascade Series in the Mt. Jefferson area into three age groups: an older sequence of strongly faulted and dissected flows and breccias (Outerson lavas), an intermediate sequence of basaltic shield lavas (Minto and Battle Ax lavas), and a young series of flows and pyroclastic rocks that were erupted from the vents and cones that comprise the present-day High Cascade crest (Olallie lavas). New radiometric age determinations for rocks from the north-central Cascade Range indicate that post-Miocene volcanism in this region took place during two distinct episodes, one about four to six million years ago and a second beginning about two million years ago and continuing to the present time. McBirney and others (1974) assigned the lavas erupted during the earlier episode to the Outerson Formation and restricted the term "High Cascade" to lavas of Quaternary age.

Most lavas in the Outerson Formation were erupted from vents located along the eastern margin of the Western Cascades. They consist primarily of finely porphyritic olivine-bearing basaltic andesites which appear in marked contrast to the coarse-grained pyroxene andesites that comprise most of the lavas of the Elk Lake and Sardine Formations. Lavas with mildly alkaline geochemical affinities have been identified near the base of the Pliocene volcanic section at widely scattered localities in southern Oregon (Maynard, 1974), in the area west of Mt. Washington (McBirney, 1968), and in the Breitenbush Hot Springs quadrangle (this report). Naslund (1978) showed that these lavas are also enriched in TiO_2, P_2O_5, and Zr relative to younger Pliocene and Quaternary rocks, and he suggested that these compositionally distinctive lavas may form the base of the Pliocene-Pleistocene Cascade chain along much of its extent in Oregon.

The High Cascade lavas consist of basaltic to rhyodacitic flows and breccias that were erupted initially from broad shield volcanoes and later from small to large composite cones located primarily along the High Cascade crest. The early Pleistocene High Cascade lavas are not notably different in composition or appearance from the bulk of lavas in the Outerson Formation. They consist primarily of olivine-bearing basalts and basaltic andesites with intergranular or diktytaxitic textures. Taylor (1980) noted that diktytaxitic basalts in the central High Cascades are commonly overlain by late Pleistocene basaltic andesites with pilotaxitic textures. The many composite volcanoes that cap the High Cascade platform in north-central Oregon consist primarily of basaltic andesite and andesite, with subordinate volumes of basalt, dacite, and rhyodacite being important constituents in some cones. Most of the large volcanoes, such as Mt. Jefferson and Three Fingered Jack, were built during two or more discrete eruptive episodes, each of which produced a compositionally distinctive suite of lavas (Sutton, 1974; White, 1980; Davie, 1980).

DESCRIPTIONS OF UNITS IN THE BREITENBUSH HOT SPRINGS QUADRANGLE

The lithologic, petrographic, and geochemical characteristics of the various mapped units of Plate 1 are summarized below. Chemical analyses of selected samples are given in Appendix II. Rock names are based on silica content (H_2O free) according to the method used by Taylor (1978) for lavas in the SW Broken Top quadrangle. Subdivisions are made at five-percent increments of SiO_2 for basalt (48-52), basaltic andesite (53-57), andesite (58-62), dacite (63-67), and rhyodacite (68-72); the SiO_2 contents of all analyzed samples are plotted as histograms in Figure 5. Textural terms are based on the classification of Williams (1954).

Breitenbush Formation

Pyroclastic flows and volcanic breccias of the Breitenbush Formation crop out in the extreme western edge of the map area along valleys formed by the Breitenbush and Collawash Rivers. The volcanic sediments consist of massive, coarse-grained breccias of fluvial origin interbedded with thin units of volcanic sandstone and air-fall tuff. The pyroclastic flows contain abundant coarse fragments of pumice and lithic debris and are generally gray or pale green in color.

A particularly distinctive rhyodacitic ash flow is exposed along the Breitenbush River for about two km west of the Breitenbush Campground (secs. 19 and 20, T. 9 S., R. 7 E.). This unit consists of pumice, lithic fragments, and broken crystals of plagioclase and quartz in a matrix of glass shards and fine ash. Its characteristic pale-green color is caused by finely disseminated celadonite within the ashy portions of the matrix. Plagioclase from this ash flow has yielded K/Ar ages of less than 20 million years (Sutter, 1978; Hammond, 1979); however, these ages are almost certainly too young, because rocks exposed at stratigraphic levels above this unit yield whole-rock K/Ar ages as old as 24 million years (Sutter, 1978). Hammond (1979) also obtained a fission-track age of 27 million years for the ash flow, and this value is more consistent with the known ages of other rocks in the area.

Scorpion Mountain Lavas

Dark-colored aphanitic lavas cap Scorpion Mountain (sec. 5, T. 9 S., R. 7 E.) and crop out in isolated exposures on the steep slope north of Breitenbush Hot Springs and along the east side of the Collawash River valley. A possible vent area for some of these flows is indicated by the numerous dikes and bedded agglomerate exposed in road cuts at the 3600-ft level west of Mansfield Creek (sec. 9, T. 9 S., R. 7 E.). An exhumed volcanic neck that forms Eagle Rock, about five km west of Breitenbush Hot Springs, may also have been the source of some Scorpion Mountain lavas in the map area.

Rocks in this unit range in composition from basaltic andesite to dacite. Lava flows have pilotaxitic textures and contain sparsely distributed phenocrysts of plagioclase and serpentinized monoclinic pyroxene (Figure 6a). Groundmass minerals include plagioclase, opaque ore, and pyroxene, some of which has been tentatively identified as pigeonite on the basis of its very small optic angle.

Analyzed samples of Scorpion Mountain lava differ in chemical composition from most other Cascade lavas by having lower values of CaO, Al_2O_3, MgO, and Sr; higher values of TiO_2, Rb, and Ba; and greater iron enrichment. The tholeiitic affinity of these samples is demonstrated by Figure 7, in which the ratio FeO(total)/FeO(total) + MgO is plotted versus SiO_2. The Scorpion Mountain lavas plot well within the tholeiitic field, as defined by Miyashiro (1974), whereas most samples from younger units plot close to or within the calc-alkaline field.

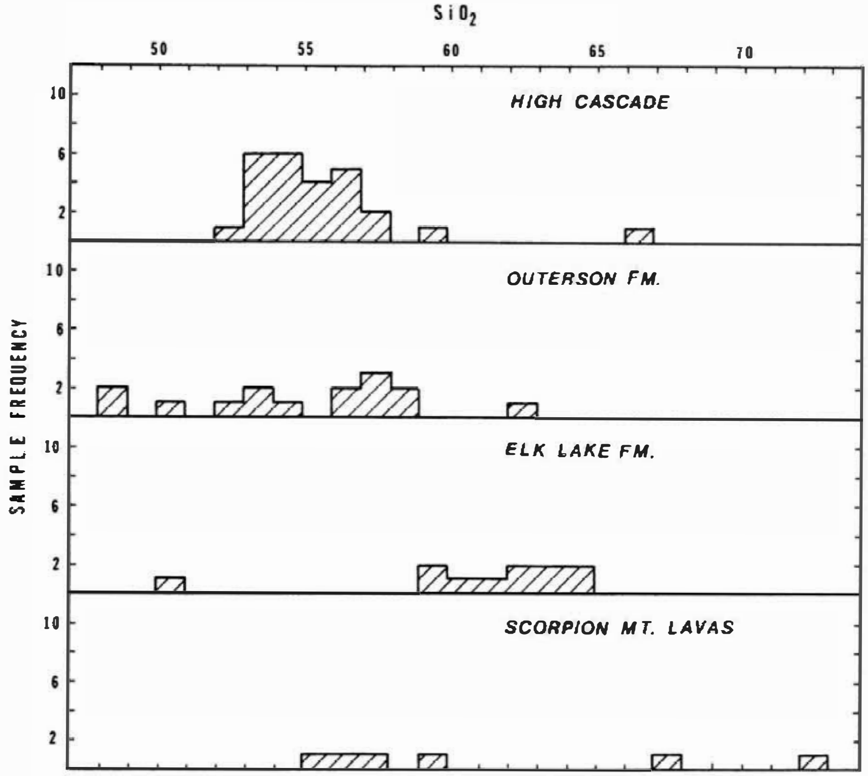


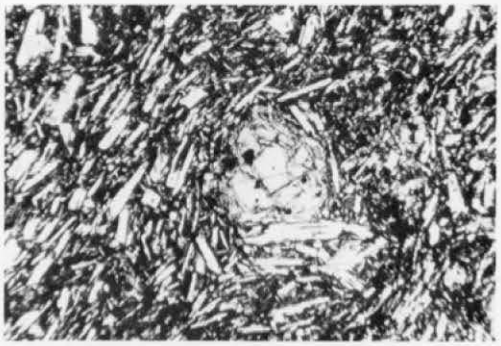
Figure 5. Histograms of SiO_2 content of samples from the Breitenbush Hot Springs quadrangle.

Scorpion Mountain lavas within the map area are similar in composition and stratigraphic position to other Cascade tholeiites that have yielded late Oligocene or early Miocene radiometric ages. A flow from near the top of the Scorpion Mountain section in the map area yielded a whole-rock K/Ar age of 19.4 million years (Appendix I).

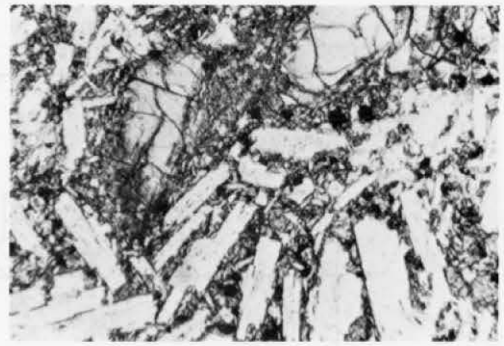
Elk Lake Formation

Flows and pyroclastic rocks of the Elk Lake Formation crop out at numerous locations in the northern, western, and southern parts of the map area, where they overlie rocks of the Breitenbush Formation with pronounced angular unconformity. The apparent absence of the Sardine Formation in this part of the Western Cascades indicates that the map area may have been a highland in middle Miocene time or may have suffered extensive erosion immediately prior to the deposition of Elk Lake lavas. Although basaltic lavas and pyroclastic rocks comprise most of the Elk Lake section in the southwestern part of the quadrangle, the majority of the formation in the western and northern portions of the map area consists of coarsely porphyritic andesitic flows and dacitic tuffs. A complex of small intrusions, lahars, agglomerate, and bedded lapilli forms the rugged terrain near Granite Peaks and was most likely the site of one or more late Miocene eruptive centers.

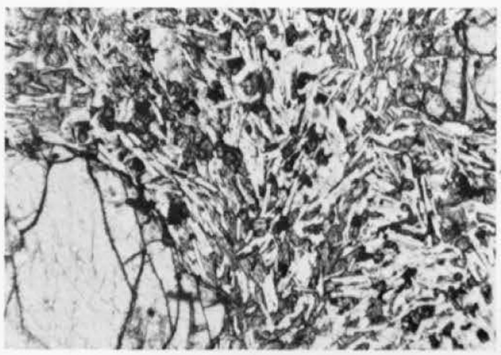
In thin section, basalts from this unit contain abundant phenocrysts of olivine and subordinate amounts of plagioclase and clinopyroxene. The mafic minerals are commonly altered to iddingsite or serpentine, giving the rocks a dark-green color and making them appear older and more weathered than less basic lavas of comparable age. The andesites are coarsely phyric and contain large phenocrysts of plagioclase and hypersthene and



a. Scorpion Mountain lava flow (CT-8); small plagioclase phenocryst in groundmass of plagioclase microlites, granular pyroxene, and opaque ore.



b. Elk Lake Formation, andesitic flow (CT-59); phenocrysts of plagioclase, hypersthene, and monoclinic pyroxene in a matrix of black glass and fine crystals.



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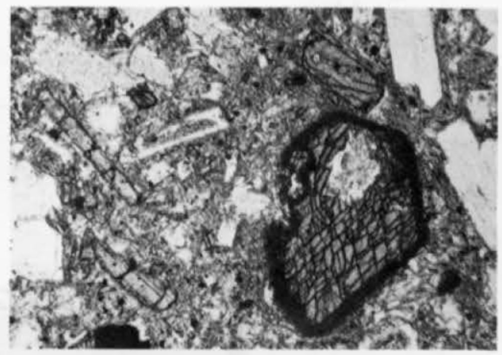
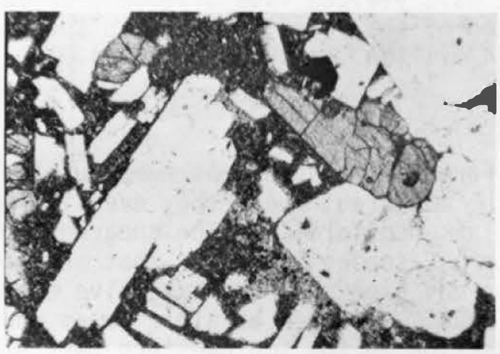


d. Outerson Formation, basaltic flow from the base of the formation; large olivine crystals in ophitic groundmass of olivine, plagioclase and optically continuous monoclinic pyroxene (CT-17).



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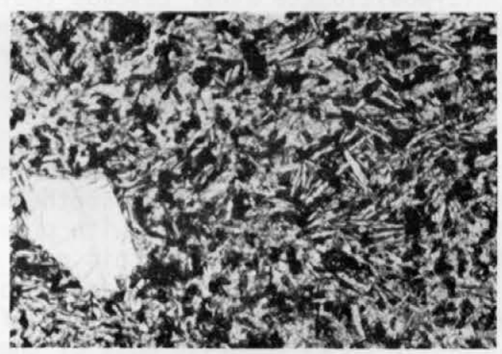


f. High Cascade lava flow, middle Pleistocene basaltic andesite; small olivine phenocrysts in pilotaxitic groundmass of plagioclase and two pyroxenes (CT-51).

Figure 6. Photomicrographs of lavas from the Breitenbush Hot Springs quadrangle. All are at the same scale so that the height of each photo is equal to 1.6 mm.

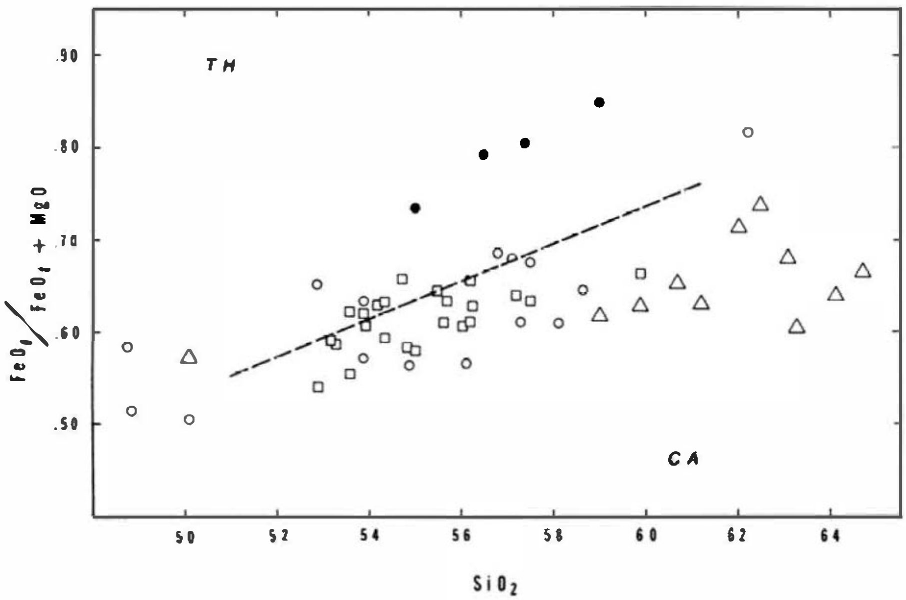


Figure 7. A plot of SiO_2 versus the ratio FeO(total)/FeO(total) + MgO for samples from the Breitenbush Hot Springs quadrangle. Analyses of Scorpion Mountain lavas are indicated by filled circles, Elk Lake Formation by triangles, Outerson Formation by open circles, and High Cascade lavas by squares. Dashed line separates field of tholeiitic compositions (TH) from calc-alkaline compositions (CA), after Miyashiro (1974).

subordinate amounts of clinopyroxene ± hornblende in a pilotaxitic groundmass of plagioclase microlites, two pyroxenes, and opaque ore (Figure 6b). Hornblende is commonly rimmed with a fine-grained mixture of pyroxene and ore minerals and may be completely altered to this material in some samples. In the dacitic dikes and small stocks of the Granite Peaks complex, hornblende is the most abundant mafic phenocryst and commonly forms crystals up to half a centimeter long (Figure 6c).

K/Ar ages were obtained for a porphyritic Elk Lake flow near the contact with the Breitenbush Formation and for a hornblende dacite dike that intrudes porphyritic lavas at the northern end of the Granite Peaks complex. These rocks yielded ages of 11.8 and 9.8 million years, respectively (Appendix I). Although the basaltic flows in the southwestern part of the map area were not dated for the present study, a basaltic sill that crops out along Devils Creek just south of the map area was dated by Sutter (1978) at 11.2 million years.

Outerson Formation

Dark-gray to light-gray basalts and basaltic andesites of the Outerson Formation cap Rhododendron Ridge and comprise most of the exposures in the north-central parts of the map area. Vents for these rocks have not been identified within the Breitenbush Hot Springs quadrangle; however, some lavas undoubtedly flowed northward from the large Pliocene shield volcano that was active in the vicinity of Outerson Mountain, about five km southeast of the hot springs. Other lavas may have come from vents to the east which have since been buried beneath the present High Cascades.

Although most lavas in the Outerson Formation are basaltic andesites, an unusual sequence of basaltic flows and breccias crops out at the base of the formation in areas

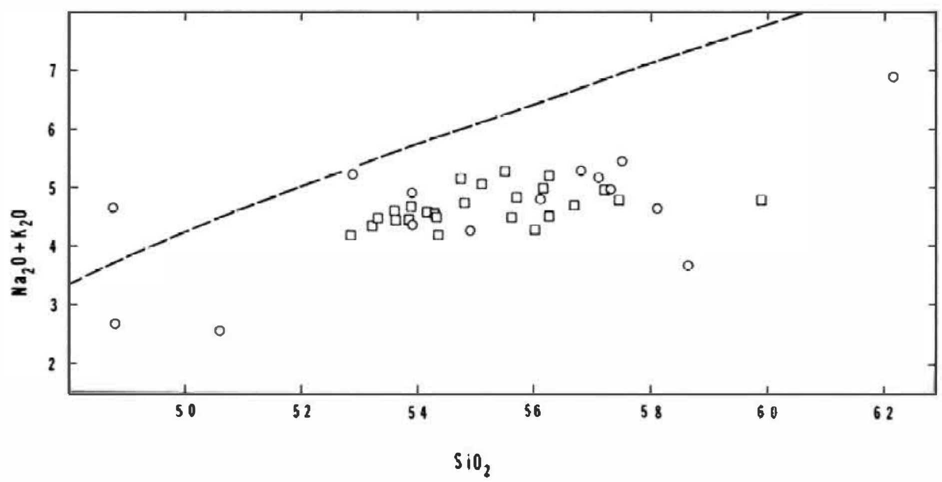


Figure 8. A plot of SiO_2 versus total alkali contents for samples of Pliocene and Quaternary age from the Breitenbush Hot Springs quadrangle. Analyses of Pliocene samples are indicated by open circles, analyses of Quaternary lavas by squares. The dashed line separates field of alkaline compositions (ALK) from subalkaline compositions (SUBALK), after Irvine and Baragar (1971).

north and south of Collawash Mountain (sec. 10, T. 9 S., R. 7 E.; secs. 33 and 34, T. 8 S., R. 7 E.). These rocks contain abundant phenocrysts of olivine and display distinctive groundmass textures in which small laths of plagioclase, granular olivine, and opaque ore are enclosed in optically continuous plates of clinopyroxene (Figure 6d). Basaltic andesites are also olivine phyric, but groundmass olivine is replaced by orthopyroxene, and the textures are commonly intergranular rather than ophitic (Figure 6e). The relatively rare andesitic lavas contain phenocrysts of plagioclase and clinopyroxene, although even at these compositions, olivine may persist as corroded relicts surrounded and embayed by orthopyroxene.

Chemical analyses of lavas from the Outerson Formation reveal that several flows display the alkaline geochemical affinity noted by Naslund (1978) for lower Pliocene lavas elsewhere in the Oregon Cascade Range. This feature can be seen in Figure 8, in which the total alkali contents of all Pliocene and Quaternary samples from the map area are plotted versus SiO_2. Two samples from the Outerson Formation display alkaline affinities, one of which plots well within the alkaline geochemical field as defined by Irvine and Baragar (1971) and is, in fact, nepheline normative. Both samples with alkaline affinities are from flows that immediately overlie pre-Pliocene rocks. In addition to their greater abundances of K_2O and Na_2O, these lavas also display higher values of TiO_2, P_2O_5, and Ba than do other Pliocene-Pleistocene lavas with similar SiO_2 contents.

Six radiometric dates have been obtained for Outerson Formation lavas in the map area, three of which were made for the present study. The ages cover a relatively narrow range from 6.1 to 3.6 million years, even though an attempt was made to sample all parts of the formation including flows just above the contact with Miocene rocks and those immediately below High Cascade lavas.

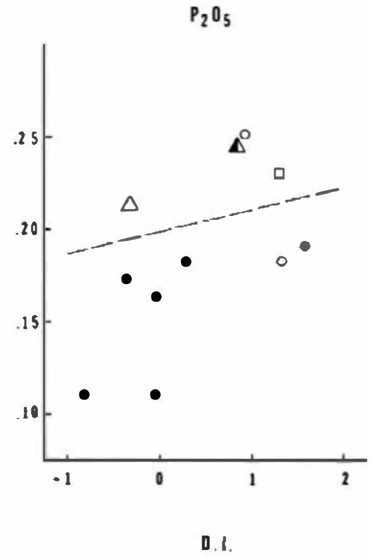
High Cascade Lavas

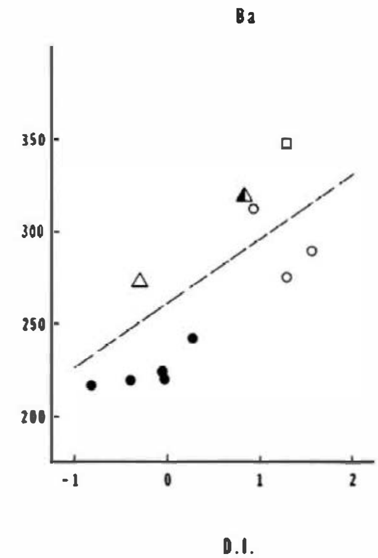
Early High Cascade lavas overlap Pliocene and Miocene rocks in the basin east of Hawk Mountain and along the Clackamas River in the northern part of the map area. They yield K/Ar ages of one to two million years and include both normally and reversely polarized flows. These lavas are in turn overlain in the southeastern and east-central parts of the quadrangle by the young flows and cones that comprise the High Cascade platform. The topography in this area is dominated by the relatively uneroded composite cones of Olallie Butte, Sisi Butte, and the Pinhead Buttes, although many smaller cones can also be identified on the high plateau south and west of Olallie Lake. Because no lavas having reversed remanent magnetism have been found on the Olallie Lake plateau or on any of the large cones, it is likely that they were erupted during the present magnetic period and are therefore less than 660,000 years old.

The early Pleistocene High Cascade flows are dominantly composed of olivine-phyric basaltic andesites with intergranular or diktytaxitic textures. These lavas are overlain by slightly more siliceous basaltic andesites, many of which have pilotaxitic textures (Figure 6f). The late Pleistocene lavas that make up the large cones or are associated with the small vents on the plateau of Olallie Lake range in composition from basaltic andesite to dacite and are generally more porphyritic than the older High Cascade lavas. Samples from Olallie and Sisi Buttes contain abundant phenocrysts of plagioclase up to three millimeters in length. Mafic phenocrysts in these rocks include clinopyroxene, corroded and jacketed olivine, and small crystals of orthopyroxene. Small plugs of microdiorite with hypidiomorphic-granular textures are exposed at the summits of these volcanoes.

Andesitic and dacitic lavas were erupted from a northwest-trending line of vents that includes Campbell Butte, Pyramid Butte, and Double Peaks. The most extensive of these lavas forms a flat-topped ridge that extends for about three km northeast of Breitenbush Lake and can be traced back to a complex of dikes and small intrusions on the rounded knob between Ruddy Hill and Campbell Butte. In thin section, these lavas consist of plagioclase, orthopyroxene, amphibole, and minor amounts of clinopyroxene in an intergranular groundmass of plagioclase, pyroxene, and opaque ore. Some specimens have small crystals of olivine preserved within glomerocrysts of plagioclase and pyroxene.

Flows, plugs, and bombs from the various cones and vents of late Pleistocene age were chemically analyzed in order to assess the compositional variations within a single volcano and between volcanoes of similar age. Analyses of five samples from the summit and flanks of Olallie Butte indicate that this volcano is composed of a single geochemically related suite of lavas, in contrast to the two or more suites commonly found in the larger Cascade cones. When lavas from different vents are compared, at least two suites can be distinguished on the basis of their trace- and minor-element contents (Figure 9). All of the samples from Olallie Butte and two of the three samples from Sisi Butte have lower contents of Ba and P_2O_5, and higher ratios of K/Ba than other young lavas at similar stages of differentiation. The K/Ba ratio may be particularly significant. Because it should not be affected by fractionation of phenocryst phases found in these lavas, it may reflect compositional differences between "primitive" batches of magma. Although additional sampling and more complete analyses would be necessary for a thorough petrogenetic study, the available data indicate that the small and intermediate-size cones of the Olallie Lake area, if taken together, have geochemical trends similar to those seen in large, multigenetic volcanoes.





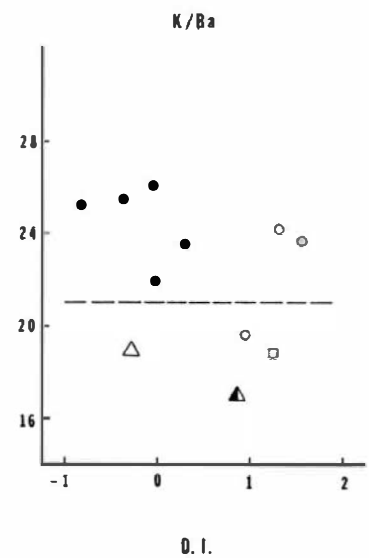


Figure 9. *Plots of P_2O_5 (wt. percent), Ba (ppm), and the ratio K/Ba versus a modified Larsen differentiation index of (1/3 Si + K - Ca - Mg) for samples from cones and vents along the High Cascade crest in the Breitenbush Hot Springs quadrangle. Filled circles indicate analyses of samples from Olallie Butte, open circles from Sisi Butte, half-filled triangle from Potatoe Butte, open triangle from Twin Peaks, square from West Pinhead Butte. Dashed lines separate geochemically distinctive suites.*

DESCRIPTIONS OF STRUCTURES IN THE BREITENBUSH HOT SPRINGS QUADRANGLE

Rocks in the map area were folded and faulted during at least three principal episodes of tectonism: a middle or late Miocene episode that produced northeast-trending folds and faults, a late Pliocene and Quaternary episode of north-south faulting, and a Pliocene and Quaternary episode that produced northwest-trending faults. The northeast-trending structures can be seen best in the bedded pyroclastic and epiclastic rocks of the Breitenbush Formation. These rocks are asymmetrically folded into a broad upwarp that extends into the western edge of the map area, where it is unconformably overlain by lavas of late Miocene and Pliocene age. Dips on the northwestern limb of this structure reach 30° in the west-central part of the map area and as much as 60° in exposures near Detroit. Although lavas of the late Miocene Elk Lake Formation are not folded, they are cut by northeast-trending faults that strike in approximately the same direction as the major fold axis.

A second prominent structural trend is defined by several en echelon normal faults that strike in a north-northwesterly to northerly direction and are downthrown to the east. These faults juxtapose rocks of Miocene age against Pliocene lavas of the Outerson Formation at locations in the southwestern and northwestern parts of the map area. An additional north-trending fault probably runs through the south-central part of the quadrangle, where Pleistocene rocks along the North Fork of the Breitenbush River appear to have been displaced downward relative to the Pliocene lavas that cap Bald Butte and Breitenbush Mountain. This inferred structure is also coincident with the prominent north-south lineament formed by the Clackamas River and Cub Creek in the northern and central parts of the map area. The cumulative displacement across these faults is greatest in the southern half of the quadrangle, where a throw of at least 750 m (~2,500 feet) is indicated by the stratigraphic offsets.

A third and probably very young structural trend is indicated by the strong northwesterly alignment of creeks in most parts of the map area. Northwest-trending faults can be identified in isolated outcrops where slickensides indicate small strike-slip or oblique-slip movements. The most prominent northwest-trending structure is one indicated by the alignment of small streams and springs in the central part of the quadrangle and by fault surfaces and northwest-trending dikes located in scattered outcrops along this trend. The stratigraphic offset of Miocene and Pliocene rocks across this zone is consistent with downward displacement of the northeastern side, probably combined with a component of right-lateral movement. Pleistocene lavas have not been vertically offset by this fault but may have suffered some degree of lateral displacement.

The structural grain in the Breitenbush Hot Springs area can be seen in Figure 10, in which lineaments drawn from high-altitude infrared photographs are presented along with the locations of springs and young volcanic vents. The major lineament trends generally correspond with the structural features observed on the ground; northeasterly trends are confined to the western part of the map area where rocks of Miocene and late Oligocene age are exposed, whereas northerly and northwesterly trends are most prominent in the eastern and central areas where older rocks are covered by lavas of Pliocene and Quaternary age. North- and northwest-trending lineaments are also defined by the alignments of springs in the central part of the map area and by the locations of cones and small vents along the High Cascade crest.

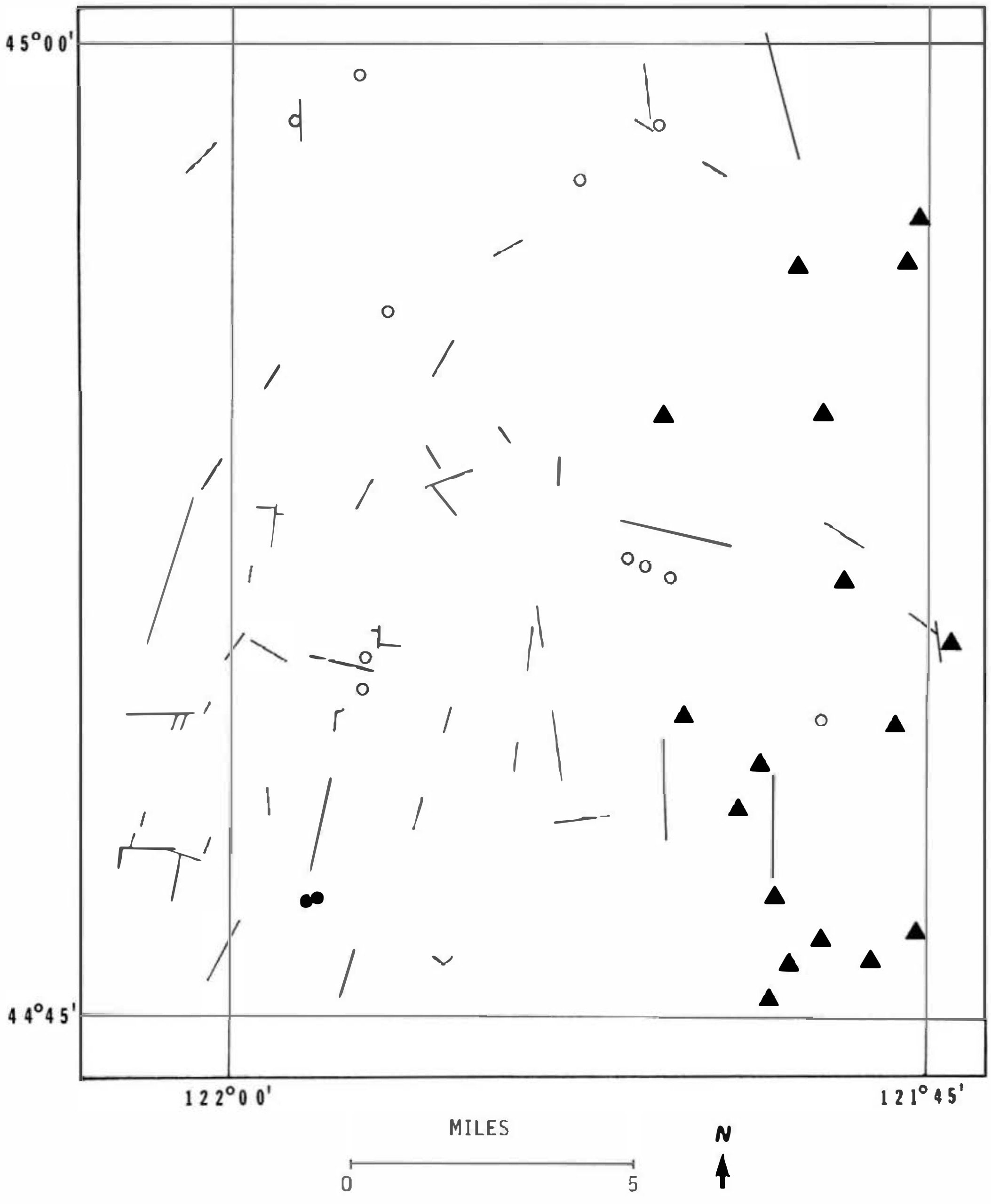


Figure 10. Lineament map drawn from high-altitude infrared photographs of the Breitenbush Hot Springs quadrangle. Also shown are the locations of young volcanic vents (triangles), hot springs (filled circles), and cold springs (open circles).

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APPENDIX I

K/Ar AGES OF SAMPLES FROM THE BREITENBUSH HOT SPRINGS QUADRANGLE

Newly Acquired Ages (this report)

	Analysis No. (Appendix II)	Field No.	%K	$\%Ar^{40}_{rad}$	Age (M. Y.)
1.	52	CT-51	0.63	10	1.02 ± 0.14
2.	46	CT-32	1.00	20	1.07 ± 0.08
3.	42	CT-75	0.70	11	1.49 ± 0.09*
4.	40	CT-52	0.86	18	1.62 ± 0.14
5.	43	CT-22	0.64	10	1.97 ± 0.27
6.	32	CT-41	2.17	41	4.04 ± 0.17
7.	22	CT-68	0.78	42	4.74 ± 0.19
8.	18	CT-17	0.44	29	6.05 ± 0.31
9.	16	CT-64	0.897	34	9.83 ± 0.46
10.	9	CT-59	1.25	66	11.8 ± 0.4
11.	5	CT-14	2.08	22	19.4 ± 0.4*
-	2	CT- 8	1.291	88	25.5 ± 0.8**
-	29	CT-62	1.063	11	1.59 ± 0.21**

Note: Ages followed by (*) were determined at the K/Ar laboratory at Oregon State University; all others were determined at the Department of Geology and Geophysics, University of Utah.
Addendum: Ages followed by (**) were received after this report was prepared.

Previously Published Ages

	Field No.	Rock Type	Source	Age (M. Y.)
12.	DMS-47	Basaltic andesite (wr)	Sutter (1978)	3.60 ± 0.05
13.	PH 1D	Tephra (plag)	Hammond and others (1980)	4.20 ± 0.30
14.	DMS-48	Basaltic andesite (wr)	Sutter (1978)	4.72 ± 0.19
15.	DMS-43	Ash flow (plag)	Sutter (1978)	19.7 ± 0.2
16.	PEH-77-8	Ash flow (plag)	Hammond and others (1980)	23.2 ± 0.8 24.3 ± 1.1

Note: (wr) indicates whole-rock age, (plag) indicates dated plagioclase separate.

APPENDIX II

CHEMICAL ANALYSES OF SAMPLES FROM THE BREITENBUSH HOT SPRINGS QUADRANGLE

	BREITENBUSH FORMATION	SCORPION MOUNTAIN LAVAS					ELK LAKE FORMATION		
	1	2	3	4	5	6	7	8	9
SiO_2	65.91	53.16	55.20	56.25	55.20	63.46	48.64	58.00	58.80
TiO_2	.40	1.87	1.26	1.29	1.27	.56	1.17	.93	.92
Al_2O_3	12.70	15.36	16.52	16.74	15.24	13.57	16.34	17.52	17.29
Fe_2O_3	3.35	3.40	3.83	4.85	4.03	2.34	8.19	3.41	3.52
FeO	nd	6.72	6.24	3.95	4.34	3.32	1.39	2.47	2.59
MnO	.08	.16	.19	.13	.19	.13	.13	.10	.09
MgO	.37	3.57	2.54	1.99	1.42	.79	6.54	3.44	3.41
CaO	2.96	7.25	5.87	6.79	5.45	3.19	9.45	7.08	6.08
Na_2O	3.00	3.26	4.23	3.76	3.46	3.61	3.41	4.02	3.97
K_2O	2.03	1.56	1.34	1.84	2.49	2.97	1.32	1.15	1.29
P_2O_5	.06	.32	.48	.37	.45	.10	.42	.13	.17
H_2O	8.46	1.66	1.74	2.14	5.50	5.27	2.40	1.46	1.44
Total	99.32	98.29	99.44	100.10	99.04	99.31	99.40	99.71	99.56
Ba	nd	486	467	637	830	951	690	280	305
Rb	72	52	34	57	75	93	15	27	30
Sr	152	324	409	365	336	231	1222	483	548
Cr	nd	6	tr	tr	tr	tr	258	65	34
Ni	nd	77	33	6	6	tr	123	43	33

	ELK LAKE FORMATION							
	10	11	12	13	14	15	16	17
SiO_2	59.20	60.50	61.15	61.54	61.72	62.88	63.27	63.69
TiO_2	.83	.88	.90	.61	.76	.73	.65	.65
Al_2O_3	17.68	16.84	16.93	17.52	16.13	16.74	16.74	15.84
Fe_2O_3	2.41	2.33	3.52	3.28	2.90	2.35	1.41	2.19
FeO	3.16	3.56	2.40	2.37	2.63	2.50	3.11	2.74
MnO	.10	.09	.07	.11	.08	.07	.07	.09
MgO	2.85	3.31	2.23	1.89	2.47	3.01	2.46	2.36
CaO	6.61	6.47	5.84	5.40	5.49	5.76	5.44	5.24
Na_2O	3.46	3.64	4.07	4.41	3.96	3.95	4.34	4.12
K_2O	1.07	1.16	1.37	1.08	1.53	1.31	1.08	1.42
P_2O_5	.13	.11	.11	.14	.17	.09	.11	.13
H_2O	1.67	.76	1.54	1.84	1.39	1.14	.75	1.18
Total	99.17	99.73	100.13	100.19	99.23	100.53	99.43	99.65
Ba	256	242	289	284	333	271	198	345
Rb	20	24	31	26	37	32	16	31
Sr	501	494	437	431	452	768	911	339
Cr	29	17	20	14	54	16	15	31
Ni	31	25	18	12	44	33	38	15

	OUTERSON FORMATION								
	18	19	20	21	22	23	24	25	26
SiO_2	47.73	47.99	48.70	52.08	53.16	53.16	54.05	56.40	55.60
TiO_2	1.43	.94	.76	1.40	1.19	1.29	1.07	1.09	1.34
Al_2O_3	16.34	16.57	15.47	17.28	17.57	16.62	16.59	17.34	16.82
Fe_2O_3	3.99	3.32	3.25	5.84	3.52	3.40	2.43	2.31	3.78
FeO	6.94	6.12	5.74	3.23	4.29	5.54	5.31	4.91	4.26
MnO	.16	.17	.15	.13	.12	.15	.14	.12	.10
MgO	7.46	8.55	8.49	4.52	5.59	5.02	5.83	5.40	3.47
CaO	9.05	11.82	11.12	8.21	8.45	8.00	8.54	7.83	7.09
Na_2O	3.61	2.60	2.41	3.81	3.53	3.86	3.34	4.08	3.84
K_2O	.93	.05	.03	1.29	.83	.99	.86	.76	1.34
P_2O_5	.26	.10	.09	.59	.38	.57	.28	.27	.21
H_2O	1.14	1.15	3.20	1.33	.93	.56	.67	.16	1.72
Total	99.04	99.33	99.41	99.71	99.56	99.16	99.11	100.67	99.57
Ba	245	75	134	1131	398	436	340	303	356
Rb	7	4	3	10	13	14	12	11	36
Sr	430	249	217	1151	1176	847	774	950	739
Cr	189	268	303	43	114	94	112	102	68
Ni	141	137	145	46	83	77	87	102	35

	OUTERSON FORMATION					
	27	28	29	30	31	32
SiO_2	57.29	56.80	56.60	57.08	57.50	62.31
TiO_2	1.16	1.09	1.20	.75	1.02	1.25
Al_2O_3	17.29	16.93	17.55	16.89	17.69	15.50
Fe_2O_3	2.61	2.05	2.29	3.16	3.14	3.57
FeO	5.38	5.14	4.87	4.00	4.02	4.05
MnO	.12	.12	.10	.10	.11	.11
CaO	7.21	7.34	6.75	7.21	7.02	4.56
Na_2O	3.95	4.06	4.11	3.52	3.13	4.37
K_2O	1.27	.89	1.25	1.06	.48	2.53
P_2O_5	.37	.28	.27	.12	.16	.34
H_2O	.39	.28	.60	1.03	1.34	1.00
Total	100.58	99.40	99.04	99.28	99.38	101.22
Ba	468	348	391	286	282	636
Rb	24	13	17	19	15	61
Sr	456	617	747	612	831	340
Cr	10	100	25	281	51	tr
Ni	48	51	35	81	51	7

APPENDIX II (continued)

	HIGH CASCADE								
	33	34	35	36	37	38	39	40	41
SiO_2	51.96	52.39	53.70	53.04	53.70	53.04	52.08	53.33	53.04
TiO_2	.91	1.10	1.08	.89	.99	1.10	1.01	1.27	.89
Al_2O_3	17.63	18.56	18.81	18.53	18.99	19.09	18.54	16.97	18.87
Fe_2O_3	3.66	1.59	2.43	3.27	2.34	3.86	3.88	3.01	2.77
FeO	4.79	6.14	5.34	4.45	5.42	3.23	4.10	5.21	5.15
MnO	.12	.12	.12	.11	.11	.10	.11	.14	.11
CaO	8.00	8.88	8.40	8.88	8.73	8.89	8.05	8.45	8.77
Na_2O	3.47	3.66	3.88	3.77	4.00	3.52	3.65	3.65	3.82
K_2O	.67	.65	.68	.66	.70	.57	.75	.93	.61
P_2O_5	.21	.11	.18	.17	.11	.16	.21	.26	.21
H_2O	1.44	.94	.73	.75	.16	2.21	2.04	.73	.56
Total	99.73	99.36	99.73	99.23	99.80	99.79	99.73	100.24	99.43
Ba	303	217	242	219	224	222	314	380	271
Rb	8	7	8	7	9	10	10	9	7
Sr	620	723	720	736	1071	791	657	798	720
Cr	264	49	26	45	44	56	113	149	74
Ni	191	37	26	28	23	33	116	130	75

	HIGH CASCADE								
	42	43	44	45	46	47	48	49	50
SiO_2	53.75	53.54	53.70	53.52	54.58	54.90	55.20	55.60	55.00
TiO_2	1.20	.86	1.25	1.29	1.19	1.19	.88	1.11	1.06
Al_2O_3	17.40	17.90	17.91	16.44	17.80	17.17	17.94	18.07	17.13
Fe_2O_3	3.17	2.84	2.74	2.91	4.00	2.93	1.58	3.44	6.96
FeO	5.62	4.79	5.72	5.32	3.18	5.11	6.12	4.50	1.10
MnO	.14	.12	.13	.14	.10	.14	.12	.12	.13
MgO	4.80	5.04	4.23	5.65	4.92	4.27	4.86	4.38	4.73
CaO	7.91	8.69	6.87	7.32	8.07	7.51	7.90	7.56	7.56
Na_2O	3.70	3.77	4.00	3.93	3.85	4.09	3.80	4.05	3.56
K_2O	.90	.70	1.06	.73	1.17	1.14	.70	.78	.64
P_2O_5	.46	.24	.47	.36	.26	.43	.19	.23	.24
H_2O	1.12	.96	1.39	.98	.32	.44	.63	.70	1.03
Total	100.17	99.45	99.47	98.59	99.44	99.32	99.92	100.54	99.14
Ba	369	316	421	268	538	416	297	345	319
Rb	14	11	14	9	9	14	9	10	10
Sr	675	659	550	545	1461	758	944	625	751
Cr	75	128	73	188	103	78	53	38	67
Ni	66	84	58	159	88	71	83	69	72

APPENDIX II (continued)

	HIGH CASCADE							
	51	52	53	54	55	56	57	58
SiO_2	56.00	55.30	55.60	56.48	57.00	57.09	60.00	66.93
TiO_2	1.15	.97	1.11	.81	1.09	.94	.82	.56
Al_2O_3	17.23	17.81	18.06	18.05	17.97	17.34	18.26	16.32
Fe_2O_3	2.68	2.11	2.91	3.40	2.22	2.52	3.53	3.22
FeO	5.68	5.31	3.89	3.32	4.36	4.70	2.97	.76
MnO	.13	.12	.10	.11	.10	.12	.10	.09
MgO	4.19	4.55	3.85	3.93	3.57	4.04	3.12	1.39
CaO	7.17	7.48	7.96	8.51	8.17	7.65	6.51	3.73
Na_2O	3.98	3.78	4.37	3.96	4.14	3.84	3.88	4.59
K_2O	1.07	.66	.79	.73	.82	.91	.96	1.74
P_2O_5	.44	.25	.18	.25	.19	.21	.05	.20
H_2O	.60	.87	.34	.52	.35	.56	.52	.52
Total	100.32	99.21	99.16	99.99	99.98	99.92	100.72	100.05
Ba	469	380	275	312	289	362	260	
Rb	13	9	9	7	9	16	12	
Sr	592	798	1037	1173	1035	702	634	
Cr	105	149	33	36	34	73	53	
Ni	59	130	26	35	26	59	30	

	DUPLICATE ANALYSES BY XRF				STANDARD ROCKS			
	44	39	53	9	AMH-1*	(AMH-1)	TMS-1+	(TMS-1)
SiO_2	54.79	52.99	55.58	58.09	59.80	60.27	60.00	59.48
TiO_2	1.21	.97	1.03	.91	.79	.83	.17	.13
Al_2O_3	17.43	18.87	18.58	17.44	17.14	17.48	17.92	18.35
Fe_2O_3	8.55	8.17	7.16	6.49	6.36	6.15	5.31	5.20
MnO	.14	.11	.10	.09	.09	.10	.22	.19
MgO	3.99	4.96	3.78	2.97	3.11	3.06	.17	.29
CaO	6.83	7.94	8.06	6.23	6.02	6.07	1.48	1.27
Na_2O	4.00	3.65	4.37	3.97	4.14	4.11	9.07	8.82
K_2O	1.10	.69	.80	1.31	1.22	1.25	4.14	4.23
P_2O_5	.44	.28	.19	.21	.12	.18	.11	.16
H_2O	1.39	2.04	.34	1.44	.97	.39	1.46	1.27
Total	99.87	100.67	99.99	99.15	99.76	99.89	100.05	99.39

Note: (AMH-1) and (TMS-1) are averages of multiple analyses by XRF.

* Mt. Hood Andesite

\+ Marys Peak Syenite

APPENDIX III

LOCATIONS OF ANALYZED SAMPLES

(Roads and section, township, and range locations are those of U.S. Forest Service Map of Mt. Hood National Forest, revised edition 1979. The map is available from the Mt. Hood National Forest Headquarters, 19559 S.E. Division, Gresham, OR 97030; or the U.S. Forest Service Regional Office, 319 S.W. Pine, Portland (mailing address: P.O. Box 3623, Portland, OR 97208).

1. (BX-102) Rhyodacitic ignimbrite in road cut on RS46 at Cleator Bend campground, center, sec 19, T 9 S, R 7 E.

2. (CT-8) Basaltic andesite flow in road cut on S760C, west-central edge, sec 29, T 8 S, R 7 E.

3. (CT-15) Basaltic andesite dike in road cut on 040, east-central edge, sec 18, T 9 S, R 7 E.

4. (CT-25) Basaltic andesite flow on ridge between Scorpion Mountain and Mansfield Mountain, 4500' elevation, SW ¼, sec 5, T 8 S, R 7 E.

5. (CT-14) Thin andesitic flow in road cut on 030, SW ¼, sec 9, T 9 S, R 7 E.

6. (CT-57) Dacitic flow immediately beneath flow of sample 5.

7. (CT-13) Basaltic flow in road cut on 4685, NE ¼, sec 27, T 9 S, R 7 E.

8. (CT-58) Andesitic flow in road cut on S760, SW ¼, SE ¼, sec 29, T 8 S, R 7 E.

9. (CT-59) Andesitic flow in road cut on S760, 0.1 mi north of sample 8, eastern edge, SE ¼, sec 29, T 8 S, R 7 E.

10. (CT-65) Andesitic bomb in agglutinate on Granite Peaks ridge, 4960' elevation, north-central edge, sec 7, T 7 S, R 7 E.

11. (CT-67) Andesitic flow in road cut on S701C, NE ¼, SE ¼, sec 32, T 7 S, R 7 E.

12. (CT-69) Andesitic flow in road cut on S701C, NW ¼, SW ¼, sec 28, T 8 S, R 7 E.

13. (CT-28) Stock of hornblende andesite in small quarry on road S701B, NE ¼, sec 18, T 7 S, R 7 E.

14. (CT-63) Dacitic flow in road cut on S635A, center of northern ½, sec 5, T 7 S, R 7 E.

15. (CT-30) Dacitic flow in road cut on S701C, SW ¼, sec 4, T 8 S, R 7 E.

16. (CT-64) Dike of hornblende dacite in road cut on S635A, SE ¼, SW ¼, sec 32, T 6 S, R 7 E.

17. (CT-61) Sill of hornblende dacite in road cut on S7010, NW ¼, sec 20, T 7 S, R 7 E.

18. (CT-17) Basaltic flow in road cut on 4688, SE ¼, NW ¼, sec 10, T 9 S, R 7 E.

19. (CT-54) Basaltic flow in road cut on S701, south-central edge, sec 34, T 8 S, R 7 E.

20. (CT-21) Basaltic flow in road cut on S760N, center, sec 33, T 8 S, R 7 E.

21. (CT-36) Basaltic flow in road cut on S650, NW ¼, SE ¼, sec 8, T 7 S, R 7 E.

22. (CT-68) Basaltic andesite flow exposed on cliff face at Gyp Point, 4960' elevation, south-central part, sec 21, T 8 S, R 7 E.

23. (CT-55) Basaltic andesite flow exposed on cliff face at Bald Butte, 4800' elevation, NW ¼, sec 12, T 9 S, R 7 E.

24. (CT-66) Basaltic andesite flow exposed in cliff face just east of Bob Meadow, 4000' elevation, SE ¼, sec 20, T 7 S, R 7 E.

25. (CT-56) Basaltic andesite flow in road cut on RS46, SE ¼, SE ¼, sec 12, T 9 S, R 7 E.

26. (CT-34) Basaltic andesite flow in road cut on RS46, NW ¼, SE ¼, SW ¼, sec 6, T 7 S, R 8 E.

27. (CT-37) Basaltic andesite flow in road cut on S650, south-central edge, sec 4, T 7 S, R 8 E.

28. (CT-53) Basaltic andesite flow in road cut on S701, center, sec 27, T 8 S, R 7 E.

29. (CT-62) Basaltic andesite flow in road cut on S652, NE ¼, NE ¼, sec 3, T 7 S, R 7 E.

30. (CT-24) Basaltic andesite dike in road cut on S756, north-central edge, NW ¼, sec 25, T & S, R 7 E.

31. (CT-20) Andesitic flow in road-rock quarry on S701, NW ¼, NW ¼, sec 15, T 8 S, R 7 E.

32. (CT-41) Andesitic flow in road cut on S707, center, sec 21, T 7 S, R 8 E.

33. (CT-39) Basaltic flow in road cut on S707, SE ¼, SE ¼, sec 21, T 7 S, R 8 E.

34. (CT-7) Basaltic flow in outcrop at northwestern base of Olallie Butte, 4800' elevation, NW ¼, NE ¼, sec 36, T 8 S, R 8 E.

35. (CT-6) Basaltic andesite flow in outcrop along Olallie Butte trail, 5120' elevation, central part, E ½, sec 36, T 8 S, R 8 E.

36. (CT-5) Basaltic andesite flow in outcrop along Olallie Butte trail, 5280' elevation, south-central part, sec 36, T 8 S, R 8 E.

37. (CT-3) Basaltic andesite flow in outcrop near the summit of Olallie Butte, 6900' elevation, NW ¼, NW ¼, sec 2, T 9 S, R 8½ E.

38. (CT-4) Basaltic andesite bomb from bedded cinders north of the summit of Olallie Butte, 6750' elevation, NW ¼, NW ¼, sec 2, T 9 S, R 8½ E.

39. (CT-42) Basaltic andesite flow in road cut on RS46, north-central edge, SE ¼, sec 13, T 7 S, R 7 E.

40. (CT-52) Basaltic andesite flow in road cut on S737, north-central edge, sec 24, T 8 S, R 7 E.

41. (CT-2) Basaltic andesite flow in outcrop northwest of Olallie Lake, 5100' elevation, north-central part, sec 11, T 9 S, R 8 E.

42. (CT-75) Basaltic andesite flow in outcrop at head of canyon along the North Fork of the Breitenbush River, 3280' elevation, SW ¼, sec 21, T 9 S, R 8 E.

43. (CT-22) Basaltic andesite flow in road cut on S756, SE ¼, sec 13, T 7 S, R 7 E.

44. (CT-1) Basaltic andesite flow in outcrop west of Top Lake, 5100' elevation, SE ¼, sec 10, T 9 S, R 8 E.

45. (CT-33) Basaltic andesite flow in road cut on RS46, west-central edge, sec 7, T 7 S, R 8 E.

46. (CT-32) Basaltic andesite flow in road cut on S806, NW ¼, SE ¼, sec 18, T 8 S, R 8 E.

47. (CT-47) Basaltic andesite flow in outcrop north of Fish Lake, 4480' elevation, center, sec 34, T 8 S, R 8 E.

48. (CT-70) Basaltic andesite flow in outcrop east of Berry Creek, 3100' elevation, center, sec 25, T 8 S, R 7 E.

49. (CT-10) Basaltic andesite flow or small intrusion, rubbly outcrop at summit of West Pinhead Butte, 5500' elevation, north-central edge, sec 26, T 7 S, R 8 E.

50. (CT-45) Basaltic andesite cinders, summit of Potatoe Butte, 5280' elevation, SE ¼, NW ¼, sec 4, T 9 S, R 8 E.

51. (CT-44) Basaltic andesite flow in road cut on S42 west of Ollallie Lake, center, sec 11, T 9 S, R 8 E.

52. (CT-51) Basaltic andesite flow in road cut on S737, SE ¼, sec 24, T 8 S, R 7 E.

53. (CT-48) Basaltic andesite flow in outcrop on west summit of Sisi Butte, 5600' elevation, north-central edge, sec 9, T 8 S, R 8 E.

54. (CT-50) Basaltic andesite dike in outcrop between summits of Sisi Butte, 5440' elevation, north-central edge, sec 9, T 8 S, R 8 E.

55. (CT-49) Plug of micro-diorite, east summit of Sisi Butte, 5600' elevation, south-central edge, sec 4, T 8 S, R 8 E.

56. (CT-46) Basaltic andesite flow in road cut on S829, SE ¼, sec 29, T 8 S, R 8 S.

57. (CT-43) Hornblende andesite flow in road cut on S42 north of Gibson Lake, NE ¼, SW ¼, sec 24, T 9 S, R 8 E.

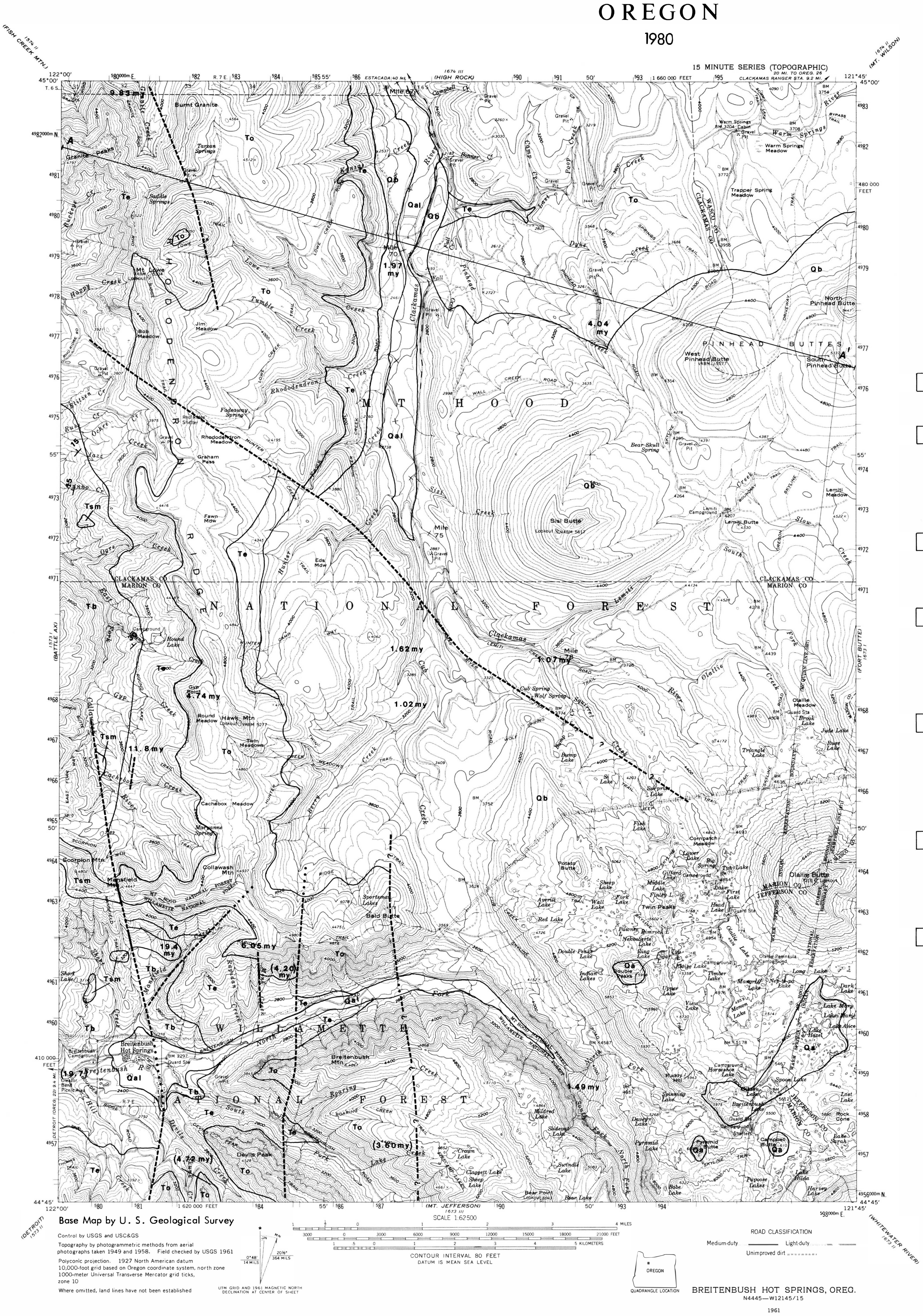
58. (S-150) Dacitic flow in outcrop at Double Peaks, sec 9, T 9 S, R 8 E; analysis reported by Thayer (1937).

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

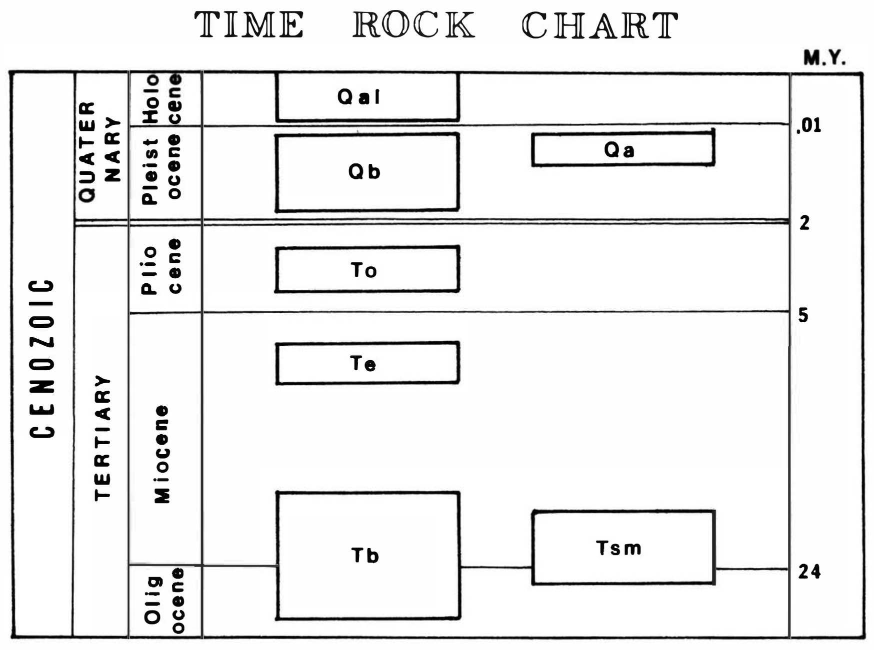
SPECIAL PAPER 9

GEOLOGIC MAP of the BREITENBUSH HOT SPRINGS QUADRANGLE, OREGON

1980



TIME ROCK CHART



EXPLANATION

Qal Quaternary alluvium: *Unconsolidated deposits of boulders gravel, and sand in the flood plains of the Breitenbush and Clackamas Rivers*

Qb High Cascade lavas, basalt and basaltic andesite: *Flows, breccia, and small intrusions of olivine basalt and olivine-pyroxene basaltic andesite; laterally extensive flows erupted from shield volcanoes or fissures make up most of the section; small- and intermediate-size composite cones are abundant in the upper part of this unit in the southeastern and east-central parts of the map area*

Qa High Cascade lavas, andesite and dacite: *Flows and small intrusions of hornblende-pyroxene andesite and dacite; lavas were erupted onto older High Cascade basalts and basaltic andesites from several vents located south and west of Olallie Lake*

To Outerson Formation: *Flows, breccia, lapilli tuff, and small intrusions; basaltic flows having distinctive ophitic textures and containing groundmass olivine crop out at the base of the Outerson Formation near Collawash Mountain; most lavas in this unit are olivine-pyroxene basaltic andesite with intergranular or diktytaxitic textures; subordinate volumes of andesite crop out in the northeastern part of the map area*

Te Elk Lake Formation: *Flows, lapilli tuff, and intrusive rocks; weathered, olivine-bearing, basaltic flows and bedded lapilli crop out in the southern part of the map area; coarsely porphyritic, hornblende-pyroxene andesite overlies rocks of the Breitenbush Formation in the western part of the map area; hornblende-bearing, dacitic flows, tuff, and small intrusions form the rugged terrain around Granite Peaks, in the northwestern part of the map area*

Tsm Scorpion Mountain lavas: *Flows and subordinate amounts of breccia and lapilli tuff; dark-gray, aphyric flows of tholeiitic basaltic andesite and andesite cap Scorpion Mountain and are exposed in isolated outcrops along the western edge of the map area; Scorpion Mountain lavas appear to be intercalated with tuffs and tuffaceous sediments in the upper part of the Breitenbush Formation*

Tb Breitenbush Formation: *Ash flows, tuff, volcanic breccia and sandstone, and subordinate lava flows; light-gray and pale-green ash flows with rhyodacitic compositions crop out along the Breitenbush and Collawash Rivers in the southwestern and west-central parts of the map area; andesitic to dacitic volcanic breccias are exposed in isolated outcrops; white or pale-pink tuff and tuffaceous sandstone occurs at the top of the unit*

GEOLOGIC SYMBOLS

CONTACTS

Locations of most contacts are inferred from the distribution of rock types in isolated outcrops

ATTITUDES

30

Strikes and dips of bedded tuffs and epiclastic rocks in the Breitenbush Formation

FAULTS

Exposed *Inferred* *Concealed*

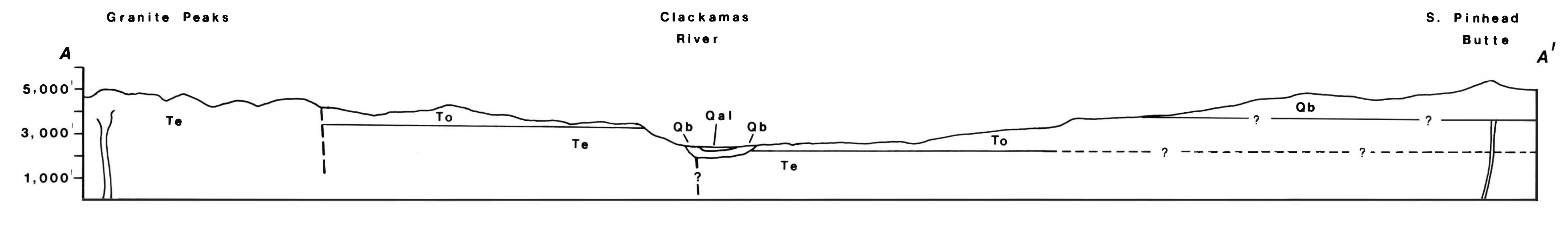
RADIOMETRIC AGES

4.74 my — *K/Ar whole-rock age obtained for this report*

(3.60 my) — *K/Ar whole-rock or mineral age taken from previously published reports*

Exact locations of samples used for age dating are given in appendix of text

Geologic Cross Section



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