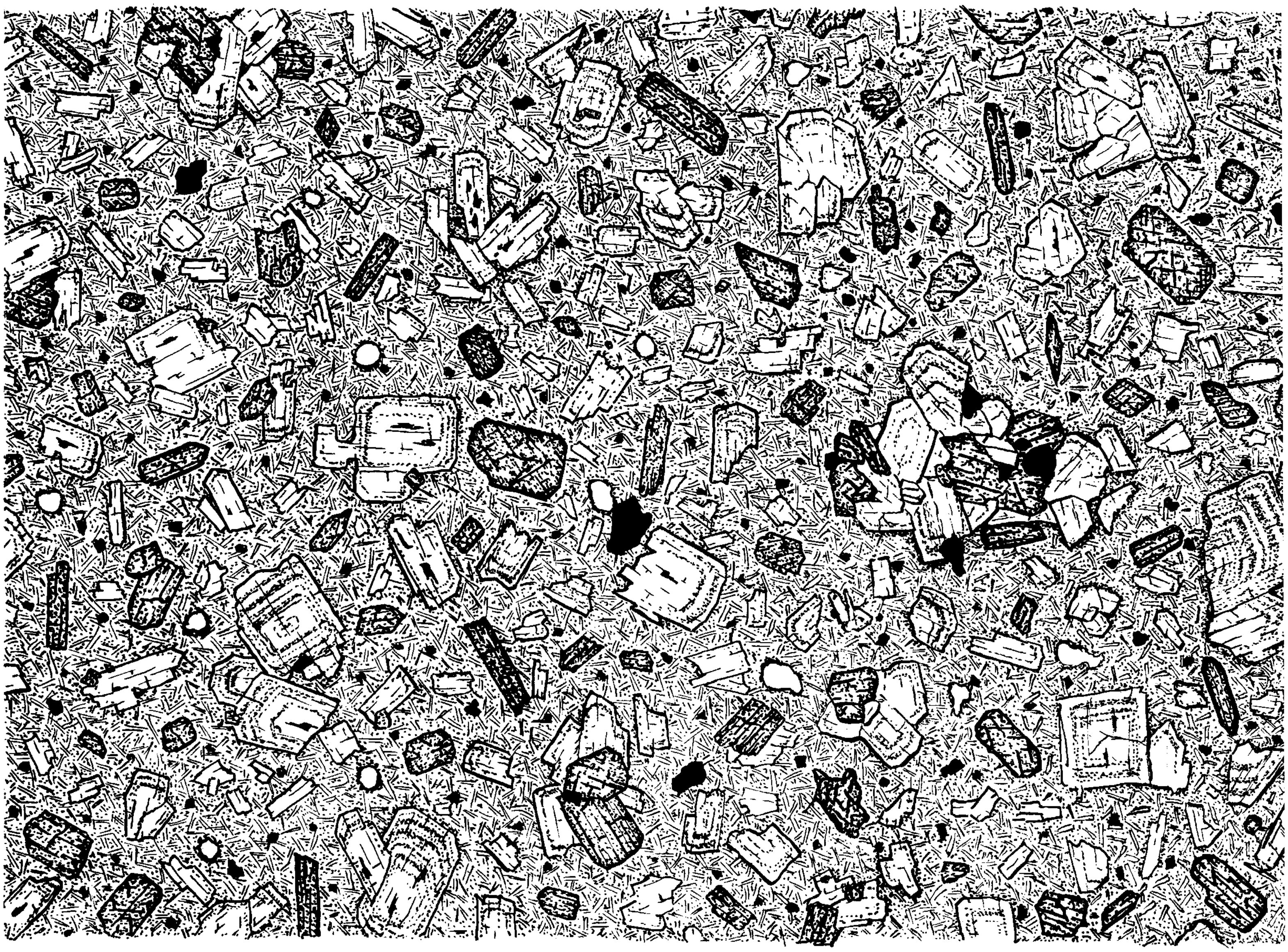
ANDESITE CONFERENCE GUIDEBOOK



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ANDESITE CONFERENCE

July 1 to 6, 1968 Eugene and Bend, Oregon U. S. A.

Sponsored by: University of Oregon Center for Volcanology
A. R. McBirney, Director

International Upper Mantle Committee
Prof. Hisashi Kuno, Chairman
Working Group on Petrology and Volcanism

State of Oregon Department of Geology and
Mineral Industries H. M. Dole, State Geologist

Financial assistance for the Andesite Conference was provided by the International Union of Geodesy and Geophysics and by the International Union of Geological Sciences.

The Upper Mantle Project is an international program of research on the solid earth sponsored by the International Council of Scientific Unions; the program is coordinated by the International Upper Mantle Committee, an IUGG committee set up jointly by the International Union of Geodesy and Geophysics and the International Union of Geological Sciences, with rules providing for the active participation of all interested ICSU Unions and Committees.

Cover Picture: Andesite Thin Section

Cover design is a microdrawing of the hypersthene-augite andesite at the highest peak of Mount Jefferson. The rock is typical of the andesites of the Oregon Cascades in both its petrographic features and chemical composition. An analysis of the rock is given in table I, no. 5, page 55
Rock was collected and drawn by A. R. McBirney.

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DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
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ANDESITE CONFERENCE GUIDEBOOK

Editor, Hollis M. Dole
Cartographer, C. J. Newhouse

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FOREWORD

In the last few years, geologists of many interests have turned their attention to the great chain of andesitic volcanoes that rims the Pacific Ocean. They have become increasingly conscious of the fundamental problems related to the origin of andesitic rocks and their role in the evolution of continents and mountain-building systems. The Andesite Conference was organized through the joint efforts of the Upper Mantle Committee, The Center for Volcanology, and the State of Oregon Department of Geology and Mineral Industries to provide an opportunity for persons currently specializing in the varied aspect of andesitic volcanism to come together and discuss informally the results and directions of their research.

The High Cascades of Oregon provide a fitting setting for such a conference. Visits to the volcanic centers described in this guidebook were organized so as to utilize the growing wealth of geologic, geochemical, and geophysical data they provide as a stimulus for discussion of andesitic volcanism on a broad scale.

The field trips, therefore, constitute a very important part of the meeting. They have been made possible only through the combined efforts and contributions of many individuals and organizations. Chief among these are:

The people of Bend and their Lunar & Planetary Base Research, Inc.
The staff of Crater Lake National Park
The staff of Deschutes and Willamette National Forests
The Eugene Water and Electric Board
Central Oregon Community College
Pacific Northwest Bell Telephone Co.
Pacific Power & Light Co.
Pacific Trailways

We wish to express our gratitude for the invaluable assistance these persons have provided and to the contributors to this guidebook and the leaders of the separate field excursions.

Hollis M. Dole
State of Oregon Department of Geology
and Mineral Industries
Hisashi Kuno
Upper Mantle Committee
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Center for Volcanology

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MCKENZIE PASS AREA

ROADSIDE GEOLOGY
SANTIAM AND MCKENZIE PASS HIGHWAYS, OREGON

By Edward M. Taylor*

Introduction

Some general remarks about central Cascade geology

The Cascade Range in Oregon consists of two parallel volcanic mountain belts known as the Western and High Cascades. Rocks of the Western Cascades are relatively old (ranging perhaps from 5 to 40 million years) and have been so deeply eroded that a mountain peak is more likely to be a remnant of a resistant lava flow than the site of an ancient volcano. Minor faults, broad folds, and extensive areas of hydrothermally altered rocks are commonplace in the Western Cascades. While basalt is the predominant rock type, dacite and rhyodacite tuffs and welded tuffs are also common. Andesites and small plutons of quartz diorite and quartz monzonite are present but are relatively rare.

In contrast, the High Cascades are younger; nearly all of the mountains have been active volcanoes within the last few million years and some have been active within the last few thousand years. Faults are rare, folded rocks have not been recognized, and the lavas have been hydrothermally altered only in the vicinity of volcanic plugs. Large andesitic volcanoes such as Mount Jefferson and South Sister rest upon a broad platform of coalescing basaltic shield volcanoes. In terms of relative volume, andesite is insignificant when compared to the basalt of this platform. Dacite and rhyolite are even less abundant and only a few welded tuff units are known.

In spite of the general contrast between the Western and High Cascades, their common boundary is difficult to locate. In many areas, adjacent rocks of both provinces are flat-lying, unaltered, and are similar in chemical and mineralogical composition. To resolve this problem, individual rock units must be traced from areas in which the boundary is easily fixed, into areas in which the position of the boundary would be otherwise obscure. This has now been accomplished in the central Cascades and several important relationships are apparent: (1) A distinctive and widespread unit of homogeneous coarse-grained basalt marks the base of the High Cascade sequence. It is usually diktytaxitic and occurs in thick sections of many thin flows. (2) A more variable, finer grained, dense basalt overlies the coarse-grained diktytaxitic section and forms the bulk of the High Cascade platform. (3) The High-Western Cascade boundary is outlined by the western limit of the coarse-grained diktytaxitic rocks. Locally, where they overlap the coarse-grained section, the fine-grained, dense basalts form the boundary. (4) A profound erosional and/or angular unconformity exists at the boundary. Coarse-grained, diktytaxitic early High Cascade basalt inundated eastern foothills of previously deformed Western Cascade rocks and, in places, poured west for 10 miles through the same major valleys which penetrate the Western Cascades today. (5) If the boundary is controlled by a major north-south fault, as has been suggested by several authors, this fault is not exposed to view and has not displaced the High Cascade rocks. In fact, the principal faults along the boundary are generally less than one mile in length, trend northwest, and involve displacements of less than 100 feet. They are restricted to the Western Cascades.

The foregoing relationships suggest that neither erosion nor faulting has greatly altered the central part of the Western Cascades since High Cascade volcanism began. It seems likely that the entire High Cascade platform and the peaks which rest upon it may have been formed in much less time (1.5 million years?) than the commonly accepted Pliocene and Pleistocene interval. In the writer's opinion, the many

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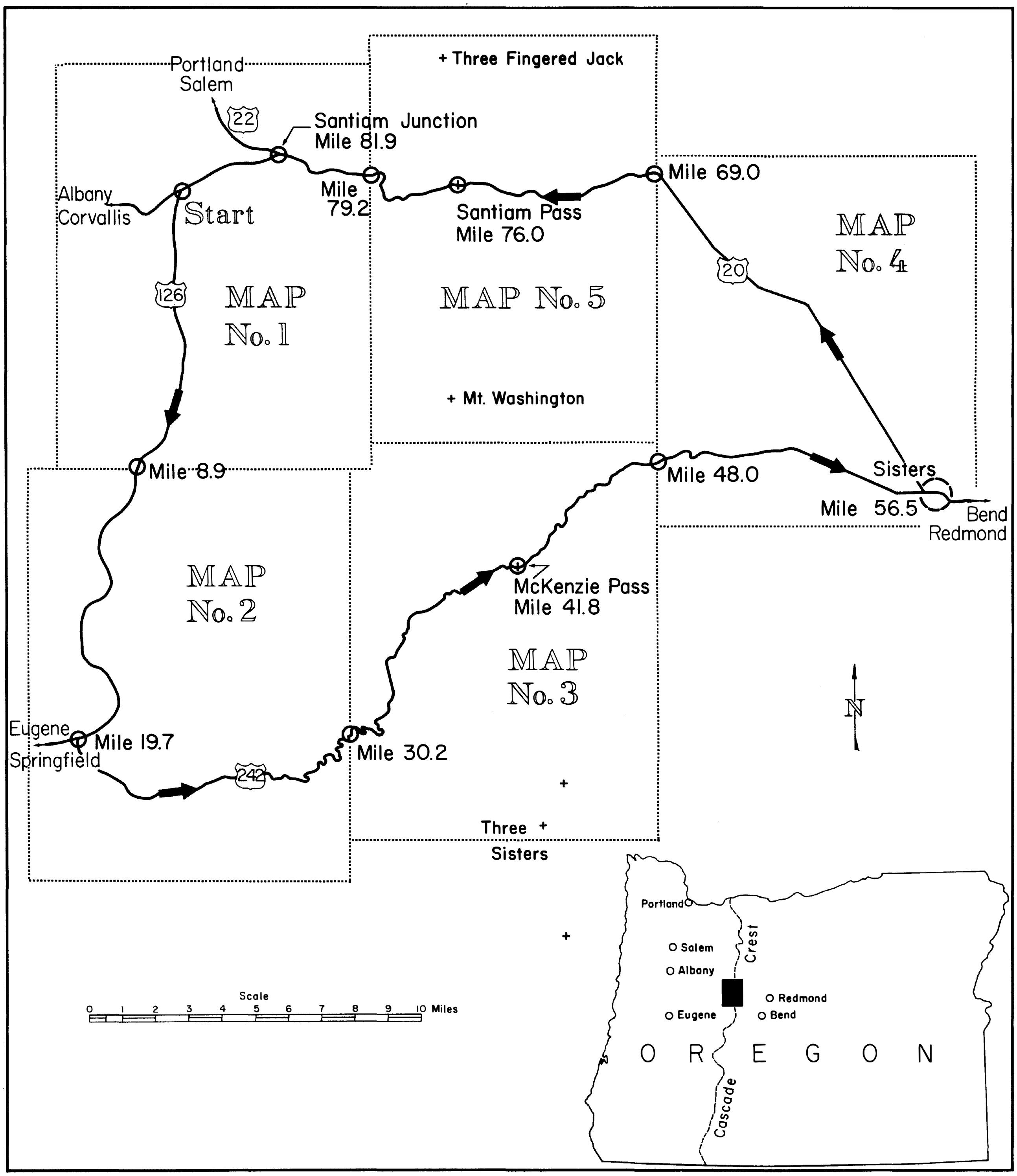
INDEX MAP



+ Three Fingered Jack
Portland
Salem
22
Santiam Junction
Mile 81.9
Mile 69.0
Albany
Corvallis
Start
Mile
79.2
Santiam Pass
Mile 76.0
MAP
No. 4
20
126
MAP
No. 1
MAP No. 5
+ Mt. Washington
Mile 8.9
Mile 48.0
Sisters
Mile 56.5
Bend
Redmond
MAP
No. 2
McKenzie Pass
Mile 41.8
MAP
No. 3
N
Eugene
Mile 19.7
Springfield
Mile 30.2
242
Three
Sisters
Scale
0 1 2 3 4 5 6 7 8 9 10 Miles
Portland
Salem
Albany
Redmond
Eugene
Bend
Crest
O R E G O N
Cascade

areas of "High Cascade" rocks which have been mapped within the Western Cascade Province are not to be associated in time or in place of origin with High Cascade volcanism.

High Cascade rocks appear to be continuous with, or transitional into, rocks of the lava plains to the east. A sharp time boundary separating distinct geologic provinces probably does not exist here.

In the central part of the High Cascades, andesites, dacites, and rhyolites crop out only in the vicinity of the Middle and South Sisters. Porphyritic and nonporphyritic basalts, olivine basalts, basaltic andesites, hypersthene- and augite-bearing andesites, hypersthene-bearing dacites, rhyolites, and rhyolite vitrophyres all seem to have been erupted during all stages in the development of these volcanoes. Insofar as a chronological sequence of the most abundant rock types can be recognized, it is (1) rhyolite, (2) andesite, and (3) basalt.

The great extent and depth of glacial ice which lay upon the High Cascades of Oregon during the Pleistocene have not been stressed in geologic literature. In the central Cascades, three episodes of glaciation are easily recognized. The most recent episode is represented by fresh moraine and outwash between 7000 and 9000 feet elevation on high peaks. Radiocarbon ages of associated lavas and ash deposits indicate that these moraines were formed less than 2500 years ago and should be referred to the Neoglacial "Little Ice Age." A minor glacial advance near the end of the last century slightly reworked some of the "Little Ice Age" moraines.

The next oldest glacial stage ended 10,000 to 12,000 years ago and is here referred to the latest Wisconsin. During this time, a broad ice field accumulated in the High Cascades. It surrounded the major peaks, buried all but the highest summit ridges, and fed numerous glaciers, some of which were 19 miles long. Neither the ice field nor its satellite glaciers extended beyond the High Cascade platform; in the central Cascades few of these glaciers existed below 3600 feet elevation.

The oldest glacial events are collectively referred to as "pre-latest Wisconsin." They are recorded in deeply weathered and poorly preserved lateral and ground moraines, far removed from the Cascade Crest. These deposits lack the andesitic and rhyolitic rock types which are common in the summit peaks and in the latest Wisconsin moraines.

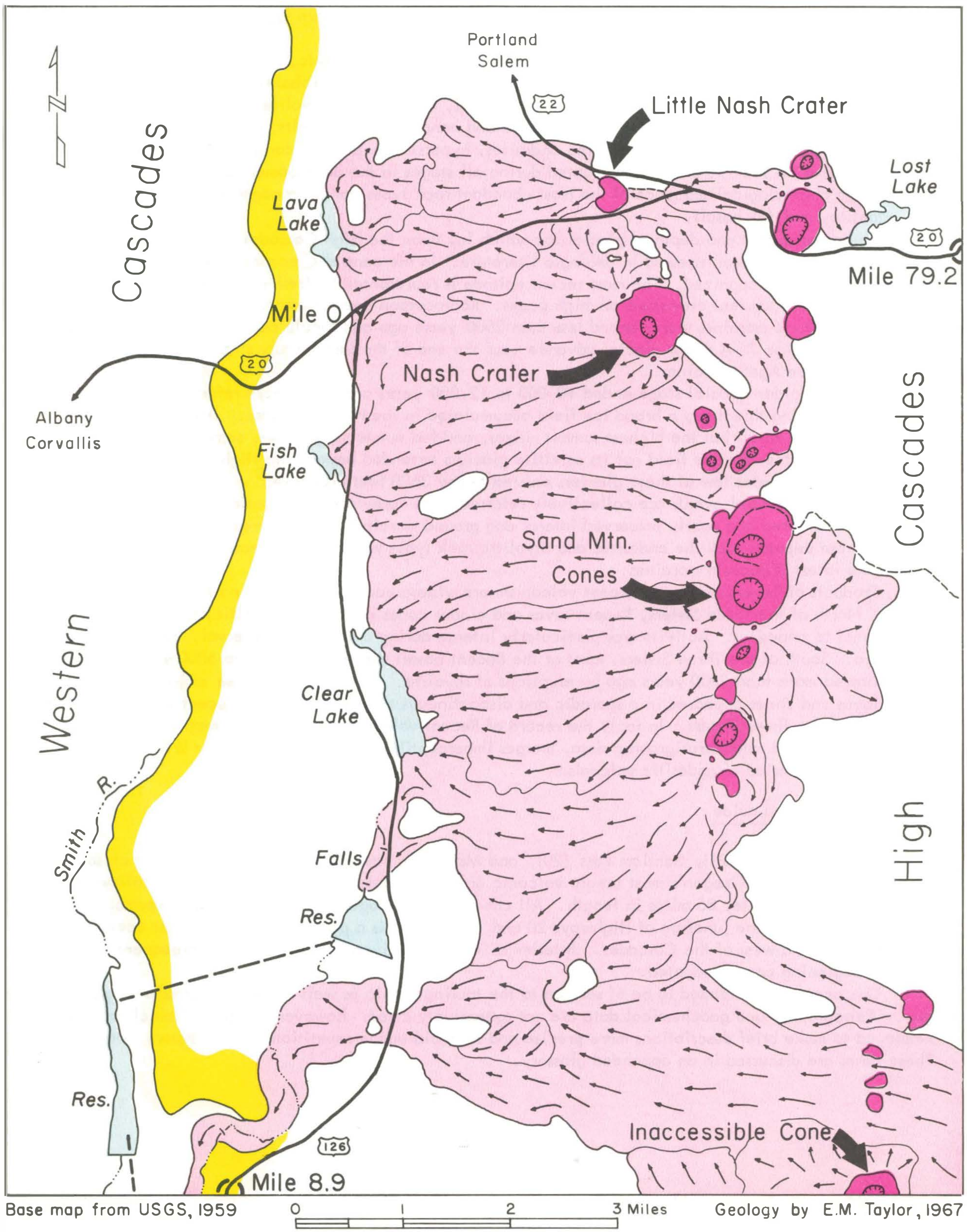
Products of Recent and near-Recent volcanism are widespread in the central part of the High Cascades. North of the Three Sisters, Recent lavas and cinder cones are chiefly basaltic, although some are transitional to andesites. Activity was particularly intense during a 2500-year interval, beginning 4000 years ago. South of the Three Sisters, most of the Recent basalt was erupted prior to 6000 years ago and was followed more than 2000 years ago by eruptions of rhyolite. In addition to these major events, basaltic lavas and cones appeared in a sporadic and discontinuous manner throughout Recent time, both north and south of the Three Sisters. In fact, the record of Recent volcanic activity, now supported by 15 radiocarbon ages and much stratigraphic data, merges imperceptibly into that of the latest Wisconsin and thence into the period of andesitic volcanism.

How to use this road guide

The Clear Lake (126), Santiam Pass (20), and McKenzie Pass (242) Highways provide a closed circuit through one of Oregon's most scenic volcanic areas (see index map). This road guide follows a counter-clockwise route, 85 miles in length. All checkpoint mileages are underlined and express cumulative distance from the junction of Highways 20 and 126, which is a place of beginning most accessible from both east and west of the Cascades. Interim mileages are given in parentheses; consequently, any point of beginning can be adopted.

This account is intended to be of service to the touring public as well as to the professional geologist. Petrographic and geochemical data are not extensively cited; however, a few technical terms are employed to make brief descriptions more precise and to avoid undue repetition of explanatory material. These terms are discussed in an appended glossary.

MAP No. 1 Geologic Features From Mile 0 To Mile 8.9



ROAD LOG: SANTIAM AND McKENZIE CIRCUIT

Mileage

0.0 Start: Junction of Highways 20 and 126; Map No. 1.

(0.1)

It is probable, by extension from nearby outcrops, that the junction area is underlain by coarse-grained diktytaxitic basalt which marks the base of the High Cascade sequence. In the hills immediately west, this is overlain by gray, fine-grained basalt. Both units were overridden by pre-latest Wisconsin glacial ice; long roadcut west of the junction exposes outwash deposits. The High-Western Cascade boundary lies 2.5 miles west.

The junction area has been invaded by Recent basalt flows on three separate occasions: 3800 years ago from a group of cones between Nash Crater and Sand Mountain (lava exposed on floor of Lava Lake, 0.5 miles north), subsequently from a buried vent of Nash Crater (lava surrounding the junction), and finally from exposed vents at the northwest base of Nash Crater (lava front about 200 feet south of the junction). Each of these units differs from the others in surface features, rock texture, and composition.

0.1 (0.6) Contact between Lava Lake Flow (second flow at junction) and Fish Lake Flow (third flow at junction) passes beneath highway at this point. Fish Lake Flow from Nash Crater turned here and moved south for 1.5 miles. Mountain peaks visible from this section of highway are, from north to south, Jefferson, Three Fingered Jack, Sand Mountain Cones, Mount Washington, and Three Sisters.

0.7 (0.7) Roadcuts west expose basaltic ash derived for the most part, between 3800 and 3000 years ago from early cones north and south of Sand Mountain. Slightly more siliceous contributions to the ash deposits came from North Sand Mountain about 3000 years ago. Highway passes onto Fish Lake Flow 0.2 miles ahead.

1.4 (0.4) Road west to Fish Lake Campground. Fish Lake is dry throughout the summer, but this was apparently not so up to the turn of the last century. The Fish Lake Flow does not actually extend to the lake shore. The lake basin was formed 3800 years ago when lava from vents to the east blocked Hackleman Creek. This lava flow is seen on the east shore and on both sides of the highway southeast of the lake.

1.8 (0.1) Obscure track on lava to the east is the Old Santiam Toll Road. It was built in 1866 and was one of the first extensively used links between central Oregon and the Willamette Valley. A grave marker, 0.5 miles to the northwest, records the misfortune of wagoneers, caught in the first snows of winter. Surface of the lava along this section is unusually smooth, indicating high fluidity before solidification. Several horizontal and vertical tree molds are found here, one 5 feet in diameter. Ash deposits occur upon this lava, but not beneath it.

1.9 (0.6) Fish Lake Creek channel. The channel follows the contact between Recent lava and High Cascade fine-grained basalt. The creek runs full only in winter and soaks into lava flows 0.5 miles downstream.

2.5 (0.4) Ikenick Creek. Fine-grained basalt bedrock which is exposed on hillsides to the north and south, is here obscured by alluvium and volcanic ash.

Mileage

2.9 (0.7) Road cuts expose several flows of High Cascade fine-grained basalt, separated by flow breccias and sedimentary interbeds.

3.6 (0.5) Road left to Clear Lake: recommended side trip. Clear Lake is 1.5 miles long and more than 100 feet deep in places. It is fed, in part by Ikenick Creek, but chiefly from large springs along the north and east shores. It is drained at the south end by the McKenzie River. The lake occupies the bed of an ancestral upper McKenzie, whose watershed extended from Tombstone Pass on the west to Pyramid Mountain on the north and from Three Fingered Jack on the northeast to Mount Washington on the east. Lava has buried so many of the old river channels that much of this area is now drained by underground streams.

Clear Lake was formed behind a dam of lava which issued from a cinder cone south of Sand Mountain and which poured across the McKenzie River. Lava on the east shore is younger and came from a different source. Rising lake waters inundated a standing forest; several dozen snags are still rooted on the lake floor. Wood samples from the interiors of some of these drowned snags have been identified as Douglas fir and are as sound as any modern counterpart. Wood from the snags and charcoal from beneath the east shore lavas both possess a radiocarbon age of about 3000 years.

4.1 (0.4) Broad mountain visible on the southeastern horizon is Scott Mountain, a glaciated High Cascade shield volcano composed of gray, fine-grained basalt and capped by a small, much eroded cinder cone.

4.5 (0.6) Bridge over McKenzie River. Upstream from the bridge, the river follows an artificial channel carved into the same Recent lava which dammed Clear Lake. A dark, horizontal band of dense rock marks the once-liquid interior of one flow, bounded above and below by layers of scoriaceous rubble. Roadcuts ahead demonstrate that a lava flow can move even when composed chiefly of broken fragments.

5.1 (0.3) Sahalie Falls parking area. The lava flow of the Clear Lake dam chilled to a halt just below here. After re-establishing its channel on top of the flow, the McKenzie River carved an amphitheater into the lava margin. In the course of geologic time, processes like these excavate canyons and destroy lakes.

5.4 (0.2) At this point the highway crosses over a segment of the Clear Lake Dam Flow which poured westward through a narrow gap between two large hills, 100 yards east. The flow moved 0.2 miles farther downstream, where it now forms the lip of Koosah Falls.

5.6 (0.4) First road right leads to Koosah Falls and campground. Second road right leads to Carmen Reservoir, from which a part of the McKenzie River is diverted two miles southwest through a tunnel to the Smith River. Cliffs at the head of the reservoir are diktytaxitic, coarse-grained High Cascade basalt.

6.0 (0.3) Talus and cliffs on the ridge immediately east are part of the basal, coarse-grained High Cascade unit, but not all flows here and in the roadcuts ahead are diktytaxitic.

6.3 (0.4) Road cuts reveal the thin, irregular character of basalt flows in the basal High Cascade sequence. Rocks here are only sparsely porphyritic; flows higher in the ridge possess a coarse, fluxion-oriented, diktytaxitic texture. Along the uppermost surface of these road cuts, streamers of yellow pumice can be seen in the talus. This is volcanic ash from Mount Mazama (Crater Lake), which drifted over the area some 6600 years ago.

6.7 North edge of Recent lava flows from Belknap Crater (which is located 8 miles to the

North and South Sand Mountain Cones viewed from the northwest:

Basaltic ash fallout from these cones covered an area of approximately 150 square miles. Source vents at the base of the cones gave rise to surrounding fields of basaltic lava. (Oregon Department of Geology and Mineral Industries photograph 67-296)

Clear Lake viewed from the southwest:

Lava flows dammed the upper McKenzie River approximately 3000 years ago. Rising lake water inundated and preserved a forest which still stands, bare of limbs, in the depths of the lake. (Oregon Department of Geology and Mineral Industries photograph 67-297)

Mileage

(0.2) southeast). This low-level topographic gap carried the entire western discharge of melt water from the sheet of latest Wisconsin ice between Mount Washington and Scott Mountain. The incised canyon to the west contained an even larger river, because it received melt water from the upper McKenzie watershed.

Flows from volcanoes south of Sand Mountain approached this gap but were covered 1500 years ago by Belknap lava. The Belknap flows poured in a double cascade down the cliffs to the west and spread out upon the floor of the canyon. A swampy area known as Beaver Marsh developed upstream; near the terminus, 2 miles downstream, Tamolitch Falls spilled over the lava margin.

6.9 (0.5) South edge of Belknap flows. Road cuts immediately ahead expose fine-grained High Cascade basalt which overlies a diktytaxitic sequence in the canyon walls to the west.

7.4 (0.6) Small roadcuts in glacial alluvium which is probably of pre-latest Wisconsin age.

8.0 (0.2) Kink Creek logging road: left. Fine-grained basalt in the hillside east rests upon a coarse-grained diktytaxitic sequence in the canyon walls to the west.

8.2 (0.2) From this point south, the highway follows the crest of a ridge between McKenzie River and Kink Creek, down to the floor of the canyon. The ridge is composed of many thin layers of diktytaxitic basalt and is capped by deeply weathered glacial alluvium.

8.4 (0.5) Road right to Tamolitch Falls overlook. Before hydroelectric projects were completed, the waterfall plunged into a large spring-fed lagoon of unusual depth and clarity. Erosional remnant of Belknap lava forms a terrace on the far side of the river.

8.9 (0.2) Boundary between Maps No. 1 and No. 2.

9.1 (0.4) Long road cuts in many thin flows of diktytaxitic basalt.

9.5 (0.3) Highway fill over valley of Kink Creek. Diktytaxitic basalt crops out on hillside to the southeast.

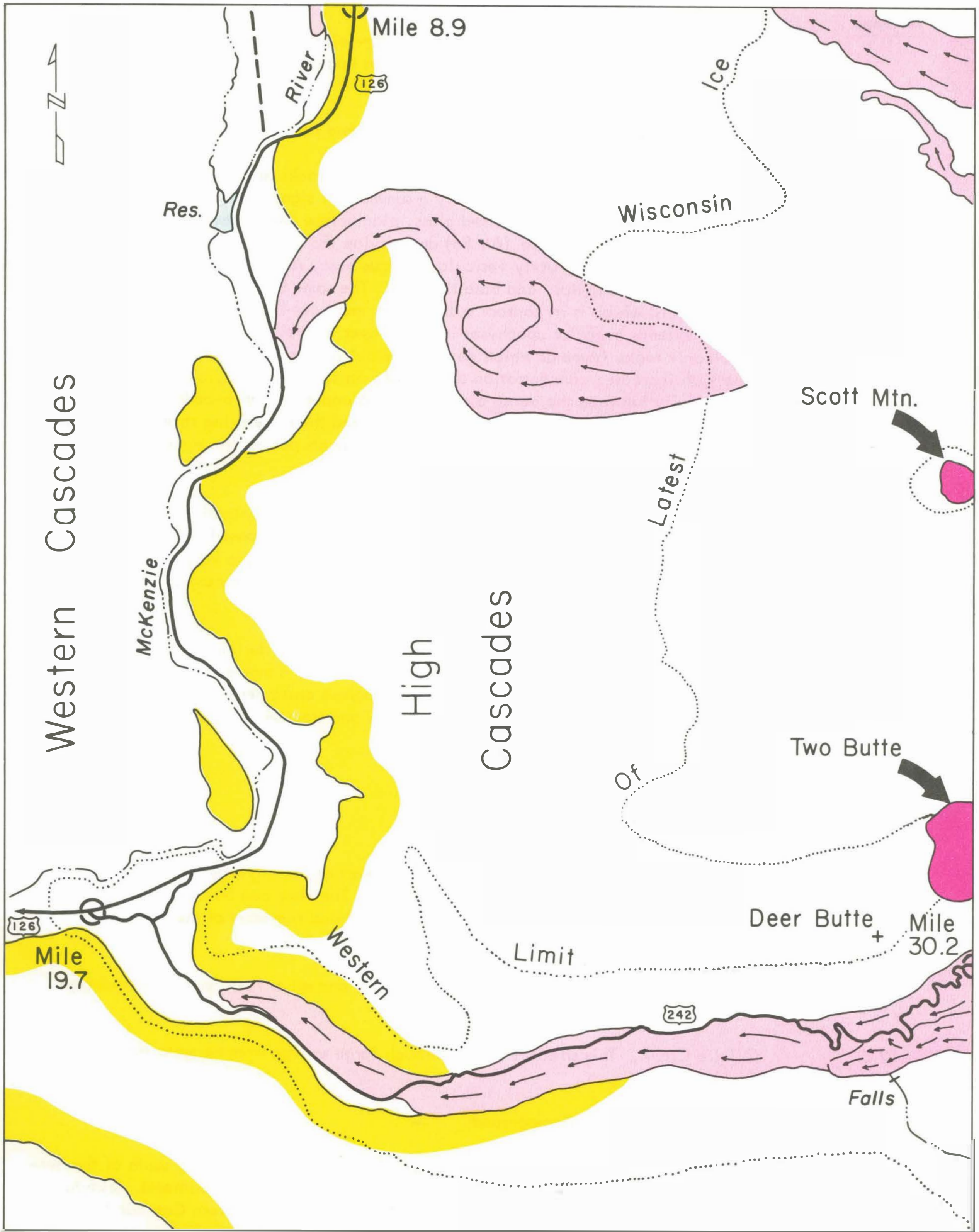
9.8 (0.3) Long road cut on left leads down to floor of McKenzie Canyon. At north end of cut, glacial alluvium; at south end, flat-lying diktytaxitic basalt flows with a conformable, thin-layered interbed of sand and silt. In the middle of the cut, the glacial alluvium shows scour-and-fill structure and rests in channels which were carved into the lava and the interbed.

10.1 (0.4) Alluvial floor of upper McKenzie Valley. Recent and late Pleistocene deposits of gravel and sand cover most of the valley floor from here to the Willamette River.

10.5 (0.2) Cliffs to the left are part of the diktytaxitic sequence but are here relatively fine-grained because lava poured over wet ground and cooling was rapid. Many of the flows are pillowed and are separated by sandy interbeds. As witnessed by several springs in the face of the road cut, this type of lava is often a very permeable aquifer. At the west end of the road cut, pillowed lavas rest unconformably upon relatively impermeable tuffs, sands, gravels, and basalts which are part of the Western Cascades. Across the McKenzie River is a power-generating facility which utilizes water conducted nearly 2 miles through a ridge from Smith Reservoir. Cliffs behind the generators are composed of inclined Western Cascade basalt flows and breccias.

10.7 (0.4) Road right to hydroelectric facilities, Trailbridge Reservoir Campground, and Smith Reservoir.

MAP No. 2 Geologic Features From Mile 8.9 To Mile 30.2



Base map from USGS, 1959 — 0 1 2 3 Miles — Geology by E.M. Toylor, 1967

Mileage		
11.1	(0.1)	Left of highway is an inclined flow of columnar-jointed Western Cascade basalt. There are several northwest-southeast normal faults in this area which have broken the Western Cascade rocks into a set of earth-blocks inclined 10° to 25° down to the northeast.
11.2		Trailbridge Reservoir visitor information display and parking area: recommended stop.
	(0.3)	In the adjacent road cut is one of the most peculiar rocks in the Western Cascade sequence. Space limitations permit only a summary of significant features: A dense black layer consisting of devitrified glass, plagioclase microlites (oriented by flowage), and phenocrysts of bytownite (An 86) and olivine (Fo 85), grades imperceptibly downward into a reddish, minutely vesicular, porous base, resting with sharp contact upon layered volcanic detritus and basaltic lava. The same black layer grades upward into a porous crust which is in contact with a thick mudflow-like overburden. The black interior extends irregular apophyses into the layer above. Angular, unsorted fragments of volcanic rocks (some of which do not crop out in this area) are abundant in the black zone with increased concentration downward. In some outcrops, all attempts to find a discontinuity between the dense black zone and underlying thin-bedded sediments have failed. In such instances, the red porous zone and the underlying strata are both rich in chabazite. The black matrix and the reddish crusts possess the same basaltic (SiO_2 50%) composition. The highway outcrop is cut by at least five faults and the inclination of the rocks is correspondingly variable. However, the same layers are exposed in the hills west and northwest, and the regional dip is 15° NE. This is, in fact, a very distinctive marker horizon and it has been traced, without notable change in features, for 7 miles north and south along the Western Cascade foothills. It is the writer's opinion that these layers were all formed during the same eruptive episode and that the nonstratified components moved as a molten froth of inclusion- and gas-charged basalt. Formation of thick, porous crusts served to insulate a hot, liquid interior through which inclusions settled and from which gas escaped. Much, however, remains to be learned.
11.5	(0.4)	Road right to Trailbridge Dam.
11.9	(0.3)	Road right to fish ladder facilities.
12.2	(0.3)	Anderson Creek. Forested slope immediately east of the highway is the margin of a basaltic lava flow of pre-latest Wisconsin age. The flow can be traced uphill to the east for 4 miles. At higher elevations, only isolated remnants of the Anderson Creek Flow have survived glaciation.
12.5	(0.1)	Ollalie Creek logging road: left. Lava levees and other features of the Anderson Creek Flow are easily seen from this road.
12.6	(0.2)	Ollalie Creek. This stream emerges through large springs from beneath the Anderson Creek Flow.
12.8	(0.1)	Road right to Ollalie Campground.
12.9	(1.4)	Terminus of Anderson Creek Flow just east of highway. The clearing south of the terminus is a pit excavated in valley alluvium. In the hills to the southeast, diktytaxitic basalt rests with great erosional unconformity upon altered Western Cascade basalts.

Mileage		
14.3	(0.2)	Cliff on the opposite side of the river is an erosional remnant of the same High Cascade diktytaxitic basalts that are exposed in the road cut just left of the highway.
14.5	(0.2)	Deer Creek logging road: right.
14.7	(0.6)	Boulder Creek logging road: left. About 1 mile up this road, cuts expose diktytaxitic basalt flows resting upon inclined Western Cascade sediments and lavas. Road cuts 1 mile farther reveal fine-grained High Cascade basalt overlying the diktytaxitic variety.
15.3	(0.1)	Western Cascade basalt in cliffs just left of highway.
15.4	(0.9)	Long series of road cuts in Western Cascade basalt flows, interbeds, and breccias. A northeast-trending dike, about 2 feet wide, is exposed near the south end of the cuts.
16.3	(0.8)	Ancient stream channel in Western Cascade rocks is represented by the gravel beds in this road cut. The gravel rests upon "garden variety" Western Cascade basalt at the north end of the cut and upon a highly porphyritic basalt at the south end. The porphyritic basalt occurs in the gravels and in the cliffs west of the McKenzie River. Above the gravels, a section of flat-lying beds of tuffaceous sand is overlain by a thick flow of columnar-jointed Western Cascade basalt. Still higher to the east is the High Cascade boundary, represented by diktytaxitic basalt.
17.1	(0.1)	Frissell logging road: right.
17.2	(0.5)	Scott Creek logging road: left. A side trip, 2 miles up this road, will reveal an unusual aspect of the High-Western Cascade boundary. Below the boundary is a complex assemblage of non-porphyritic, platy basalts, porphyritic massive basalts, breccias, and interbeds which are cut in many places by east-west normal faults and are generally inclined to the south. Above the boundary is a remarkable section of basaltic pillows, dikes, flows, and palagonitic tuffs which is a facies of the diktytaxitic sequence. Early High Cascade lavas must have blocked major streams in this area, forming extensive lakes and swamps. Succeeding lava flows poured into the lakes and were converted, through reaction with the water, into an intimate mixture of pillows and altered glass shards. One dike, now exposed in a road cut, appears to have discharged basalt pillows into and on top of the wet tuffaceous sediments. Lakes were occasionally filled in this manner and were then covered over by ordinary diktytaxitic lava flows. During a period of quiescence, additional palagonitic material and volcanic ash were washed into the area, burying the pillow lavas beneath several hundred feet of bedded sand, silt, and mud. Still later, streams carved valleys into the sediments and more diktytaxitic lava flows appeared. A cross section through one of these flows is exposed about 1.5 miles up Scott Creek road. Where it filled an ancient valley, the flow is more than 80 feet thick and displays columnar joints and spiracles in its basal part.
17.7	(0.5)	Scott Creek. Near this point is the west end of the Scott Trail, established over the McKenzie Divide in 1862.
18.2	(0.2)	Rimrock cliff across the river is a fine-grained basalt flow, resting upon a diktytaxitic basalt section. Both units are erosional remnants of the High Cascade sequence and have exact counterparts in cliffs to the southeast.
18.4	(0.3)	Old section of highway: right (now closed). This point marks the beginning of an extensive, hummocky, poorly drained portion of the valley floor which is covered by

Mileage

latest Wisconsin terminal moraines.

18.7 (0.4) First road left is Cupola logging road. Cuts along this road expose the same Western Cascade rock types and High Cascade diktytaxitic sequence as is seen on the Scott Creek road. However, the pillow lava and palagonitic tuff facies is not as extensive; it merges into interbeds of river gravel which can be traced southeastward for 3 miles between lava flows.

Second road left leads to Highway 242; stay on Highway 126.

Road right leads to Belknap Hot Springs. The springs emerge from a Western Cascade breccia layer on the north bank of the McKenzie River.

19.1 (0.6) Lost Creek. This stream drains the west slopes of North and Middle Sisters. Most of its journey is underground, beneath Recent lava.

19.7 (0.6) Junction of Highways 126 and 242. Road cuts west and east slice through terminal moraines emplaced by a latest Wisconsin glacier. Boulders of andesite, rhyolitic obsidian, and other rock types from the Middle Sister are found in these moraines. The glacier issued from Lost Creek Canyon to the southeast and nearly blocked the McKenzie drainage. The McKenzie River was displaced to the north side of the valley but was apparently able to maintain its channel; no evidence of a related backfill has been found upstream.

Turn south onto McKenzie Pass Highway (242). This highway is closed during the winter; inquiry can be made at McKenzie Bridge Ranger Station, 2 miles west on 126.

20.3 (0.1) Cliffs on hill to east contain many thin flows of High Cascade diktytaxitic basalt surmounted by a massive rimrock of fine-grained, non-porphyritic basalt. The diktytaxitic units accumulated to an aggregate thickness of approximately 1500 feet in this area and can be traced west in a broad medial ridge, 5 miles down the McKenzie Valley. Erosional remnants occur along the sides of the valley, downstream for an additional 4 miles.

20.4 (0.2) Road left to Highway 126.

20.6 (0.3) Road cuts in glacial alluvium. This is typical of the floor of Lost Creek Canyon, except where it is covered by Recent lava.

20.9 (0.2) Logging road: right. Clear-cuts on this part of the valley floor are often frequented by collectors in search of obsidian boulders.

21.1 (0.6) Road to Limberlost Campground: left. The rim of the north canyon wall supports latest Wisconsin lateral moraines. The glaciers must, therefore, have been at least 1000 feet thick, 1 mile from the terminal moraines.

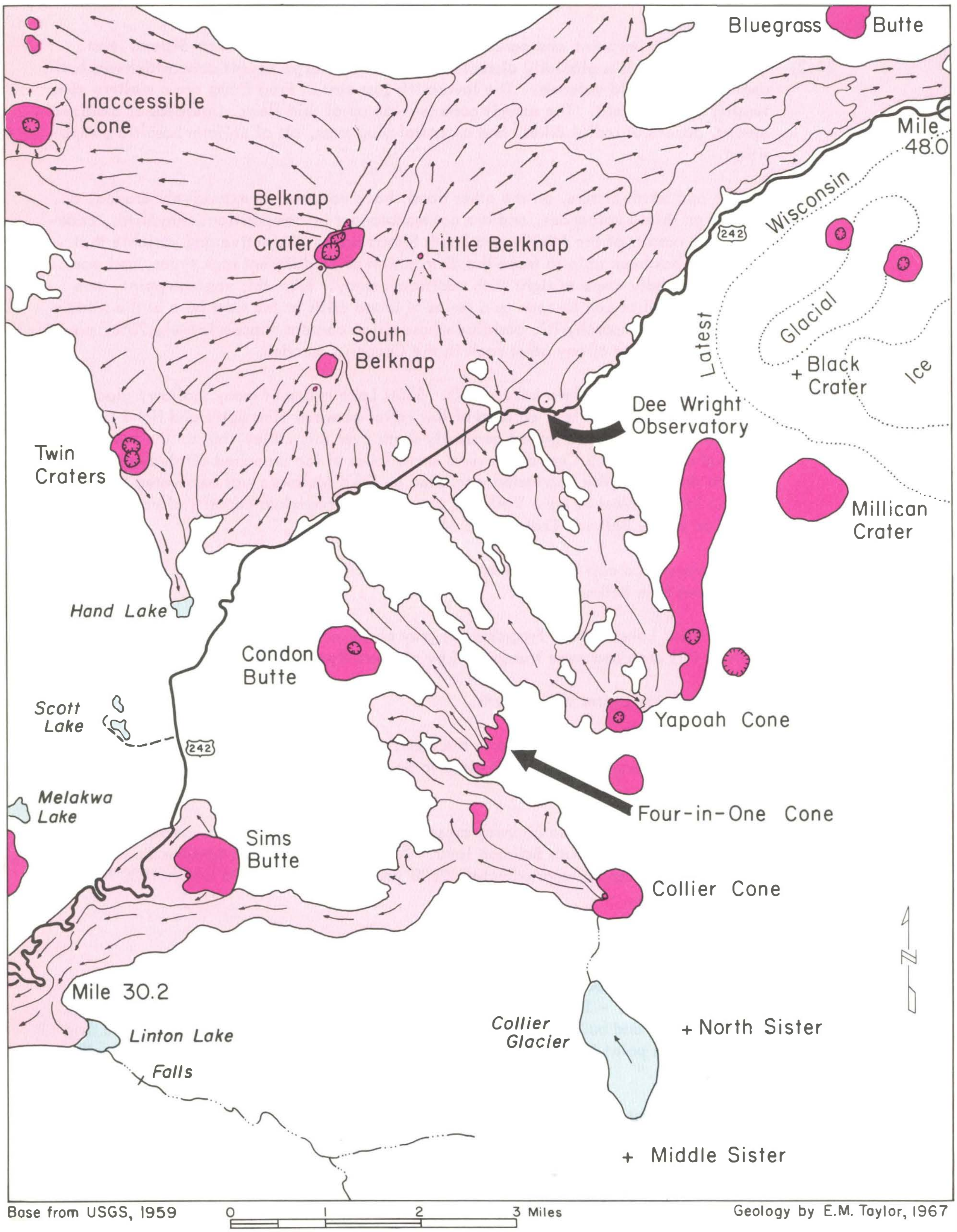
21.7 (0.3) Highway crosses onto Recent basalt lava flow which came from Sims Butte, 9 miles to the east.

22.0 (0.4) Road to quarries, clear cuts: left. Canyon walls to the south provide a cross section through an outlying Western Cascade foothill composed of several types of basalt and a thick welded-tuff unit. The entire complex was buried in a flood of thin diktytaxitic basalt flows.

Mileage		
22.4	(0.9)	Series of small road cuts in the scoriaceous surface of Sims Butte lava. Alluvial material from the canyon walls has buried the lava margins. Virgin timber, unspoiled even by selective cutting, can be seen in a few places along this section of highway.
23.3	(0.8)	White Branch Creek and view north to Cupola Rock. Both walls of the canyon are composed of diktytaxitic basalt flows, separated by thin, brick-red, baked soil horizons. All of the flows are relatively coarse-grained aggregates of olivine and augite set in a porous matrix of tabular plagioclase crystals.
24.1	(0.1)	Talus apron at base of Cupola Rock. Large blocks have fallen from the cliffs and have come to rest far out on the Sims Butte lava flow.
24.2	(0.5)	Logging road: right. During the latest Wisconsin glaciation, the canyon at this point was so full of ice that a small tongue overtopped the north rim and deposited moraines (with obsidian boulders) 2 miles down an adjacent valley.
24.7	(1.1)	Logging road: right.
25.8	(0.1)	Highway turns abruptly to the right. Just north of this point, an interbed of sand and gravel which can be traced between diktytaxitic flows to the west overlies a section of thin-bedded tuffaceous silt. Dips are about 5° to the northeast. This value is confirmed by interbeds elsewhere in the canyon walls and by a general eastward inclination of the entire diktytaxitic sequence. It may be inferred that the High Cascade platform has subsided somewhat, in response to its own weight.
25.9	(0.2)	View east to Three Sisters volcanoes.
26.1	(0.4)	Road to Youth Camp: right. The top of the diktytaxitic basalt sequence passes beneath the canyon floor in this area and presumably extends much farther east; accidental blocks of diktytaxitic basalt have been ejected during Recent eruptions along the High Cascade crest.
26.5	(0.8)	View east to Three Sisters volcanoes. Low-level cliffs left of highway are part of a thick flow of nonporphyritic, fine-grained basalt which locally overlies the diktytaxitic sequence.
27.3	(0.4)	View northeast to Deer Butte on north canyon wall. This is one of the old basaltic shield volcanoes of the High Cascade platform. The central plug, together with satellite dikes, outwardly dipping lavas, and scoriaceous interbeds, has been laid bare by glacial erosion.
27.7	(0.1)	First hairpin curve. In the forest to the south lies the terminus of a Recent basaltic lava flow from Collier Cone, which is located on the Cascade Crest, 7 miles east. The Collier Flow is less than 2500 years old and rests upon the lava from Sims Butte.
27.8	(0.2)	View northeast to Deer Butte.
28.0	(0.3)	Road cuts in thin scoriaceous basalt flows from Sims Butte.
28.3	(0.3)	High-standing margin of Collier Flow abuts highway on the right.
28.6	(0.1)	Parking area and trail to Pyroxy Falls. Many waterfalls spill down the south face of the canyon; some are fed by springs from interbeds in the cliffs, but the main falls is that of Pyroxy Creek, which drains a hanging valley. The trail to the falls crosses two flow units of Collier lava whose chemical and mineralogical compositions are markedly different.

Mileage		
28.7	(0.5)	Best view north to Deer Butte and associated rocks. Most road cuts for the next 6 miles will be in Sims Butte lava.
29.2	(0.9)	Large block of coarse-grained basalt just right of the highway tumbled onto the canyon floor from the Deer Butte plug.
30.1	(0.1)	Alder Springs Campground: right. Trail to Linton Lake.
30.2	(0.5)	Alder Springs: left. Boundary between Maps No. 2 and No. 3.
30.7		Hairpin curve with parking area; short-cut trail to Linton Lake: right.
	(0.8)	At the head of Lost Creek Canyon, Linton Creek pours over a series of Husband Volcano lava flows, producing the largest and most spectacular waterfalls in the Three Sisters area. Below the falls, lava from Collier Cone dammed the creek to form Linton Lake. The canyon has been blocked by lava flows and sculptured by ice on several occasions. Some of the first andesitic and basaltic lavas from Middle Sister vents moved 5 miles westward, filling a broad and deep U-shaped valley, just east and north of the modern Linton Lake. It is probable, therefore, that an ancestral Lost Creek Canyon was formed by pre-latest Wisconsin glaciers long before the Middle or South Sisters came into existence.
31.5	(0.5)	Clear area through trees: left. This is one of several outcrops along the canyon walls which consist of massive, coarse-grained basalt stained brown by deuteric alteration of olivine. Such rocks are of common occurrence in Cascade plugs, but here they were probably formed during slow cooling in exceptionally thick lava flows.
32.0	(0.5)	Highway turns abruptly left; margin of Collier Flow can be seen through trees on right.
32.5	(1.3)	The next mile of road cuts presents a seemingly endless succession of thin, slaggy basalt flows which issued from the Sims Butte vents and poured down the head of Lost Creek Canyon. Occasional views of the lower canyon, The Husband, and South Sister are encountered.
33.8	(0.4)	Roadside parking area. Coarse yellow cinders, ejected from Sims Butte, can be seen in several road cuts for the next mile. Ahead on the right is the margin of the Collier Flow.
34.2	(0.2)	Central crest of the most recent lava flow from Sims Butte. The main vent is 3000 feet east of this point, at the west base of the cone; other lava vents, now obscured, were located at the north and south bases. Most of the cinders and ashes drifted east while the lava moved west.
34.4	(0.4)	Flat alluvial fill for the next 0.4 miles. The alluvium is mostly reworked ash and fine cinders, deposited in a depression along the north margin of the Sims Butte lava.
34.8	(0.4)	Road cuts in glaciated basalt. Vast areas on the High Cascade platform are underlain by this variety of fine-grained, light-colored rock. Mount Washington in view ahead.
35.2	(0.4)	Road to Frog Camp and trails to higher elevations: right. The Frog Camp area is bordered on the south by an ash-covered lobe of Sims Butte lava and on the east by cliffs of glaciated basalt. In the base of the cliffs is a pillowed lava from which springs emerge.

MAP No. 3 Geologic Features From Mile 30.2 To Mile 48.0



Mileage		
35.6	(0.2)	Three Sisters viewpoint and parking area: Sims Butte, south; Three Sisters, east. The North Sister is a glacially dissected remnant of a large summit cone which was built upon a broad shield volcano. The lava cliffs just east of Frog Camp are a western extension of that shield. The summit cone is made up of thin flows, interbeds of oxidized ejecta, dozens of radial dikes, and a central plug mass, all of uniform basaltic composition. Middle and South Sisters, on the other hand, have not been as extensively eroded, do not rest on shield volcanoes, and are not monotonous in composition. Rhyolites, andesites, and basalts of the Middle and South Sisters are so distinctive and variable that the author has been able to trace the distribution of 26 different rock types, and more will undoubtedly come to light with additional study. From this vantage point, one variety of rhyolite can be seen as a series of broad cliffs at the west base of the Middle Sister. It is a nonporphyritic obsidian whose silica content (approximately 75%) may be higher than that of any other rock in the Oregon Cascades.
35.8	(0.6)	Road to Scott and Melakwa Lakes: left. Scott Lake is one of many shallow, glaciated depressions in Lake Valley, an area of low relief between Sims Butte and Hand Lake. Latest Wisconsin glaciers moved generally south over this valley, but on their way to the head of Lost Creek Canyon, several small lobes of ice branched off through low divides to the west. The depression occupied by Lake Melakwa was excavated by one of these lobes. Most of Lake Valley is covered with reworked deposits of volcanic ash from Sims Butte, Belknap Crater, and Mount Mazama.
36.4	(0.4)	First of many road cuts which, over the next 13 miles, contain layers of fine basaltic ash derived from Belknap Crater.
36.8	(1.2)	Trail to Hand Lake: left. Fragments of gray obsidian are abundant in the surficial deposits of this area and were transported by glaciers from a small plug dome 2 miles east.
38.0	(0.2)	View of Belknap Crater to the north.
38.2	(0.3)	View of Twin Craters cinder cone to the west. Highway follows the margin of basaltic lava which was erupted from vents close to South Belknap Cone, approximately 1800 years ago.
38.5	(0.6)	For the next 0.6 miles, the highway crosses a flat alluvial fill which has been deposited against the margin of South Belknap lava. A lava flow from Four-in-One Cone moved down an old stream bed approximately 2600 years ago and came to a halt 1000 feet southeast of here.
39.1	(0.5)	West Lava Campground: left.
39.6	(0.1)	Craig Memorial and parking area. Inscription on tomb: "In honor of John Templeton Craig (March 1821 - December 1877) - Pioneer mail carrier over the wagon road he himself located and built where the present highway runs. He perished in a little log cabin near this point from exposure in a terrific storm while attempting to carry mail over this route."
39.7	(0.1)	Craig Lake: right. From the roadway, glacial striations can be seen trending N. 45° W. over light-colored basalt of the Cascade platform. Approximately 8 inches of basaltic ash from Belknap vents was deposited in this area and was subsequently buried by lava flows. The dark ash is easily recognized in the uppermost section of road cuts and at the base of lava margins.

Collier Cone at the north base of North Sister:

The history of Collier Cone is unusually complex. Culminating eruptions occurred somewhat less than 2500 years ago, at which time so much lava surged from the vent that old channels (left foreground) were flooded and bypassed (flows center and far left). Lava composition changed continuously during the eruption. (Oregon Department of Geology and Mineral Industries photograph 67-288)

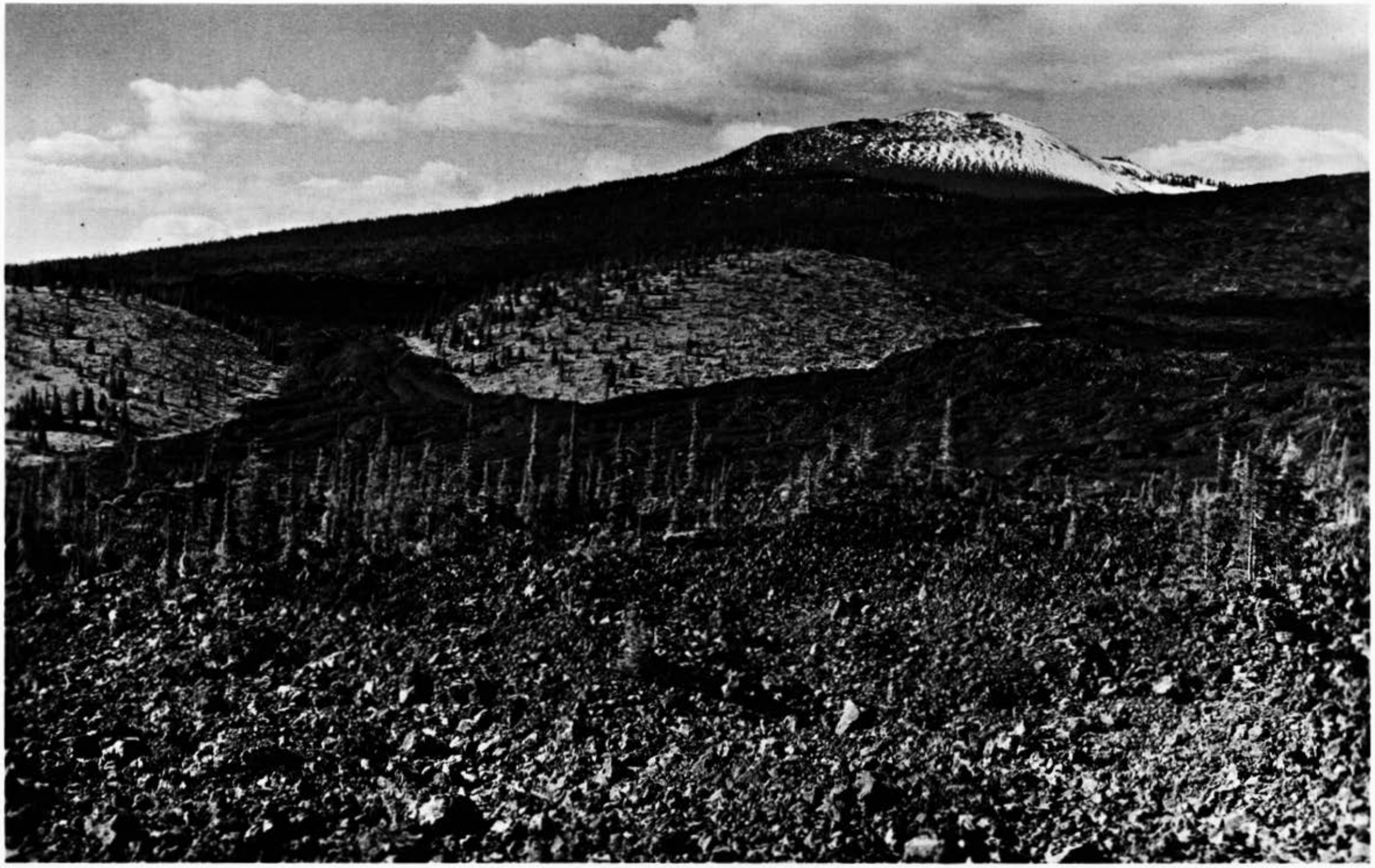
Four-in-One Cone viewed from the south:

Basaltic cinders and ashes were ejected from this alignment of cones 2600 years ago. Shortly thereafter, the cones were breached by streams of lava. In the photograph, ash deposits are seen to the right of Four-in-One Cone and lava to the left. (Oregon Department of Geology and Mineral Industries photograph 67-292)

Mileage		
39.8	(0.2)	Road to Huckleberry Lake: abrupt right.
40.0	(0.4)	Highway ascends onto surface of lava which issued from concealed vents at the southeast base of Belknap Crater. Terminus of a west lobe of lava from Yapoah Cone can be seen about 200 yards to the right, where it chilled against the Belknap flows.
40.4	(0.3)	Parking area: right. Four-in-One Cone is visible to the south. Yapoah flow is only 50 yards from the highway at this point. Small steptoe of glaciated basalt stands in the Belknap lava field 0.2 miles northwest.
40.7	(0.2)	Highway crosses southwest margin of a narrow, southern tongue of lava from Little Belknap. Total thickness of Belknap ash in this area is about 2 feet. Most of the ash lies buried beneath the earlier flows from Belknap Crater but approximately 1 inch was deposited upon their upper surfaces. No ash is found on Little Belknap or South Belknap lavas, except in close proximity to the main summit cone.
40.9	(0.1)	Crest of Little Belknap lava tongue. In spite of its fresh appearance, lava from Little Belknap is approximately 2900 years old, and predates lava from South Belknap by some 1100 years.
41.0	(0.2)	Northeast margin of Little Belknap lava tongue. Highway once again crosses onto older lava from Belknap summit cone and basaltic ash can be found within the surface material.
41.2	(0.1)	Parking area: left. Island of glaciated basalt surrounded by lava flows from Belknap summit, Little Belknap, and Yapoah Cone. Ash deposits are approximately 3 feet thick and contain thin beds of coarse cinders. An unusually well-preserved and inclined tree mold occurs in the lava margin, about 200 feet west of the parking area.
41.3	(0.5)	Skyline Trailhead: left. In a sharp curve to the right, the highway ascends a Yapoah lava margin. This flow, even if slightly forested, is younger than the bare and rough lava of Little Belknap which is in sight to the northwest.
41.8		Dee Wright Observatory parking area: recommended stop.
	(0.3)	History. This part of the crest has been used in Cascade passage for more than 100 years. Indian trails, stock driveways, and a toll road preceded the present highway. The observatory structure was built in 1927 and nature trails were added in 1966.
		View from the observatory. From the observatory roof the following landmarks are seen, proceeding clockwise from true north:

Azimuth (degrees)	LANDMARK
0	Mount Jefferson: Andesitic stratovolcano.
7	Cash Mountain: Basalt, glaciated, cinder cone remnant on summit, younger red cone on south slope.
11	Bald Peter (far horizon).
20	Dugout Butte (forested foreground): Glaciated basalt flows of the High Cascade platform.
30	Green Ridge (far horizon): Uplifted fault block.

Azimuth (degrees)	
40	Black Butte: 3000-foot basaltic cinder cone located at south end of Green Ridge fault zone. Bluegrass Butte (foreground): basaltic cinder cone, glaciated; ridge east is a lateral moraine.
82	Black Crater (fills most of eastern sector): Pre-latest Wisconsin basaltic volcano. "Crater" is really a glacial cirque open to the northeast.
105 to 155	Unnamed Cascade summit ridge composed of basaltic cinders, bombs, and flows which issued from a 5-mile set of fissures and cones. Probably was the site of spectacular lava fountains in pre-latest Wisconsin time.
168	North Sister (elev. 10,085 feet): Basaltic stratovolcano resting upon a broad shield of similar composition. Central plug mass exposed by long-continued glacial erosion. At base of North Sister stand Yapoah Cone (left) and Collier Cone (right).
174	Middle Sister (elev. 10,047 feet): Rhyolite-andesite-basalt stratovolcano supporting Collier Glacier. Younger than North Sister, but much eroded.
178	Summit of Little Brother with ridge west: Basaltic stratovolcano with exposed plug and dikes. Satellitic to North Sister.
188	Four-in-One Cones (below skyline): Four basaltic cones breached on the west by lava approximately 2600 years ago. Part of an alignment of 19 vents.
195	Huckleberry Butte (forested ridge): Glaciated basalt flows.
197	The Husband (on skyline, partly obscured): One of the most ancient and deeply eroded volcanoes in this region. Probably the largest plug mass in the Oregon Cascades.
218	Condon Butte: Recent basaltic cinder cone; no lavas; nested summit craters. Knob visible at left base is an unnamed, glaciated obsidian dome.
235	Horsepasture Mountain (far horizon): Western Cascade peak.
256	Scott Mountain: Small summit cone surmounting a broad shield. Both basalt, both pre-latest Wisconsin.
282	South Belknap Cone: Cone was formed and breached long before surrounding lavas were erupted.
285 and 306	Unnamed twin "islands" (in foreground lava field): Both are composed of glaciated basalt. They probably were never volcanoes, but volcanic vents were nearby.
309	Belknap Crater (summit cone on skyline): Focal point of a long-continued and complex episode of Recent volcanism. The broad basaltic shield which fills the northwest view is 5 miles in diameter and is estimated to be 1700 feet in maximum thickness and 1.3 cubic miles in volume. The volcano probably contains a core of cinders which interfingers with peripheral lava and whose surface expression is the summit cone. The most recent eruptions occurred at the north and south bases of Belknap Crater, approximately 1500 years ago. At this time, lava poured 12 miles to the west and ash was ejected from the north of two summit craters. The great bulk of Belknap ash, which has been traced over an area exceeding 100 square miles, was ejected earlier from a larger south crater.



<u>Belknap Crater seen from Dee Wright Observatory:</u>

Belknap Crater (snow-covered skyline) is impressive in stature, but is only a pile of cinders on the summit of a vast shield of recent lava. Forests in background grow upon old Belknap lavas; trees in foreground stand upon young lava from Yapoah Cone. Lava of intermediate age and position surrounds "islands" and issued from a subsidiary vent called Little Belknap. (Oregon State Highway Department photograph No. 423)

Lava from Little Belknap:

Desolate fields of blocky lava (foreground) from Yapoah Cone, and hummocky lava (background) from Little Belknap, lie between Dee Wright Observatory and the volcanic plug of Mount Washington. The jagged features of the Belknap lava surfaces were formed 2900 years ago. (Oregon State Highway Department photograph No. 427)

Azimuth (degrees)	
321	Little Belknap: Basaltic shield subsidiary to the main Belknap volcano; erupted approximately 2900 years ago.
340	Mount Washington: Basalt plug mass with radial dikes; surrounded by glaciated remnants of a volcano which, in size, might once have rivaled the North Sister.

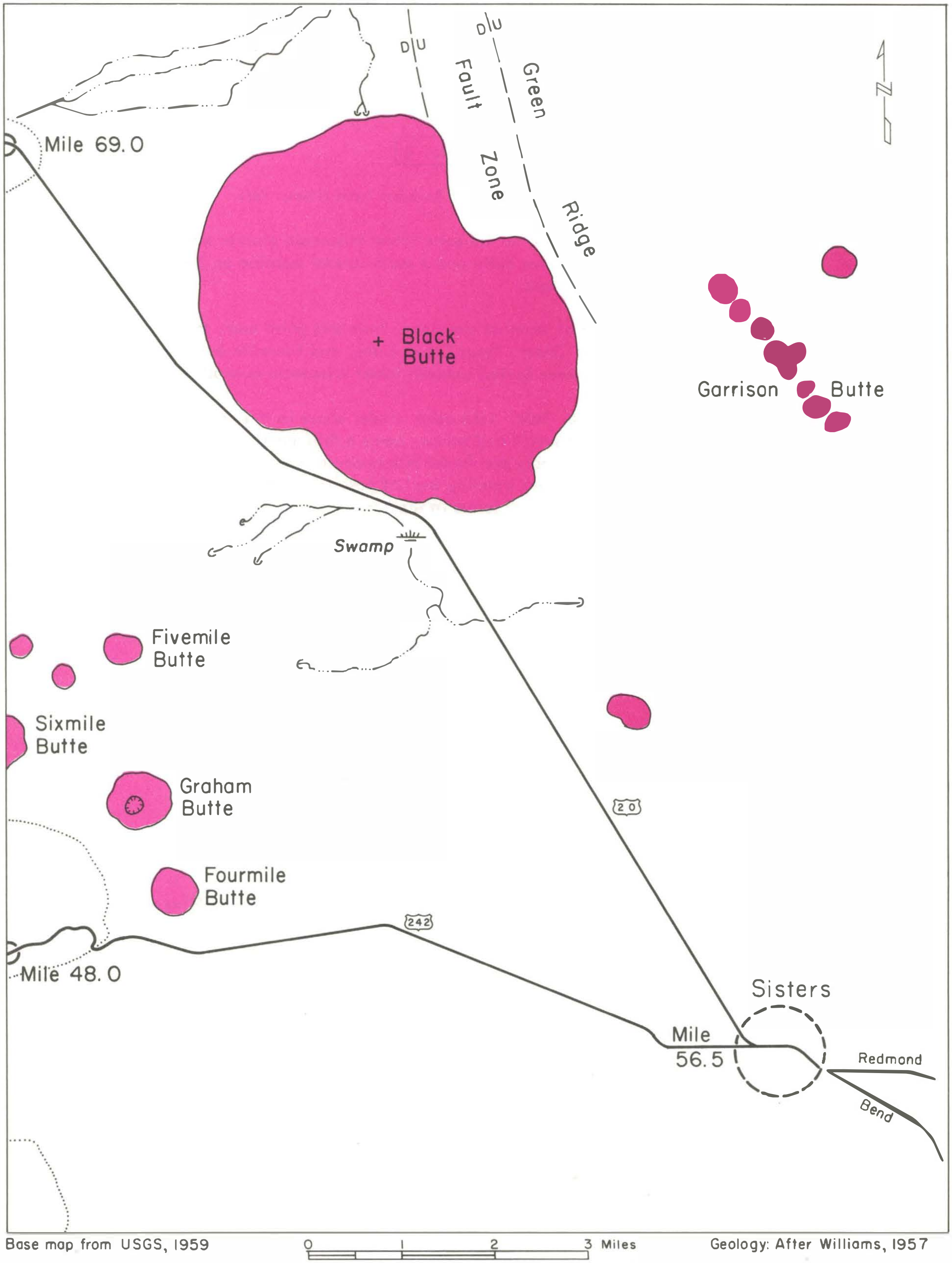
Lava trail east of the observatory. The observatory is located on the surface of a basaltic lava flow whose eruption occurred between 2600 and 2900 years ago. The source was Yapoah Cone, 3.2 miles south. An early stage in the development of the Yapoah Flow was recorded by the broad lobe of lava which now extends northwest from the observatory. This lobe formed the toe of the main stream, but as it advanced toward the opposing slope of the Belknap volcano, its movement was checked and arcuate pressure ridges appeared on its surface. Subsequent lava was deflected to the north and the area just east of the observatory became the main channel.

The "Lava River" nature trail leads from the observatory, east across the Yapoah main stream. Here the visitor can see a small lava tube whose roof has collapsed and a host of vertical cracks which were produced in the lava by thermal contraction and loss of gases just prior to final consolidation. On the east side of the main channel is an imposing levee. The visitor might well imagine the channel in full flood, rising at least as high as the levee crest and in favorable locations spilling over the eastern flank. When the supply of lava diminished, the molten interior drained away and the channel surface subsided. Lacking support, large segments of the levee tipped toward the central channel, causing deep, irregular tension cracks to open in the levee crest. The trail affords a view of one of these cracks and of several lava tongues along the east base of the levee.

Mileage		
42.1	(0.3)	Road cuts in east levee of Yapoah Flow. Several flow units can be seen in which thin lenses of dense lava are separated by thicker layers of porous flow breccia.
42.4	(0.1)	Road to Lava Camp Lake, campground, and Skyline Trailhead: right.
42.5	(1.5)	Small road cuts in glaciated fine-grained basalt. Latest Wisconsin glaciers moved in a northerly direction over this area.
44.0	(0.4)	Black volcanic ash from Belknap Crater is exposed in the upper 2 to 3 feet of road cuts.
44.4	(0.7)	Mount Jefferson in view to the north.
45.1	(0.1)	Windy Point. Glaciated promontory composed of fine-grained platy basalt. This, together with interbeds of scoria, is the basal part of Black Crater volcano. Mount Washington on skyline northwest; from this vantage point the broad shield on which the summit cone rests is easily seen. Blocky Yapoah lava in immediate foreground. Farther northwest is the lava field of Little Belknap. Just east of Windy Point and south of the Yapoah margin, is ash-covered lava from old vents at Belknap Crater.
45.2	(1.3)	Trail to Black Crater summit: right.
46.5	(0.1)	On lower left is south margin of Belknap lava flows. South of this point 0.25 miles is the crest of a latest Wisconsin lateral moraine which trends east for 2 miles, parallel to the highway.
46.6		View of Bluegrass Butte, 1 mile north. This butte is a basaltic cinder cone, essentially

Mileage		
	(0.6)	identical to others between Black Crater and Black Butte, except that it was overridden by latest Wisconsin ice and a lateral moraine extends east from its summit.
47.2	(0.8)	Road cuts in Belknap lava flows: left.
48.0	(0.5)	Boundary between Maps No. 3 and No. 4.
48.5	(0.3)	Road to Dugout Lake and terminus of Belknap lava flows: left.
48.8	(0.3)	Terminal moraine deposited by the same latest Wisconsin glacier which formed a north lateral moraine on Bluegrass Butte and a south lateral moraine on Black Crater. Belknap ash still visible in road cuts.
49.1	(0.2)	Sharp left turn; base of terminal moraine. From this point east, the surfaces of basaltic lava flows from Black Crater, Trout Creek Butte, and Fourmile Butte are encountered where they have not been buried beneath latest Wisconsin outwash deposits.
49.3	(1.5)	Road to Fourmile Butte: left. Like other cinder cones in this area, Fourmile Butte is composed of red basalt scoria and bombs, bears a thin mantle of Mazama pumice and Belknap ash, and is probably pre-latest Wisconsin in age. On the east flank of the cone is a peculiar east-west trending wall of basalt 15 feet wide, 35 feet high, and 150 feet long. The pattern of joints in the basalt and the inclination of adjacent strata suggest that the wall is a dike which was forced in a solid condition through the cone, appearing above the surface by extrusion rather than by erosion.
50.8	(0.5)	Road to Trout Creek Butte summit: right.
51.3	(1.0)	Crests of basaltic lava flows protrude through overburden of glacial outwash.
52.3	(0.2)	Near bend in highway, Cold Spring issues from lava flow margin.
52.5	(1.9)	Road to Cold Spring Campground: left.
54.4	(1.3)	Logging road overpass. Road cuts expose alluvial sands and gravels.
55.7	(0.7)	View southwest to Three Sisters and Broken Top volcanoes.
56.4	(0.1)	Oregon history information sign: "The McKenzie River route between the Willamette Valley and eastern Oregon was first used in 1862 when Felix Scott, Jr. and party with 900 cattle and 9 wagons of supplies hacked their way from the rock house 4 miles east of Vida across the divide south of Black Crater to Trout Creek in Jefferson County. The route up Lost Creek Canyon and Deadhorse Hill was discovered by John Latta in 1866 and the first travel over it was in 1872 after construction was completed by the McKenzie, Salt Springs, and Deschutes Wagon Road Company. Until 1891, tolls were collected at McKenzie Bridge, formerly known as Craig's Bridge, and then until 1894 at Blue River."
56.5	(0.3)	Town of Sisters; junction of Highways 20 and 242. Turn left and proceed northwest on Highway 20.
56.8	(1.5)	Oregon history information sign: "In this vicinity early Indian trails converged: One coming in from Tumalo Creek to the southeast, one from Sparks and Green Lakes to the southwest, one the Scott Trail (as later known) from the west, and one from The Dalles to the north."

MAP No. 4 Geologic Features From Mile 48.0 To Mile 69.0

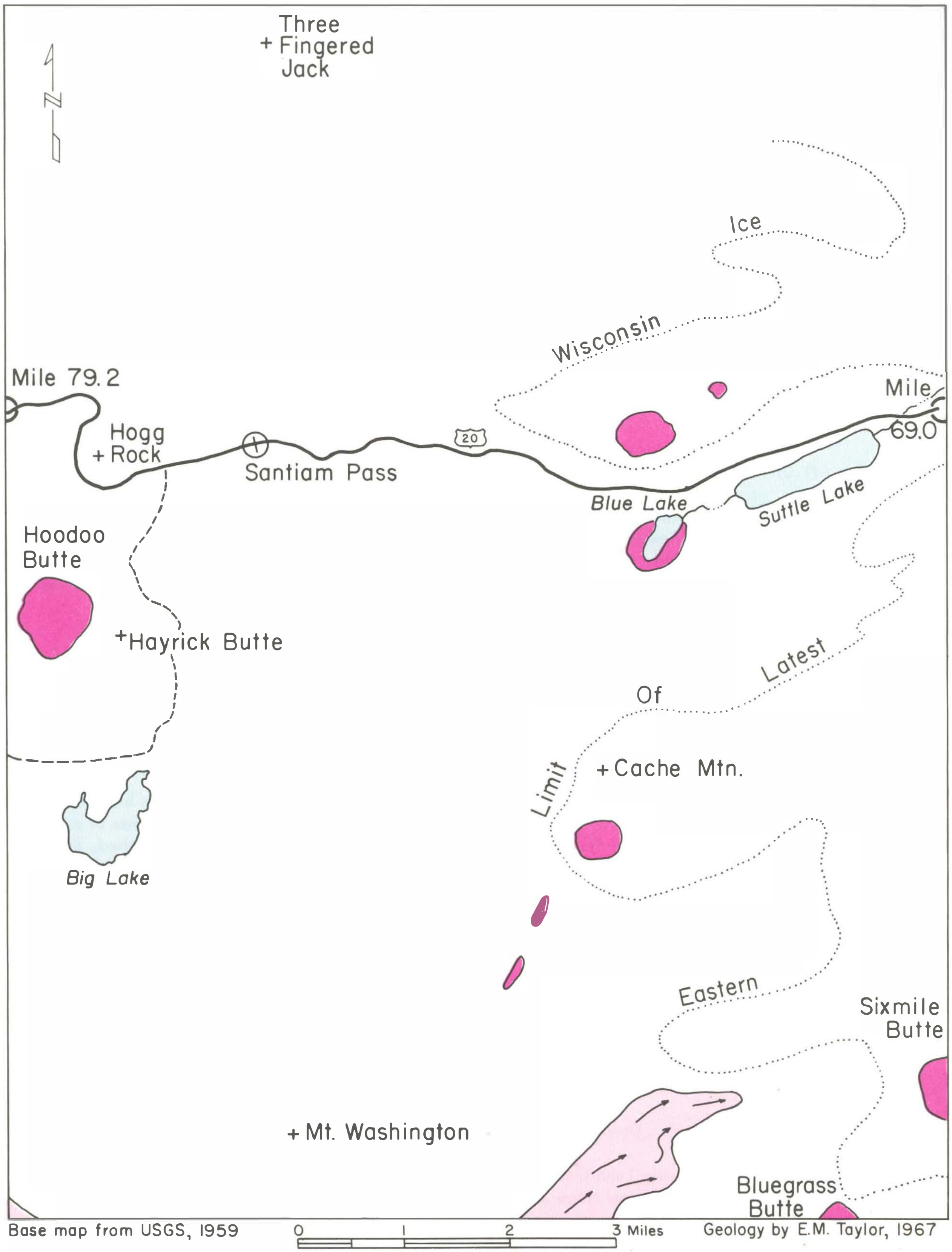


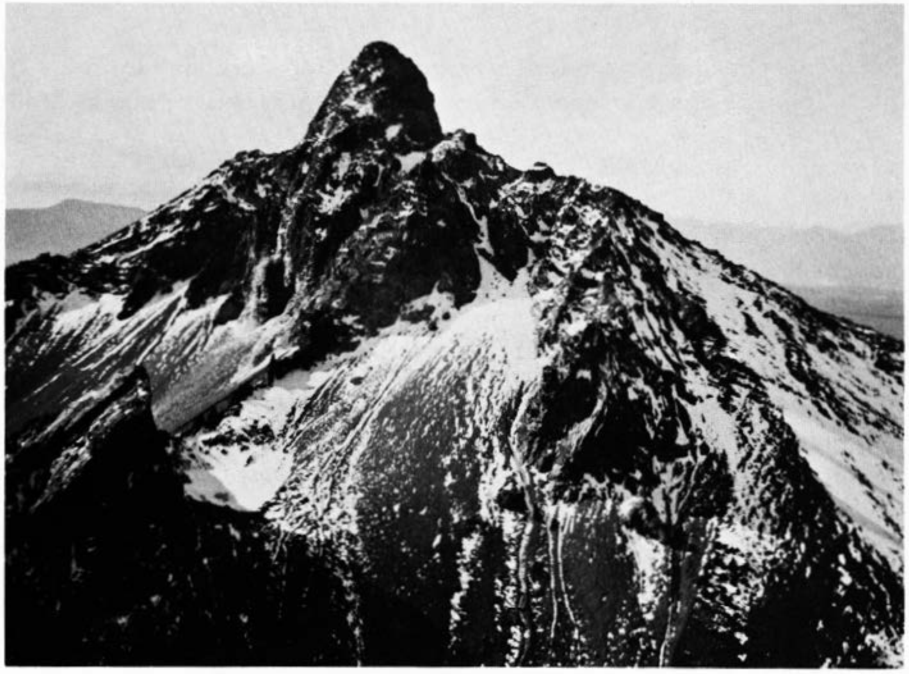
Base map from USGS, 1959

Geology: After Williams, 1957

Mileage		
58.3	(3.4)	For the next 3 miles Black Butte is intermittently in view to the northwest. On both sides of the highway the surface is generally flat and underlain by more than 20 feet of alluvium. A detailed account of roadside geology in the Sisters area must await further investigation; however, a brief description based chiefly on data from Williams (1957), is offered here. In the vicinity of Sisters, rocks which are clearly part of the High Cascade sequence to the west merge with rocks of the Madras Formation to the east. Basalt is the most common rock type in both areas but interbedded sands, conglomerates, ash-flow deposits, and welded tuffs are increasingly important to the east. Most of the surficial alluvium can be traced westward into deposits of glacial outwash, derived from the High Cascades. The surface is mantled with 1 to 2 inches of dacite pumice from Mount Mazama and as much as 3 inches of basaltic ash from the Belknap and Sand Mountain vents. Cinder cones of Recent and Pleistocene age are abundant.
61.7	(0.1)	Indian Ford Campground. Oregon history information sign: "Here was a ford on the Indian mountain trail mentioned by Lieutenant John C. Fremont. The only recorded use by early whites was by Lieutenant Henry L. Abbot and Pacific Railroad survey party in 1855."
61.8	(1.0)	Logging road overpass.
62.8	(1.0)	Black Butte Swamp. Before Black Butte came into existence, streams in this area apparently flowed north. Drainage is now obstructed by the butte and swampy areas occur where surface water soaks into the ground. This water, augmented by ground water in the butte itself, is probably ample to supply the large and well-known Metolius Springs to the north.
63.8	(2.1)	Broad, fan-shaped lava surface to the north leads up to an obscure vent at the southwest base of Black Butte. Black Butte is probably pre-latest Wisconsin in age and owes its symmetrical, nonglaciated profile to its position within the Cascade rain shadow.
65.9	(2.1)	Road to Camp Sherman and other points of interest along the upper Metolius River: right.
68.0	(0.7)	Logging road to Cache Mountain, a chain of Recent spatter cones, and an historic wagon road toll station: left. Coarse cinders visible in the uppermost few inches of soil were ejected from Blue Lake Crater, 3 miles west. As the source is approached, the cinder layer becomes thicker, darker, and more obvious.
68.7	(0.3)	Beginning of road cuts through latest Wisconsin terminal moraines. This represents the lowest elevation reached by an eastward extension of the ice sheet which accumulated between Mount Washington and Three Fingered Jack. The moraines are covered with 0.5 to 1 feet of fine ash from the Sand Mountain volcanoes and by approximately 1 foot of younger cinders from Blue Lake Crater.
69.0	(0.4)	Boundary between Maps No. 4 and No. 5.
69.4	(0.3)	Road to Suttle and Blue Lakes: left.
69.7	(0.1)	Lake Creek. Drains Suttle and Blue Lakes through gap in terminal moraine.
69.8	(1.2)	Road to Suttle Lake Guard Station: left. Sand and gravel of a lateral moraine which forms an east-west ridge 2 miles long and 600 feet high are exposed in road cuts ahead.

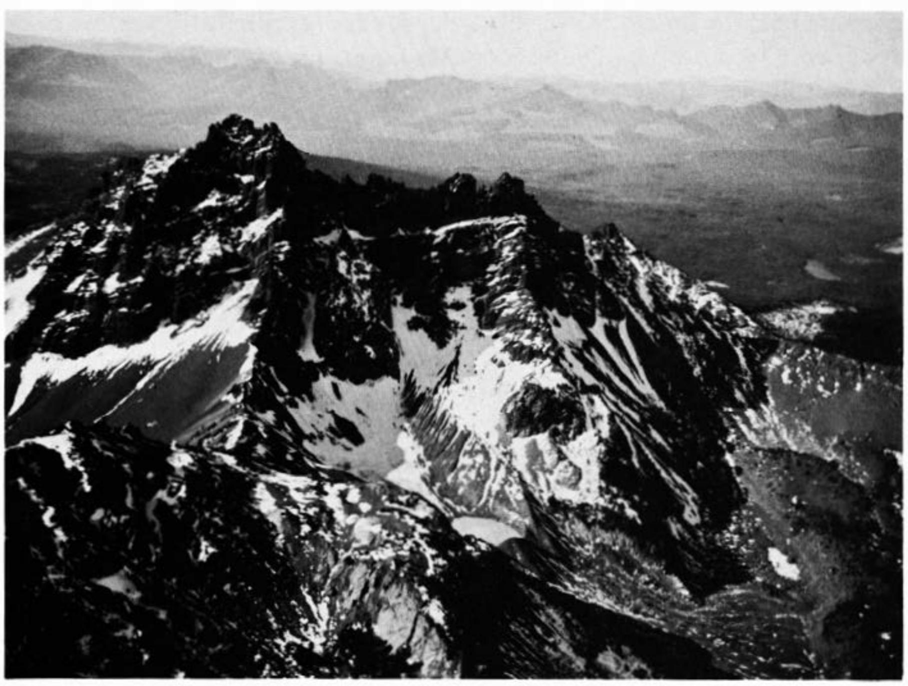
MAP No. 5 Geologic Features From Mile 69.0 To Mile 79.2





Summit cone of Mount Washington as viewed from the northeast:

Thin layers of basaltic lava, flow breccia, and agglomerate dip away from a high-standing plug which now fills the original volcanic conduit. Dikes of resistant basalt, one of which can be seen in the left foreground, occur on several radial ridges. (Oregon Department of Geology and Mineral Industries photograph 67-282)



Summit cone of Three Fingered Jack as viewed from the east:

The modern peak is a remnant of a much larger, glacially dissected basaltic volcano whose central plug, with attendant radial dikes, can be seen in the center foreground. (Oregon Dept. of Geology and Mineral Industries photograph 67-275)

Mileage		
71.0	(0.1)	View southwest to Cache Mountain and Mount Washington. Suttle Lake, below, rests in an elongate basin, enclosed by terminal and lateral moraines.
71.1	(0.6)	Road cuts ahead expose basalt flows of the High Cascade platform. They often display platy jointing and are separated by reddened interbeds of coarse breccia.
71.7	(0.1)	View of North and Middle Sisters through low point in southern horizon.
71.8	(0.3)	Deep road cuts in basalt. These lava flows are reversely magnetized and are probably part of the early shield volcano on which Three Fingered Jack now stands.
72.1	(0.6)	Blue Lake overlook. Blue Lake occupies a Recent crater surrounded by a rim of volcanic cinders and bombs, ejected approximately 3500 years ago. Although no lava appeared, the eruptions must have occurred with considerable violence, for most of the crater was blasted out of solid bedrock and large fragments were scattered in all directions. The landscape is blanketed with cinders for 3 miles east and southeast.
72.7	(1.1)	Fine basaltic ash from Sand Mountain volcanoes appears here in road cutsand becomes thicker toward the west.
73.8	(2.2)	The red cinders which are so prevalent on road cuts here (and elsewhere) have been deposited by highway snowplows and are not part of the natural stratigraphy.
76.0	(0.8)	Santiam Summit, elevation 4817.
76.8	(0.3)	Road to Hoodoo ski area, Big Lake, and Sand Mountain: left.
		Recommended side excursion; 15 miles and 2 hours round trip. Follow pavement east of Hoodoo Butte (Recent cinder cone, no lavas) and Hayrick Butte (mesa-like glaciated mass of basaltic andesite) to Big Lake (occupies glacially carved basin). Follow dirt road west to summit of South Sand Mountain (best view of north-south, 6-mile alignment of Recent cinder cones and lava fields).
77.1	(0.3)	Southeast end of Hogg Rock: right. Oregon history information sign: "The old grade crossed by the Santiam Highway at this point was built as part of the Corvallis and Eastern Railroad by T. Egenton Hogg in 1888 and was to have connected Newport and Boise."
77.4	(0.3)	View south to Hoodoo and Hayrick Buttes. Hoodoo Butte is a Recent basaltic cinder cone with a summit crater. Hayrick Butte contains the same platy-jointed basaltic andesite as is seen in the cliffs of Hogg Rock, and both masses have been completely overridden by glacial ice. The original cooling surfaces of both Hogg Rock and Hayrick Butte are outlined by black, glassy, columnar-jointed rinds which are more than 50 feet thick in places. These features are common to many other Cascade andesites and basaltic andesites.
77.7	(0.2)	View northwest to Maxwell Butte, a broad basaltic volcano of near-Recent age. Latest Wisconsin glaciers lightly scoured the upper flanks but did not extend to the west base of the mountain. Consequently, Maxwell Butte lava flows present a Recent appearance only near their western boundary.
77.9	(0.5)	Parking area: left. Lost Lake group of cinder cones, 2 miles west; Three Fingered Jack, 4 miles northeast; road cuts in Hogg Rock, right. Platy jointing tends to develop parallel to cooling surfaces; in Cascade basaltic andesites this is usually enclosed

Mileage

within a black, glassy rind in which columnar joints are perpendicular to cooling surfaces.

78.4 (0.3) In road cut right, thin flows of vesicular basalt are overlain by a thicker flow of dense, coarse-grained basalt.

78.7 (0.5) Deposits of reworked basaltic ash mantle outcrops of glacial alluvium. The ash is chiefly from Lost Lake Cones and Little Nash Crater.

79.2 (0.2) Boundary between Maps No. 5 and No. 1.

79.4 (0.6) In road cuts and on hillside north of highway are several outcrops of columnar and platy jointed basalt flows overlain by glacial alluvium and surficial deposits of basaltic ash.

80.0 (0.3) View west to Lost Lake group of cinder cones. Approximately 2000 years ago a north-south alignment of four basaltic cinder cones and associated lava flows was formed and the resulting ridge dammed Lost Creek.

80.3 (0.5) Road to Lost Lake campground: right. All but the topmost projections of lava surfaces are here obscured by deposits of ash from nearby cones.

80.8 (0.4) Crest of Lost Lake ridge of cones. Cuts on both sides of highway expose coarse cinders of South Cone. The crater is north of the highway and is approximately 1000 feet in diameter and 300 feet deep. Fine volcanic ash seen on the west slope of this cone is from Little Nash Crater, 1.5 miles west.

81.2 (0.6) The next 1 mile of highway is underlain by slaggy basalt from Lost Lake cones; however, most of the lava surface has been buried under basaltic ash from Little Nash Crater.

81.8 (0.1) View south to Nash Crater.

81.9 Santiam Junction. Continue left on Highway 20.

(0.9) A relatively complex geologic history is associated with the junction area. Latest Wisconsin lateral moraines form ridges to the north and south, outlining the last advance of glacial ice. Among the first Recent lava flows were those which moved from vents between Nash Crater and Sand Mountain, northward over the junction area, and then west to Lava Lake. These first flows were overridden by an early lava (the Lava Lake Flow) from Nash Crater. Subsequently, the Lost Lake Cones were formed and lava moved west, covering the junction area once again. After a period of quiescence, younger, more siliceous basalts (Fish Lake Flows) emerged from the south and northwest bases of Nash Crater. During this second phase of activity at Nash Crater, Little Nash Crater was formed and breached by basaltic flows. All of these volcanic episodes deposited lava or ejecta or both in the vicinity of Santiam Junction.

82.8 (0.4) Road to quarries in Little Nash Crater: right. The Little Nash cone is remarkable in that prior to eruption of volcanic material, a steam vent was blasted through underlying fine-grained basalt, and fragments of this bedrock were scattered in all directions. The resulting layer of rubble is about 1 foot thick near the cone, decreasing to nil at radial distances of 0.5 to 0.6 miles.

83.2 (0.2) Crest of Fish Lake Flow from northwest vent of Nash Crater.

Mileage		
83.4	(0.3)	Highway crosses contact between Fish Lake Flow (east) and still younger flows from Little Nash Crater (west). Fine ash from Nash Crater fell on both of these flows, but the resulting deposit is thin and to be seen it must be recovered from interstices in the lava.
83.7	(0.3)	At west end of parking area is a contact between Lava Lake Flow (smooth, almost ropy crusts; overburden of ash; extends west) and a younger flow from Little Nash Crater (blocky surfaces; thin ash cover; extends east).
84.0	(1.1)	Sawyer's Cave: left. This is a short lava tube within the Lava Lake Flow. A delicate and well-preserved ropy crust covers the east floor of the cave.
85.1		Junction of Highways 20 and 126; completion of circuit.

Glossary of Technical Terms

Andesite. Volcanic rock intermediate in composition between basalt and rhyolite.

Augite. Dark-colored silicate mineral.

Basalt. Dark-colored volcanic rock with abundant iron, magnesium, and calcium.

Breccia. A consolidated deposit of rock fragments.

Cirque. Amphitheater carved by a glacier.

Dacite. Siliceous andesite.

Deuteric. Igneous rock alteration which takes place during cooling.

Diktytaxitic. Texture of relatively coarse-grained, porous lava in which gas pockets form between crystals rather than within glass.

Diorite. Coarse-grained igneous rock of andesitic composition and deep-seated crystallization.

Hypersthene. Dark-colored silicate mineral.

Monzonite. Coarse-grained igneous rock similar to granite.

Moraine. Unsorted deposit of rock particles which accumulate at the margins of a melting glacier.

Obsidian. Rhyolitic glass.

Olivine. Dark-colored silicate mineral.

Outwash. Layered deposits of rock particles which have been transported from margins of glaciers by meltwater streams.

Palagonite. Altered basaltic glass.

Phenocryst. Large mineral grain in an igneous rock matrix which is composed of smaller grains.

Pleistocene. Interval of geologic time embracing the last 1 million years.

Pliocene. Ten-million-year interval of geologic time, ending 1 million years ago.

Porphyritic. Containing phenocrysts.

Recent. Interval of geologic time elapsed since last ice age (10,000 to 12,000 years).

Rhyolite. Light-colored volcanic rock with abundant sodium, potassium, and silicon.

Shield. Volcano with gentle slopes.

Spiracle. Blowhole formed as lava moves over wet ground.

Tuff. Consolidated volcanic ash.

Unconformity. Discontinuity separating rock units of contrasting geologic history.

Vesicle. Rounded gas pocket in lava.

Vitrophyre. Porphyritic glass.

Wisconsin. Interval of geologic time associated with last major advance of glacial ice.

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* * * * *

CRATER LAKE AREA

VOLUME OF THE MAZAMA ASH-FALL AND THE ORIGIN OF CRATER LAKE CALDERA

By Howel Williams* and Gordon Goles*

Our principal objectives are these: 1) To correct a miscalculation by Williams (1942) of the volume of ash blown from Mount Mazama during the initial phases of its climactic eruptions; 2) to acknowledge a minor miscalculation of the volume of Mount Mazama that collapsed to form the caldera that holds Crater Lake; and 3) to emphasize that the discrepancy between the volume which collapsed and the volume of erupted magma and lithic ejecta, though much less than formerly supposed, remains to be explained.

Volume of the Ash-Fall

Williams (1942) calculated that the volume of ash and pumice that fell from the air prior to the discharge of the final glowing avalanches from Mount Mazama was about 3.5 cubic miles (15 km^3). Of this volume, he supposed that only 0.5 cubic miles (2 km^3) fell beyond the 6-inch isopach. These conclusions were based on the rapid diminution in the thickness of the ash blanket between Crater Lake and the vicinity of Bend, and on an estimate that the volume of ash between the 6-inch and 1-foot isopachs was only 0.17 cubic miles (about 0.7 km^3).

Mazama ash has since been identified, by the careful studies of Powers, Wilcox, and others, over an immense area beyond the 6-inch isopach, extending into British Columbia, Alberta, Montana, and Idaho, and southeastward into Nevada (figure 1). More recently, a layer of supposed Mazama ash, composed mostly of particles of glass and measuring 4 cms in thickness, has been identified on the ocean floor 40 miles west-northwest of the mouth of the Columbia River (Royse, 1967). No doubt a considerable amount of extremely fine ash fell far beyond the presently recognized limits.

The foregoing discoveries and a helpful discussion with Dr. Bruce Bolt, Professor of Seismology, University of California, Berkeley, set us to wondering about the volume of ash that fell beyond the 6-inch isopach. We realized, of course, that an accurate calculation is impossible because most of the fine ash, far removed from its source, has long since been eroded and redistributed by wind and water during the approximately 7000 years that have elapsed since the great eruption. Moreover, airborne pyroclastic ejecta are controlled in their distribution by innumerable factors, such as the nature of the fragments themselves, their "muzzle velocities," variations in wind velocities and directions at various elevations, eddies caused by topographic obstacles, and rains accompanying the "fallout." Nevertheless, it has seemed to us warranted to make a crude estimate of the total volume of the Mazama ash-fall.

Crandall and Mullineaux (1967) noted that Mazama ash covers Mount Rainier National Park "to a maximum depth of 3 inches," and "forms a discontinuous blanket a few inches thick" over the entire region. Prof. W. H. Mathews (in litt., August 22, 1967) tells us that all of the Mazama ash seen in roadcuts in the southern part of British Columbia occurs in reworked, alluvial lenses. "About the only places I know of where chances of reworking are at a minimum are in peat bogs, some 4 or 5 meters down." Within such a bog at Jesmond, roughly 150 miles north-northeast of Vancouver, he discovered a layer of Mazama ash approximately 5 mm thick at a depth of about 433 cms. Unfortunately, no direct measurement

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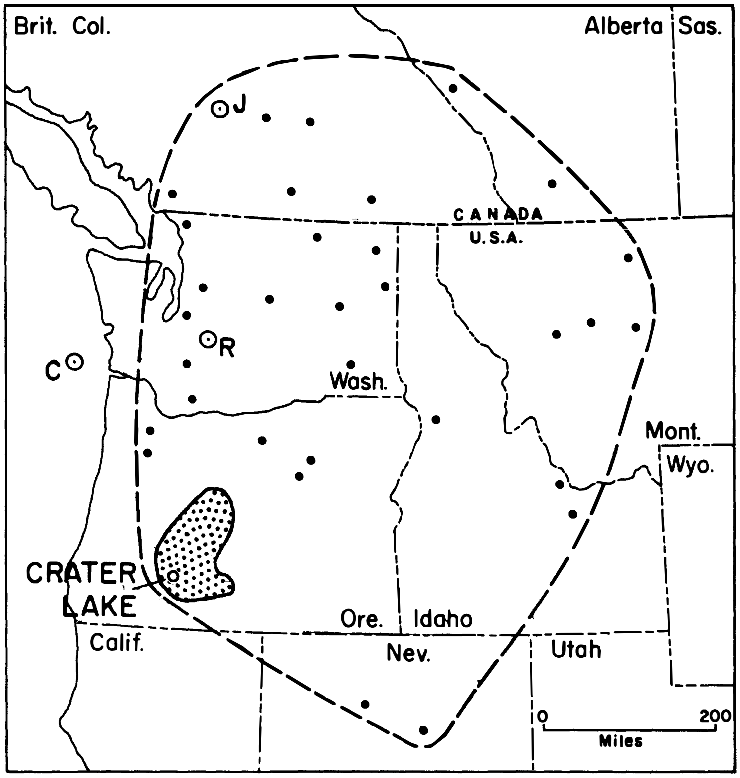

Figure 1. Distribution of Mazama ash. Stippled area shows where ash is more than 6 inches thick. Dots indicate locations of samples identified by Powers and Wilcox, 1964. J - Jesmond Marsh; R - Mount Rainier; C - submarine ash, 4 cm thick.

was made of the thickness, and Mathews warns that the Hiller borer may have smeared and spread some of the ash into the adjacent peat.

For our present purpose, we assume that the original thickness of Mazama ash which fell over Mount Rainier National Park was 2 inches (5 cm), and that which fell into the peat bog at Jesmond was 0.2 inches (5 mm). Variations in the thickness of the ash along a north vector from Crater Lake are therefore as follows:

Distance from source (miles)	Thickness (inches)
21.9	60
34.1	36
39.4	24
44.7	12
55.3	6
About 275 (Mount Rainier)	About 2
About 600 (Jesmond)	About 0.2

These figures may be fitted to an exponential curve, either graphically or by a least-squares calculation. It is then a simple matter to set up the equation for the differential volume in an arcuate segment, width dx, where the thickness decreases exponentially with increasing distance from the source, x, and integrate over distances from Crater Lake within the area known to contain Mazama ash. Figure 2 shows

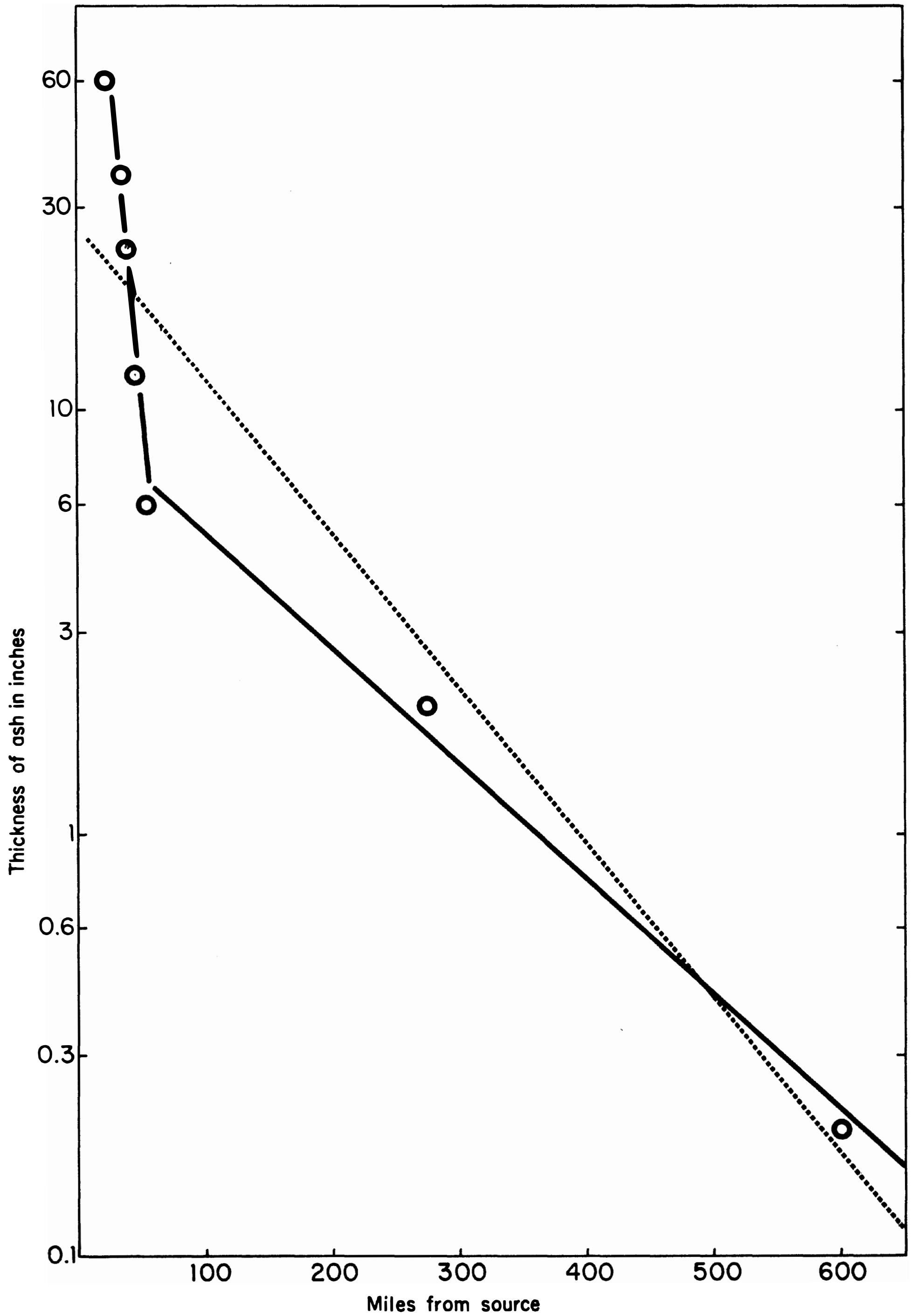

Figure 2. Mazama air-fall ash contour along north vector.

that the thickness-contour along the north vector can best be fitted by the sum of two exponential curves, implying that two different mechanisms governed the distribution of the ash. Following a suggestion by Prof. H. R. Blank of the Center for Volcanology, University of Oregon, we shall tentatively assume that these mechanisms are related to turbulent flow of ash-charged air masses close to the source, and to laminar flow (on a large scale) of more-or-less normal wind patterns at greater distances from the source. In this explanation, we assume that the relatively coarse ash could be transported efficiently only by air masses in which turbulent motions were driven by energy derived largely from the eruption itself, so that the thickness of ash close to the source decreases rapidly. In contrast, the distribution of fine ash blown to very high levels in the atmosphere is much less dependent upon local effects. Note that even if this tentative explanation of the distinction between the slopes of the two exponential curves of figure 2 is invalid, the observed distribution of Mazama ash may be treated by the simple approach we have employed. Since the volume of ash that fell within the 6-inch isopach (approximately at the break between the steep and gentle slopes of the contour) is known to be about 3 cubic miles (12 km^3), the heavy line in figure 2 represents the distribution of ash lying between 60 and 1000 miles of Crater Lake. For comparison, the dashed line was found by a least-squares fit of all the data, and this clearly yields an overestimate of the volume of ash outside the 6-inch isopach.

Our tentative conclusion is that the volume of Mazama ash that fell between 60 and 1000 miles from Crater Lake was about 5.7 cubic miles (23 km^3); it was not less than 4 nor more than 6 cubic miles, and hence was greater than the volume of ash which fell closer to the source. A test for convergence showed that the volume lying beyond 1000 miles is at most a few hundredths of a cubic mile. More measurements of ash thickness are needed, especially along directions other than north from Crater Lake. Also, this estimate does not take into account ash which may be on the ocean floor, although that omission is not likely to be serious.

The content of crystals and lithic fragments in the ash deposits diminishes rapidly away from the source while that of pumiceous particles and glass shards increases, until only vitric dust is to be expected near the limits of the fallout.

Our revised estimates of the volume of material blown from Mount Mazama just before its top collapsed are, therefore, as follows:

	Cubic miles	Cubic kilometers
Preliminary ash-fall	7 to 9	29 to 37
Glowing avalanche deposits	6 to 8	25 to 33
Final ash-fall	0.25	1
Totals	13.3 to 17.3	55 to 71

The total volume of erupted lithic fragments was between 1 and 2 cubic miles (4 to 8 km^3); the total volume of erupted crystals was between 2 and 3.5 cubic miles (8 to 15 km^3). Accordingly, the total volume of pumiceous fragments and glass shards was between 8 and 14 cubic miles (33 to 58 km^3), which is roughly equivalent to twice the volume of the original liquid magma with all of its gas in solution. We think that the aggregate volume of liquid magma, plus its entrained crystals and the lithic fragments blasted from the top of Mount Mazama during its climactic outburst, was approximately 10 cubic miles (42 km^3), rather than 6.5 cubic miles (27 km^3) as formerly supposed.

The Volume of Mount Mazama That Collapsed

How much of the top of Mount Mazama was engulfed to produce the present caldera? In 1942, Williams concluded, as Diller (1902, p. 48) had done long before, that 17 cubic miles (71 km^3) of the ancestral volcano foundered. We now think that this volume is somewhat excessive, and that the top of the volcano was considerably lower than 12,000 feet, as originally supposed. A thoughtful and stimulating letter from Prof. R. C. Sill, Department of Physics, University of Nevada, Reno (September, 1962) led us to revise our estimate. The distribution of pumice along and near the rim of Crater Lake strongly suggests that when the great eruptions took place, about 7000 years ago, there were no long glaciers on the northern slopes of Mount Mazama; nevertheless, three glaciers descended the southern sunny slopes to pass through Sun Notch, Kerr Notch, and Munson Valley, extending a mile or more beyond the present rim of the caldera.

Professor Sill suggested a reasonable explanation. "The mountain was so highly asymmetrical that the very gentle northern slopes could sustain only snow slopes or very sluggish and thin ice fields. The southern glaciers originated on a protected slope higher on the mountain and were diverted toward the south by special features, perhaps such as other satellite cones situated towards Mount Scott." Most likely, there was a huge summit-depression, probably a greatly enlarged crater, in which enough ice accumulated to feed the three long glaciers that flowed down the sunny, southern slopes. The highest walls of this summit-depression must have been on the northeast and east sides, and the lowest on the south and southeast, permitting ice to escape in those directions.

Observations made during repeated visits to Crater Lake have also suggested that many eruptions of dacite pumice took place from vents on the northern flank of Mount Mazama not long before the final collapse, and that these also diminished the volume of the upper part of the volcano. Accordingly, we now think that not 17 cubic miles (71 km^3) of the mountain-top were engulfed, but more nearly 15 cubic miles (62 km^3).

Origin of the Caldera

A serious discrepancy still persists. The volume of magma (liquid and crystals) plus the volume of old rock fragments blown out during the climactic eruptions was about 10 cubic miles (42 km^3); the volume of the mountaintop that collapsed was greater by roughly 5 cubic miles (21 km^3). If the magma in the reservoir had already begun to froth prior to the eruptions, the discrepancy would be reduced still farther, but probably not by a large amount. Hence, for lack of a better explanation, we seem to be obliged to assume that some of the space necessary to permit the collapse of the top of Mount Mazama was provided by subterranean withdrawal of magma, either through fissures in the walls of the reservoir or by recession at still greater depths. Such magmatic withdrawal may indeed have triggered the explosive eruptions that led to engulfment.

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AEROMAGNETIC AND GRAVITY SURVEYS OF THE CRATER LAKE REGION, OREGON*

By H. Richard Blank, Jr.**

Introduction

Since 1962 the U.S. Geological Survey has been engaged in a continuing program of geophysical studies in southwestern Oregon, primarily concerned with delineating and interpreting the regional Bouguer gravity field (Blank, 1966). In the course of this study the gross features of the gravity field in the vicinity of Crater Lake were delineated. It was early apparent that the Crater Lake complex does not produce a large negative gravity anomaly such as is commonly associated with calderas of the Krakatoan type (Yokoyama, 1963). This result was not unexpected in view of the evident lack of an appreciable thickness of low-density fill within the caldera. However, it was felt that a more complete definition of the geophysical environment of the caldera might shed some light on its regional structural position and on the question of whether related intrusive bodies are present at depth. To this end additional gravity work was performed, including the establishment of a number of stations within the caldera on the perimeter of the lake and on Wizard Island, and an aeromagnetic survey was made of the caldera and its immediate surroundings. The cooperation and assistance of the National Park Service greatly facilitated work within the Park and are gratefully acknowledged.

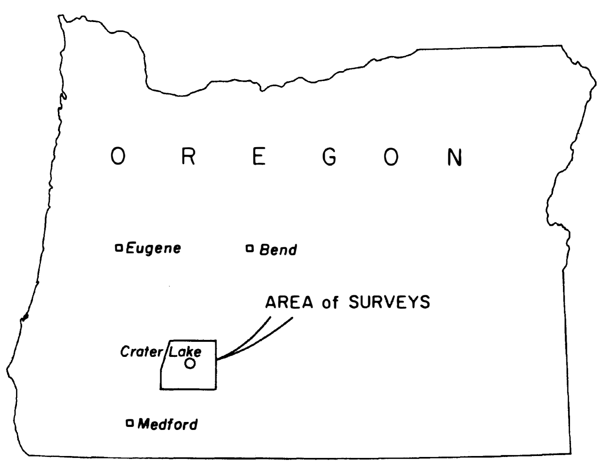


Figure 1. Index map of Oregon.

Physiographic Setting

The region considered in this paper includes all of Crater Lake National Park and extends across the entire width of the High Cascades physiographic province, from several miles east of U.S. Highway 97 to the western slopes of the upper Rogue River Valley. It is bounded on the north by approximately the latitude of Diamond Lake and on the south by the latitude of Fort Klamath. Figure 1 locates the region with respect to Eugene, Bend, and Medford.

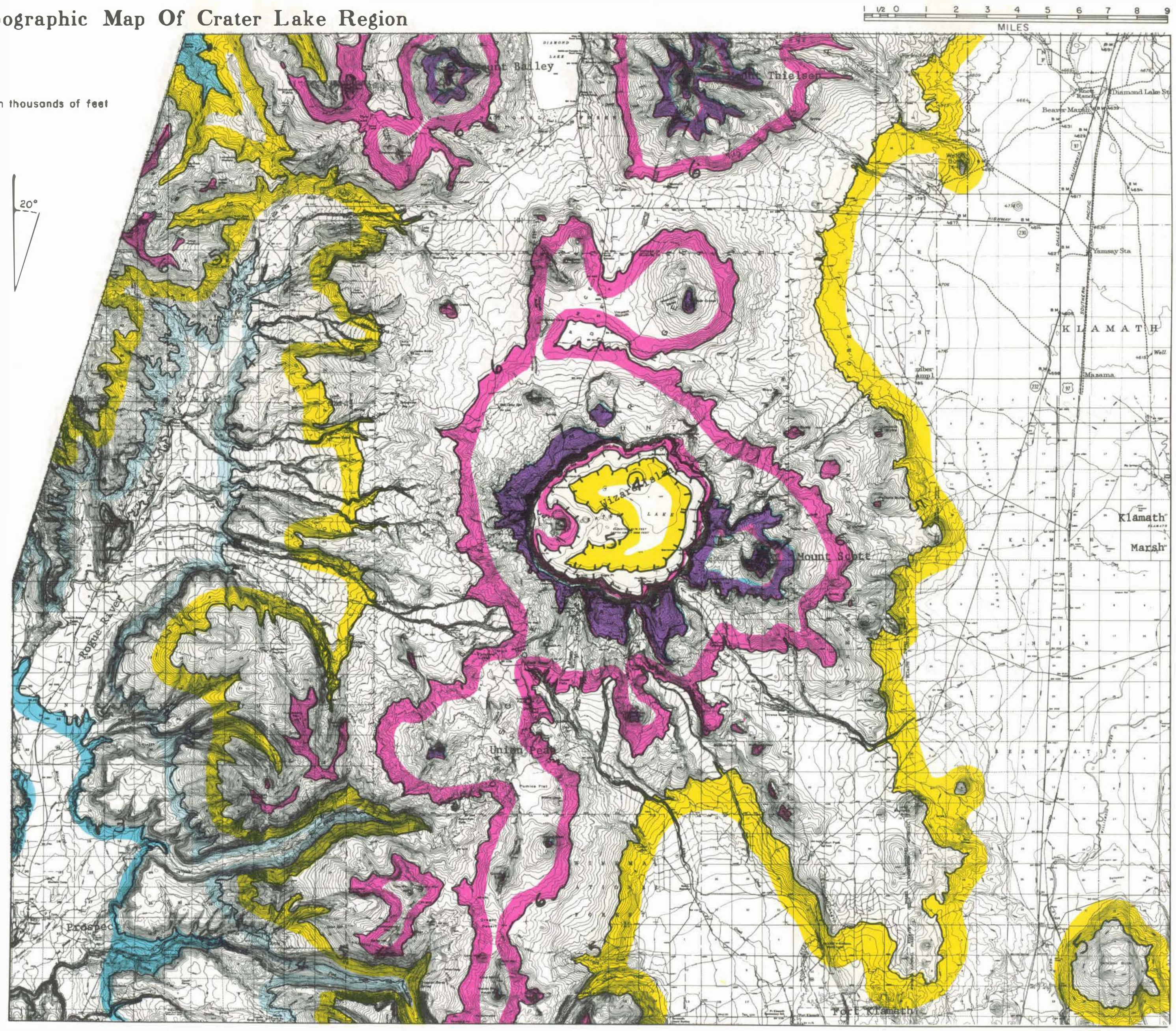
Figure 2 is a simplified topographic map of the region with contours at 1000-foot intervals. The High Cascades are roughly delineated by the belt of topography above 5000 feet in elevation east of the Rogue River. Mounts Bailey and Thielsen, west and east of Diamond Lake, respectively, and Mount Mazama, the volcanic complex whose partial engulfment resulted in the formation of Crater Lake caldera, comprise large areas above 7000 feet in elevation. Southwest of Crater Lake is Union Peak, a lesser

* Publication authorized by the Director, U.S. Geological Survey.

** U.S. Geological Survey, Menlo Park, California.

Fig. 2 Topographic Map Of Crater Lake Region

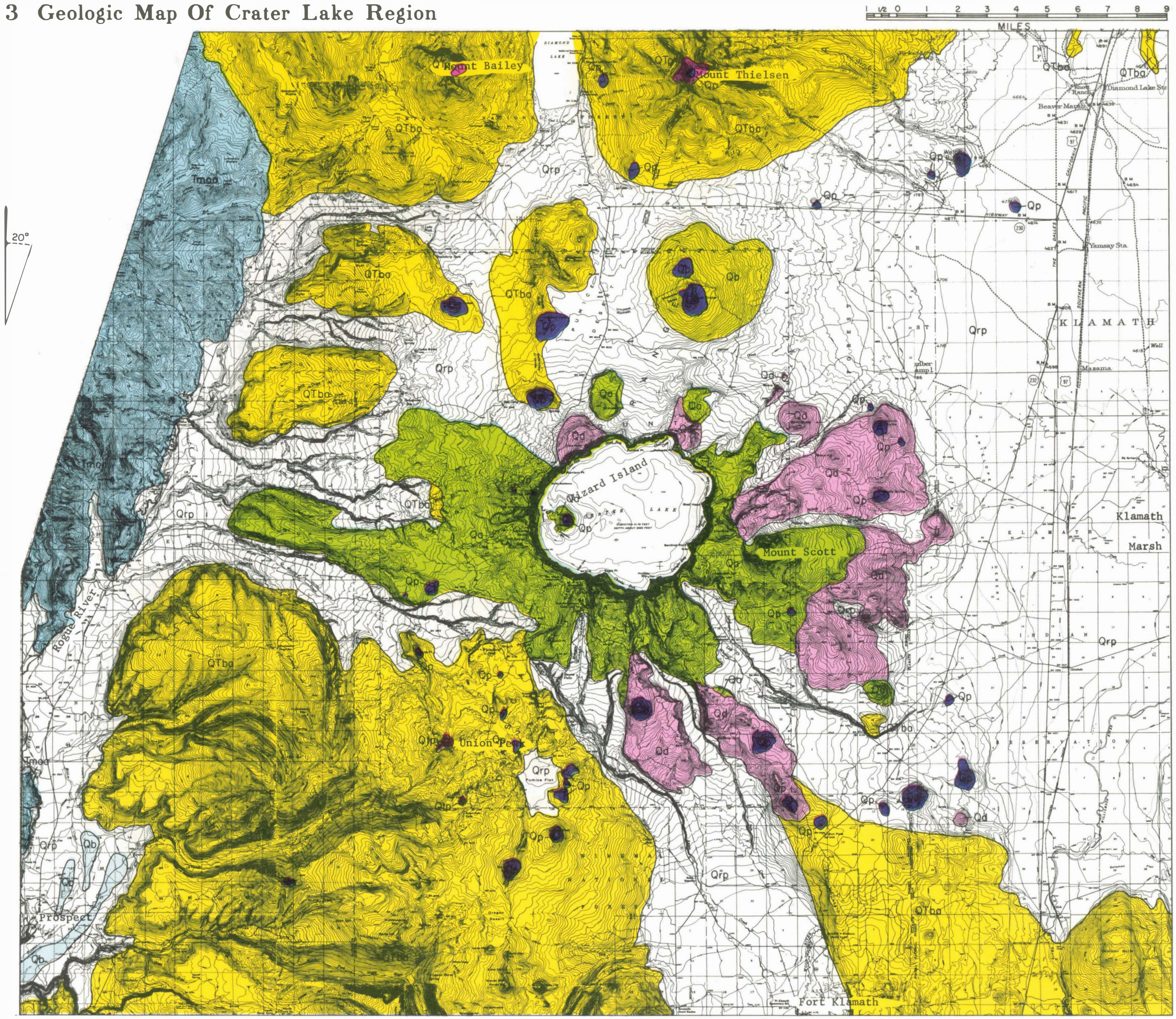
Elevations given in thousands of feet



KEY TO MAP UNITS

Period	Epoch	Unit	Description
QUATERNARY	Recent	Qrp	Dacite pyroclastic rocks erupted from Mount Mazama: Pumice, ash-flow, and ash-fall deposits; includes alluvium
QUATERNARY	Pleistocene and Recent (Age relationship not implied by position)	Qb	Basaltic and andesitic lava flows, domes, and intracanyon flows
		Qp	Basaltic and andesitic pyroclastic rocks of parasitic cones
		Qa	Mount Mazama andesites: Lava flows, domes and explosion breccia, with some interbedded glacial deposits; includes andesites of Mount Scott
		Qd	Dacite lava flows and domes
QUATERNARY – TERTIARY	Plioc. and Pleistocene (Age relationship not implied by position)	Qtp	Basaltic and andesitic pyroclastic rocks: Tuff, tuff breccia, and agglomerate; includes mafic intrusive rocks associated with vents
		Qtba	Basalt and andesite of High Cascades sequence: Lava flows with subordinate breccia, forming lava domes, cones, and intracanyon flows
TERTIARY	Oligocene and Miocene	Tmoa	Andesite and basaltic andesite of Western Cascades sequence: dominantly lava flows of middle(?) and upper Miocene age, with some older pyroclastic rocks

Fig. 3 Geologic Map Of Crater Lake Region



prominence. By extending the contours beyond the map area it can be seen that the High Cascades change their trend from nearly north-south, south of Crater Lake, to more nearly northeast, north of Crater Lake; the change in trend coincides with a change in width of the range. Three areas of high topography -- Mount Bailey, an area west of Union Peak, and the "arm" above 5000 feet extending southeast from Crater Lake -- are offset from the main range axis. Finally, a sharp offset of the eastern range front occurs near the southern margin of the map due west of Fort Klamath. These features are reflected in the geophysical maps and their possible significance will be discussed later.

The High Cascades are bordered on the east by Klamath Marsh and the upper Klamath basin, which are physiographically included in the Basin-Range province, and on the west by the Western Cascades.

Figure 2 also serves as a simplified terrain clearance map that can be used in conjunction with interpretation of the aeromagnetic map discussed in a subsequent section.

Geologic Framework

The geology of Crater Lake National Park has been described in a classic paper by Williams (1942); only a brief synopsis is in order here. The geologic map of figure 3 is adapted from Williams' National Park map and from reconnaissance maps by Williams (1957) and Wells and Peck (1961).

The oldest rocks exposed in the region are Oligocene to Miocene pyroclastics and lavas, composed chiefly of hypersthene andesite, and belonging to the so-called Western Cascades sequence. These rocks have an aggregate thickness probably in excess of 20,000 feet west of the map area; they dip generally eastward and doubtless are present at depth beneath the High Cascades.

Rocks of the so-called High Cascades sequence are Pliocene to Pleistocene in age. According to Williams (1942), they may be locally in fault contact with rocks of the Western Cascades sequence. In places they fill deep canyons carved in the older rocks. The lower part of the High Cascades sequence consists almost entirely of olivine-bearing basalt to basaltic andesite lava flows that form shield volcanoes of low relief; the upper part is more andesitic in composition, and consists of alternating lava flows and pyroclastics erupted from strato-volcanoes that were erected on a platform of coalescing shields. Mounts Bailey, Thielsen, Scott (east of Crater Lake) and Mazama and Union Peak are the largest of these strato-volcanoes in the region studied. Mafic intrusive rocks are associated with the vents of Bailey, Thielsen, and Union Peak.

Rocks of Mount Mazama affinity are distinguished separately on the geologic map. According to Williams, the development of the main volcanic edifice was characterized by relatively quiet outpourings of andesitic lava, with explosive eruptions playing a subordinate role. The waning stages of activity were marked by eruption of diverse magma types--dacite in the form of viscous flows, pumice, and domes; and basalt or basaltic andesite as parasitic cinder cones or scoria cones. Williams points out that this sequence is characteristic of many andesitic volcanoes throughout the world.

Vast quantities of dacitic pumice and ash were ejected during the climactic eruptions of Mount Mazama. The bulk of the deposits consists of pumice-flow material whose age has been established as about 6600 years (Rubin and Alexander, 1960). The air-fall deposits are thickest to the northeast and east of Crater Lake because of the influence of prevailing winds. Rapid extravasation of the dacite and consequent withdrawal of support led to collapse of the summit area and formation of the caldera. The caldera is eccentric with respect to the former summit, which apparently lay well to the south of the center of what is now Crater Lake (Williams, op. cit.).

The discovery of abundant accidental fragments of granitoid rocks, chiefly partially fused granodiorite, in the products of the culminating eruptions has recently been reported by Taylor (1967). He suggests that partial fusion of granodioritic crustal material may have produced the reservoir of dacite magma.

Crater Lake is situated astride a broad upwarp of crystalline rocks that is presumed to extend northeast from the Klamath Mountains to the Ochoco-Blue Mountains uplift of northeast Oregon (Peck and others, 1964). The possible detection of structures in the crystalline rocks through their influence on regional gravity trends has been noted previously (Blank, op. cit.). A second major set of regional structural elements is represented by vents of the Western and High Cascades, which in a broad sense lie in north-south trending belts that are probably related to deep fracture zones that channeled ascending magma (Peck and others, op. cit.). A third set of regional structural elements consists of northwest-trending shear zones in areas east of Crater Lake. One of the best documented of these structures is the Brothers fault zone, mapped by Walker and others (1967) in the east half of the Crescent 1:250,000 quadrangle. Northwest trends predominate in the geophysical data, as will be seen shortly.

Aeromagnetic Survey

The aeromagnetic survey of the Crater Lake region was carried out by the Geological Survey during the summer of 1965 under the direction of J. L. Meuschke. The equipment used consisted of a fluxgate magnetometer model AN/ASQ-10 mounted in the tail of a Convair CV-240; the basic system and procedures were similar to those described by Balsley (1952). Continuous analogue tape recordings of the total magnetic field intensity at an elevation of 9000 feet above sea level were made along east-west lines spaced at intervals of about 1 mile, with north-south control lines at wider intervals for accurate reduction to a common datum. Instantaneous position of the aircraft was ascertained by referring fiducial marks on the readout chart to corresponding marks on continuous strip photographs. However, difficulty was experienced with registration of the fiducial marks due to camera malfunction, leading to some uncertainties in horizontal position; individual profiles may be translated somewhat from their true position along a flight line. Since this survey was made, the aircraft has been equipped with a completely automated digital recording system and Doppler navigation (Evernden and others, 1967).

A total intensity magnetic contour map with a contour interval of 10 gammas (1 gamma = 10^{-5} oersted) and datum arbitrary is presented in figure 4. Flight paths are indicated by dashed lines. The color pattern has been chosen to emphasize gross levels of intensity.

The gradient produced by the earth's main field has not been removed; in the Crater Lake region, this amounts to an increase of about 8 gammas per mile northeasterly (roughly N. 33° E.), so that the map may be considered as tilted up in that direction.

Comparison of the aeromagnetic map with the simplified topographic map of figure 2 reveals at best an erratic correlation. The magnetic response due to minor topographic features is strongly dependent upon their location relative to traverse lines; the effect of some topography is "filtered out" as a result of the 1-mile traverse spacing. Other features produce a negligible response even when directly overflown. This can be attributed to weak polarization of the near-surface rocks, or, in the case of mafic cinder cones, to low density and lack of coherent effect of the permanent polarization.

One of the most significant characteristics of the map is the northwest and, to a lesser extent, northeast grain of positive anomalies with long spatial wavelength. The trends are probably real, but they are locally distorted by artificial "chevron" effects related to the horizontal position uncertainty and are further obscured by the contributions of local or particularly intense souces; hence they must be interpreted with caution. Long wavelength anomalies are generally associated with deeply buried magnetic sources. It appears that the distribution of magnetic material at depth is primarily controlled not by north-south structures associated with High Cascades lineaments, but by structures oriented more nearly parallel to the Brothers fault zone, and by other structures more or less parallel to the axis of the Klamath Mountains crystalline belt.

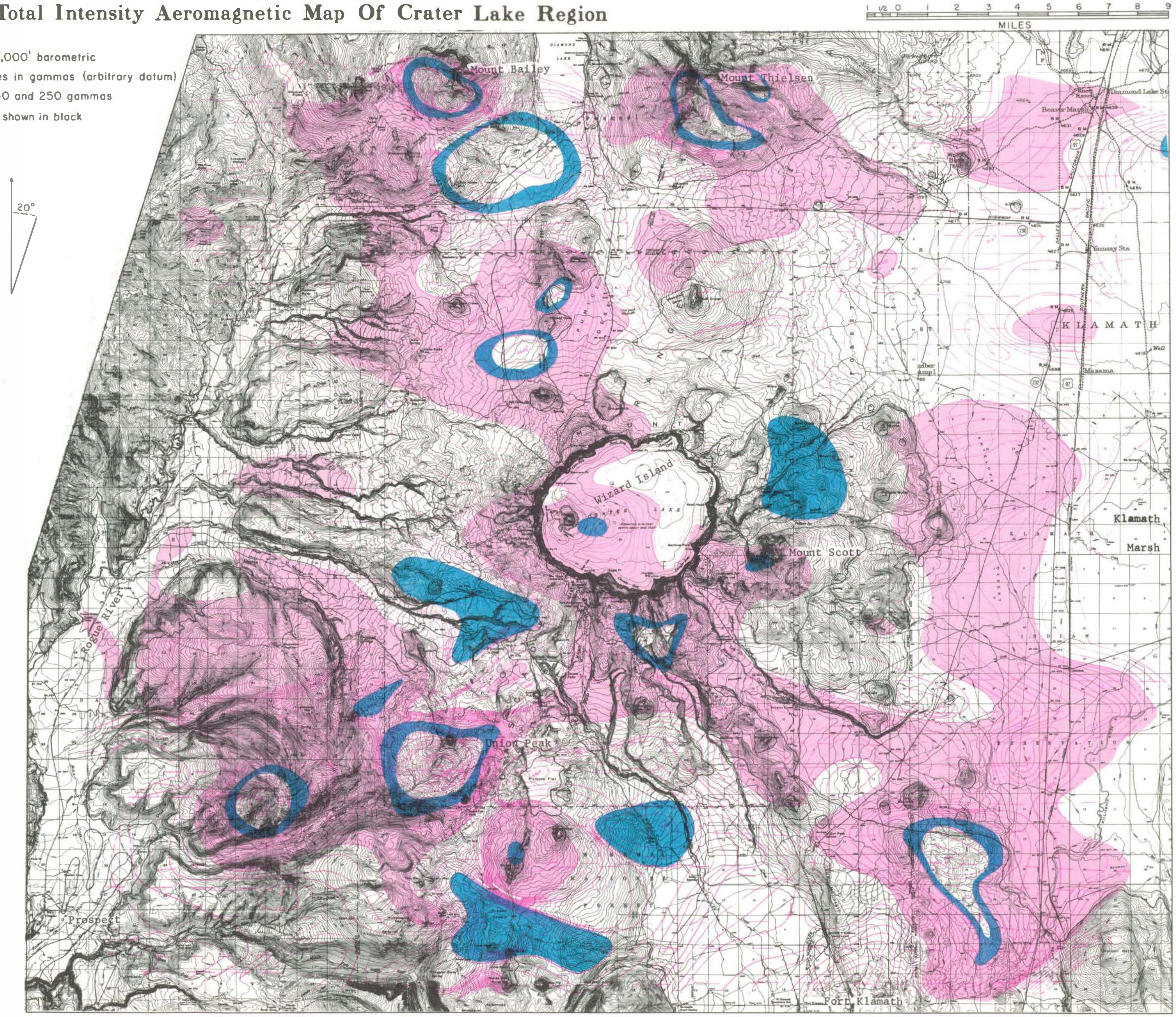
A northwest-aligned magnetic high corresponding roughly to a topographic high extends across the center of the map to the northwest wall of the Crater Lake caldera, where it terminates in a sharp magnetic discontinuity. This seems to imply that a block of magnetic "basement" has been truncated by a fault near the caldera margin. The fault would trend northeast and would intersect the "northern arc of vents" described by Williams (op. cit.). Similar magnetic features are characteristic of calderas surveyed in Japan (Blank and others, 1966); it has been speculated that they represent deep-seated tensional fractures which promoted the rapid egress of magma.

The magnetic pattern associated with Crater Lake is to some extent modified by the effect of the caldera topography. This effect should be strongest over the south rim for a perfectly symmetrical, uniformly magnetized caldera, but here it is exaggerated because the north rim is lower. Mount Scott and the Wizard Island lava field also produce distinct anomalies.

Several large positive anomalies with more or less circular symmetry command attention. The three of greatest amplitude -- 1000 to 1500 gammas above datum -- are associated with the High Cascades volcanoes Mount Bailey, Mount Thielsen, and Union Peak. These anomalies are too broad with respect to the terrain clearance to be the result only of topography; moreover, the crest of the anomaly is about 1 mile south of the summit of the volcano in each case. It is possible that they are produced by a hypabyssal mafic

Fig. 4 Total Intensity Aeromagnetic Map Of Crater Lake Region

Flight elevation 9,000' barometric
Isoanomalic values in gammas (arbitrary datum)
Contour interval 50 and 250 gammas
Geologic contacts shown in black



intrusive complex centered beneath the volcanoes, the depth to the main sources accounting for the large southerly displacement of the anomalies, and that the topographic contribution is subordinate. The known presence of mafic intrusive rock in the vents of these volcanoes lends a measure of support to this interpretation. A fourth large positive anomaly with almost perfect symmetry is located 6 miles west of Union Peak and is not related to a well-defined volcanic edifice. This may be associated with a shield volcano of the older High Cascades sequence, or with an eruptive center that is completely concealed.

The magnetic lows indicated by closed hachured contours on the total intensity map are in some cases simply polarization lows located on the north side of positive anomalies because of the northerly magnetic inclination. However, two large negative anomalies located respectively northeast of Crater Lake and southwest of Diamond Lake probably cannot be explained wholly on this basis. They appear to represent structural depressions, or alternatively, masses of inversely polarized rock. No inversely polarized rocks have yet been reported from the Crater Lake area, although they are known to be present in the lower part of the High Cascades sequence farther north (A. R. McBirney, oral communication).

A sharp northwest-oriented magnetic low near the southern border of the map is also difficult to explain by normal polarization alone. Whatever its source, the low is rather well aligned with an offset of the High Cascades range front. These features may be controlled by a northwest-trending fault zone.

Gravity Survey

Altogether some 300 gravity observations were made in the Crater Lake region, as defined here, during the summers of 1962, 1963, and 1965. Observed gravity for most stations was referred to three primary base stations located at Prospect, Diamond Lake, and Fort Klamath, as well as to a network of auxiliary base stations, including a station conveniently located on the concrete porch of the Crater Lake National Park headquarters building. The base net is ultimately tied to an assumed value of 980,236.5 mgals for observed gravity at the Woollard (1958) airport station at Medford. All data have been reduced with the aid of an electronic computer to Bouguer anomaly values based on the International ellipsoid. A standard density of 2.67 and an alternative density of 2.45 gm/cm^3 were used in the reduction.

Terrain corrections for 1962 and 1963 stations were made using the computer method of Kane (1962) with 2-km instead of 1-km unit squares. In this method the effect of topography in the interval between two squares of sides 80 x 80 km, and 4 x 4 km, centered about each station, is computed by machine, and the effect of topography within the inner square is computed by hand. The inner square was assumed equivalent to Hayford-Bowie zones A-F; this approximation introduces very small (generally less than 0.1 mgal) errors into the total correction. Terrain corrections for 1965 stations (about 20) were done by hand for Hayford-Bowie zones A through L plus $\frac{1}{2}$ M, so that they are only approximately equivalent to those done by Kane's method. Where terrain effects are large the uncertainty of the calculation is likewise large. The maximum uncertainty in the terrain corrections applies to stations on the caldera rim or lake shore, and amounts to about 2 mgals, with the exception of the correction for Mount Thielsen ($\pm$ 5-10 mgals). For inner zone corrections involving water compartments in Crater Lake the detailed bathymetric chart published by Byrne (1962) was employed.

The complete Bouguer anomaly map of figure 5 is based on a reduction density of 2.45 gm/cm^3. Ninety-five percent of the complete Bouguer anomaly values are believed accurate within $\frac{1}{2}$ contour interval ($2\frac{1}{2}$ mgals). As in the case of the magnetic map, color is used to enhance broad gravity contrasts.

Maximum gravity relief shown by the map is about 35 mgals. Much of this relief is expressed as a negative gradient directed easterly to northeasterly across the region, which tends to mask the weaker local features.

Gravity contours in the High Cascades south of Crater Lake trend more or less north-south parallel to the eastern margin of the range (probably a fault-line scarp), the Bouguer values falling off to a low over the alluvial fill of Klamath basin. North of Crater Lake the pattern abruptly changes: contours generally transect the range, and northwesterly trends prevail. A northwest-trending positive anomaly is associated with the divide between the Klamath basin and Klamath Marsh. Its axis is slightly north of the axis of the corresponding positive magnetic anomaly. This feature extends as far northwest as the vicinity of Crater Lake, where it merges with a distinct high associated with the main mass of Mount Mazama, south to southeast of the center of the caldera. The northwest rim of the caldera lies within a northeast-trending gravity embayment roughly coincident with the magnetic discontinuity. Thus the gravity data are consistent

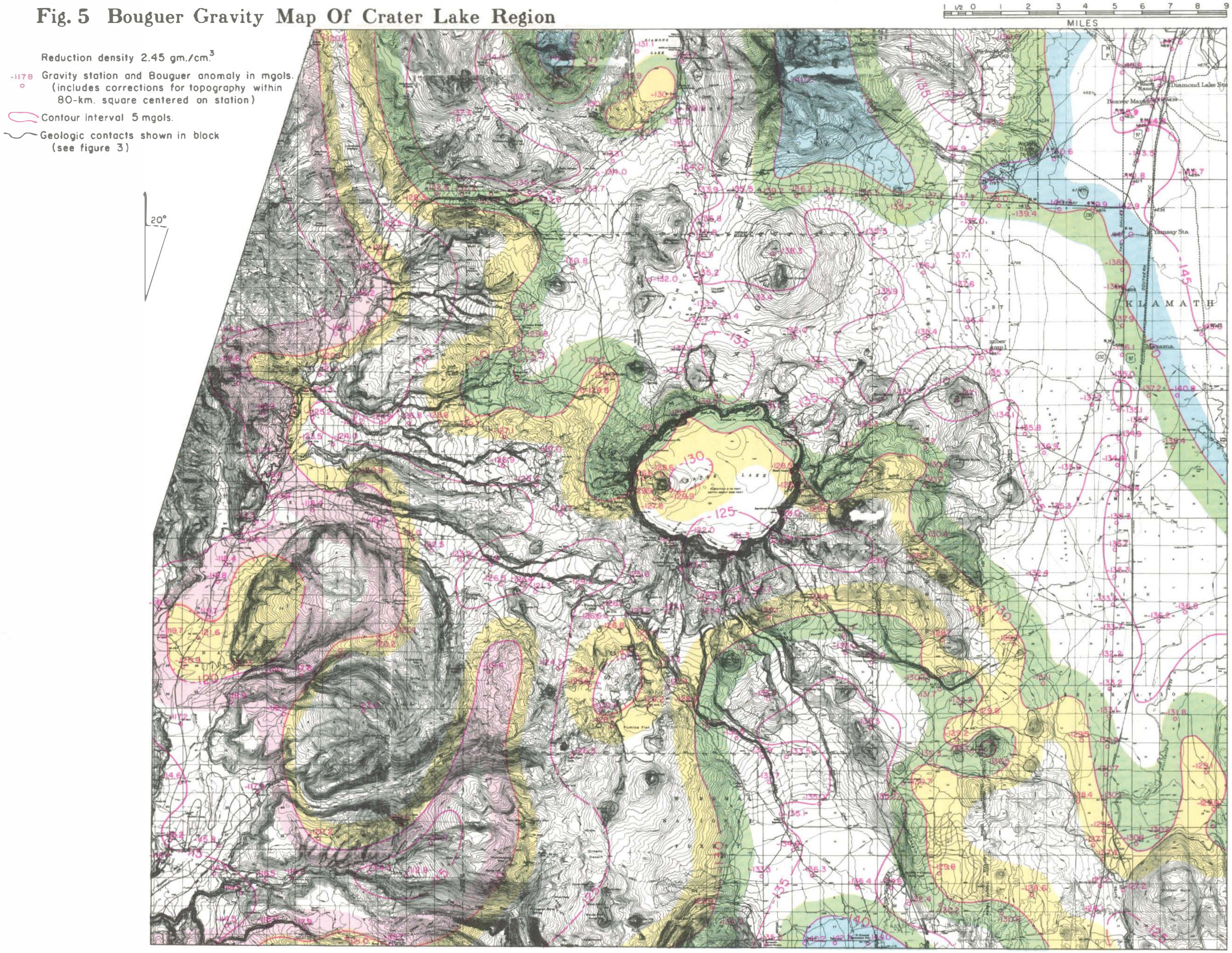
Fig. 5 Bouguer Gravity Map Of Crater Lake Region

Reduction density 2.45 $gm./cm.^3$

-117.8 Gravity station and Bouguer anomaly in mgals. (includes corrections for topography within 80-km. square centered on station)

Contour interval 5 mgals.

Geologic contacts shown in block (see figure 3)



with the concept of a northwest-trending "basement" structure truncated by a northeast-trending structure at the caldera. The nature of this structure remains a matter of speculation. It may consist of no more than upwarped or up-faulted rocks of the older High Cascades sequence.

Because of the very large topographic relief involved, the detailed configuration of the anomaly associated with the Crater Lake caldera can be altered somewhat by selection of a different reduction density. The use of a lower reduction density will increase the elevation factor and hence decrease the consistent discrepancy between Bouguer anomalies on the lakeshore and proximal points on the rim. Nevertheless the anomaly associated with Mount Mazama remains positive with respect to the regional background. This anomaly may be due to the presence of unusually large quantities of intrusive rock, probably dacite, at shallow levels within the complex. A weak negative anomaly is superimposed on the main gravity field near the center of the caldera, and other minima occur to the north and northeast. These features probably reflect local accumulations of low density pyroclastics.

Mounts Bailey and Thielsen, in contrast to Mount Mazama, appear to be associated with negative gravity anomalies, of amplitude as much as 10 mgals. This indicates a low bulk density relative to the reduction density of 2.45 gm/cm^3 and suggests that intrusive material in these volcanoes is subordinate. In the case of Union Peak no gravity effect was detected, but here the volcanic edifice is much smaller.

The broad negative gravity anomaly west of Union Peak is almost exactly coincident with the circular magnetic anomaly discussed earlier. The fact that this is both a gravity and magnetic feature makes it an inviting target for future investigation.

Conclusions

Regional gravity and aeromagnetic surveys have shown that Crater Lake lies in an area strongly influenced by northwest-trending, and to a lesser extent, by northeast-trending lineaments; north-south trending lineaments associated with the High Cascades have little or no geophysical expression. The northwest set may be part of a shear zone related to the Brothers fault zone, or it could represent a western extension of Basin-Range normal faulting; the northeast set may reflect either deeply buried structures in the Klamath Mountains belt or tensional structures associated with shearing. A prominent northwest-trending gravity and magnetic lineament entering Crater Lake from the southeast is apparently truncated near the northwest wall of the caldera by a major northeast-trending structure. The location of Mount Mazama at such a structural intersection may have facilitated the rapid rise of magma which led to its ultimate engulfment.

Several High Cascades volcanoes are compared with respect to their gravity and magnetic signatures. Mount Thielsen and Mount Bailey have a strong magnetic effect, attributable at least in part to mafic intrusive rock beneath the volcanic edifice; and each is also associated with a gravity low because of its relatively low bulk density. Union Peak does not perturb the gravity field, possibly because it is in a more advanced stage of dissection and lacks a thick mantle of low density pyroclastics, but its magnetic expression is close to that of the others. Mount Mazama has a weaker magnetic expression but produces a gravity high; this may be accounted for by the presence of weakly magnetic dacite intrusives at shallow depths within the edifice, although it is possibly due to the andesite pile alone.

A positive magnetic and negative gravity anomaly with circular symmetry in the High Cascades west of Union Peak may be associated with an as yet unknown older volcanic center.

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COMPOSITIONAL VARIATIONS
OF THE CLIMACTIC ERUPTION OF MOUNT MAZAMA

By Alexander R. McBirney*

Mount Mazama, the ancestral mountain that now contains Crater Lake, is probably the best known of the Cascade volcanoes and illustrates better than any other the compositional variations that characterize the Quaternary rocks of the southern part of the range. As Williams (1942) has shown, the volcano grew to its full height during a long period of eruption of uniform pyroxene andesite. In the later stages of its evolution, more siliceous andesites, dacites, and rhyodacites were discharged from a semicircular arc of vents around the northern slopes close to the present rim of Crater Lake. The composition of the lavas along this fissure varies systematically from rhyodacite and dacite along the central portion (Llao Rock and the Cleetwood and Redcloud flows) to andesite at the two extremities (Hillman Peak and the Watchman on the west and Sentinel Rock on the east). At the same time, dacite domes were extruded near the eastern base and basaltic cinder cones broke out over a wide area, mainly around the lower northern slopes.

The products of the great eruption that led to formation of the caldera closely resemble, at least in bulk composition, the contrasting rocks of the preceding stage. The rhyodacite pumice that makes up the first pumice fall and most of the glowing avalanche deposits is very similar to the obsidian of the earlier domes along the northern arc of vents, while the basic hornblende scoria that was erupted at the close of the eruption closely resembles in its bulk chemical composition the basaltic lavas of the earlier satellite cones around the base. Finally, the volcano reverted to andesite lavas with the post-caldera activity that formed Wizard Island.

Variations such as those in the products of the climactic eruption of Mount Mazama have been reported from other caldera-forming eruptions (Lipman and others, 1966; Katsui, 1963; Rittman, 1962), but none of these show the abrupt change from acid pumice to basic scoria seen at Crater Lake. The spectacular section of the glowing avalanche deposit at The Pinnacles (figure 1) shows the change especially well. A sudden transition from white dacite pumice to dark brown hornblende scoria occurs within a vertical distance of less than two feet. There is no evidence that this change marks a break in the continuity of the eruption. The contrasting magmas must have been discharged continuously from a compositionally inhomogeneous magma reservoir beneath the volcano.

In order to relate the nature of this change to the eruptive sequence, analyses have been made of a series of samples of the air-fall pumice and glowing avalanche deposits. Two analyses were made for each sample, one of the bulk rock and another of its glass. The analytical results, recalculated on a water-free basis, are presented in table 1 and summarized graphically in figure 2.

The most obvious conclusion to emerge from this data is that the gross features of the series are to a large degree the result of differences in the abundance and composition of phenocrysts; the variation in the glass is much smaller than that of the total rock. Total-rock SiO_2, for example, drops almost 15 percent from the air-fall pumice to the basic scoria, while the glass in the same samples differs by only about 6 percent.

The crystal content varies widely from one sample to the next, but there is a much greater average abundance of crystals in the basic scoria than in the dacite pumice. The plagioclase of the pumice is mostly labradorite zoned to oligoclase; in the scoria it is somewhat more basic - labradorite or bytownite zoned to andesine. In most pumice samples, hypersthene is the most common dark mineral, but augite is also present and hornblende is common. Pyroxenes are much less important in the basic scoria than is hornblende, which in some samples constitutes nearly half of the volume. Some of the hornblende crystals

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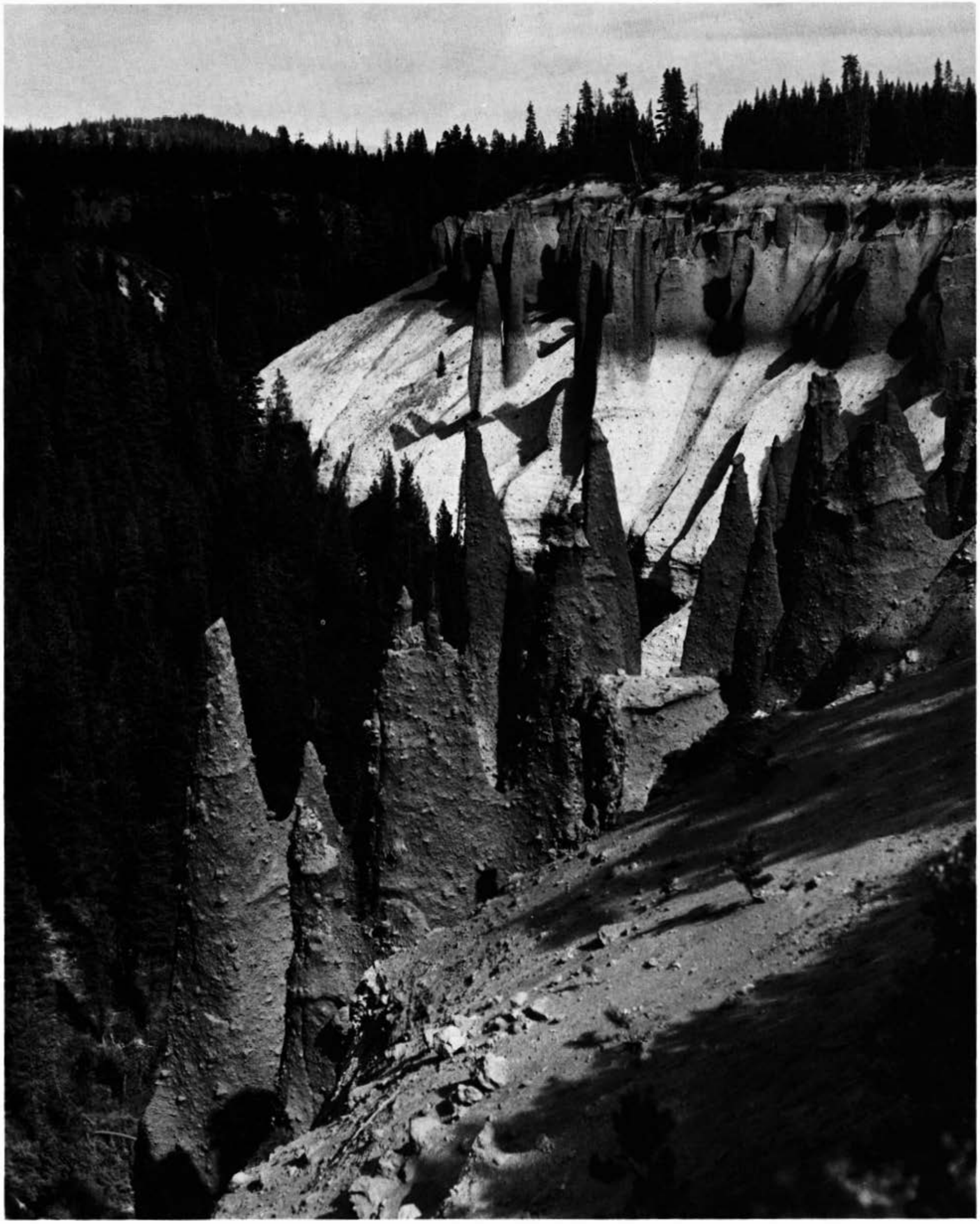

Figure 1. The Pinnacles, Crater Lake National Park.

View of glowing avalanche deposits in Sand Creek. Pumice was erupted at the later stages of the climactic eruption of Mount Mazama and changed composition abruptly from rhyodacite (light colored pumice in lower section) to crystal-rich hornblende scoria (dark colored layer at top of section). (Oregon State Highway Dept. photograph 5301.)

Table 1. Chemical composition of products of the climactic eruption of Mount Mazama.

	1	1g	2	2g	3	3g	4	4g	5	5g	6	6g
SiO_2	72.07	73.65	70.71	72.70	70.25	71.82	69.70	72.30	57.36	67.89	56.53	67.25
TiO_2	0.48	0.37	0.54	0.49	0.58	0.49	0.57	0.51	1.05	0.67	0.76	0.81
Al_2O_3	15.04	14.52	15.00	14.48	15.21	15.07	15.46	14.46	18.46	16.08	19.96	16.74
Fe_2O_3	1.18	0.49	1.80	1.12	2.08	1.33	2.09	-	3.58	1.79	2.78	1.36
FeO	1.39	1.52	1.05	0.84	1.14	0.89	0.94	2.20	2.80	1.62	2.82	2.31
MnO	0.03	0.02	0.04	0.03	0.07	0.06	0.04	0.02	0.08	0.07	0.15	0.07
MgO	0.28	0.22	0.55	0.31	0.61	0.44	0.61	0.32	3.71	0.87	3.80	1.03
CaO	1.67	1.16	2.40	1.78	2.33	1.91	3.00	1.45	7.17	3.29	8.29	2.80
Na_2O	5.07	5.08	5.07	5.10	4.93	5.02	4.87	5.63	4.18	5.21	3.84	5.41
K_2O	2.72	2.92	2.77	3.09	2.68	2.89	2.65	3.05	1.30	2.24	0.99	2.04
P_2O_5	0.06	0.04	0.08	0.06	0.11	0.07	0.08	0.06	0.30	0.25	0.07	0.19

1. Earliest air-fall pumice
2. Basal pumice deposit in Sand Creek
3. White pumice 15 feet above the creek bed at The Pinnacles
4. Gray pumice 25 feet above the creek bed at The Pinnacles
5. Dark basic scoria 35 feet above the creek bed at The Pinnacles
6. Dark basic scoria at top of section at The Pinnacles

NOTE: All analyses recalculated on water-free basis. For each sample the composition is given for the total rock and glass (indicated by 'g'). (Analyses by Ken-ichiro Aoki, Tohoku University, Japan.)

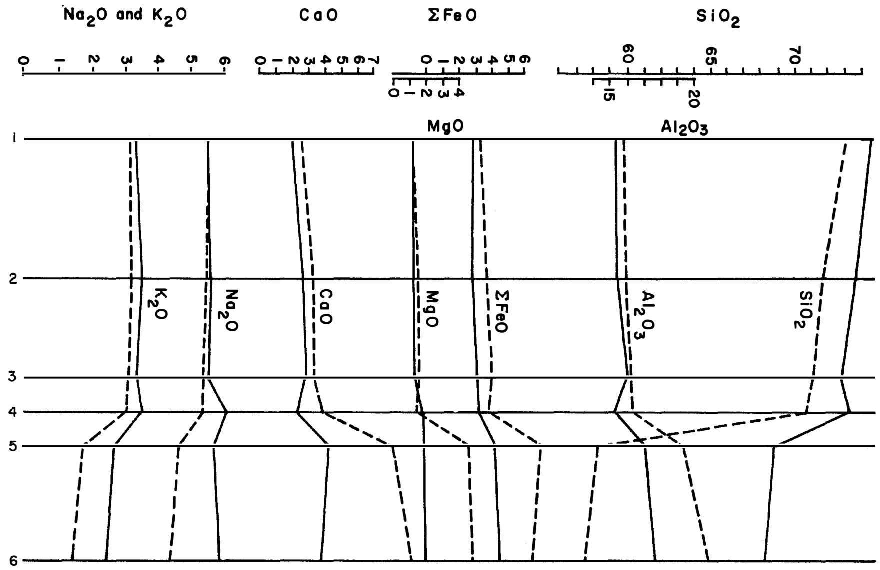

Figure 2. Variation of major elements in the ejecta of the climactic eruption of Mount Mazama. Oxide weight percent on a water-free basis is plotted against the approximate stratigraphic position of the sample in the section at The Pinnacles. Broken line refers to total-rock and solid line to glass.

contain small grains of olivine.

There is no evidence of resorption of the crystals of either unit, although some of the plagioclase of the dacite pumice is extremely porous and resembles that of partially fused plutonic xenoliths that were among the debris discharged toward the close of the eruption (Taylor, 1967).

The compositional differences of the glass fractions, even though they are less marked than those of the total rock analyses, are significant. They appear to require moderately strong vertical zoning of the liquid in the magma chamber before the eruption. Passing downward to deeper levels in the chamber, there was a decrease of silica and alkalis and an increase of calcium, iron, and magnesia. The greatest part of this variation was compressed within a narrow vertical interval corresponding to the visible transition from white dacite pumice to dark basic scoria.

An interesting feature of this variation is the reversal of slope that is seen in the variation curves for SiO_2, Al_2O_3, CaO, Na_2O, and K_2O. These inflections are confined to the glass and do not appear in the corresponding bulk compositions. The complementary nature of the SiO_2 and Al_2O_3 and of the CaO and alkalis suggests that the transition zone may have been diffusion controlled and related in some way to the equilibrium relations of each liquid to plagioclase. It is clear, of course, that many factors such as temperature and pressure gradients, distribution of water, and relative movement of crystals and liquid must have influenced the compositional variations, but our meager knowledge of the effects of these factors on the physical and chemical behavior of silicate liquids rules out a better interpretation at this time.

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NEWBERRY CALDERA AREA

NEWBERRY CALDERA FIELD TRIP

By Michael W. Higgins* and Aaron C. Waters**

The Caldera Wall Sequence

Mount Newberry is an extensive shield volcano which rises from the basalt plateaus of central Oregon just south of Bend and about 40 miles east of the Cascade crest (figure 1). At the summit of the shield is Newberry Caldera, a large, nested caldera with two sizable lakes and a variety of volcanic features on its floor (figure 2).

Howel Williams (1935) studied Newberry Volcano in the early 1930's. Since then, numerous short papers have described specific features of the volcano and caldera. Newberry has served as a training ground for two classes of U.S. astronauts, and as a test area for NASA's technical and analytical equipment.

The bulk of the Newberry shield probably consists of mafic flows and cones similar in petrography and chemistry to those of the adjacent basalt plateaus (Waters, 1962). However, the shield is so recent in age that deep canyons have not been cut into it, and only the uppermost 10 to 20 feet of rock is available for inspection over most of it. Therefore, the most significant exposures are in the walls of the caldera and in the gorge of Paulina Creek, which drains the caldera. Nevertheless, the creek gorge and the caldera walls contain a remarkable stratigraphic sequence of rocks which allows a fairly detailed interpretation of the later history of the volcano, of the formation of its caldera, and of the magma-differentiation which produced the rocks. Figure 3 summarizes the stratigraphic sequence and gives generalized petrographic descriptions of the four main units. The generalized geologic map (figure 4) and figures 5 to 13 show the distribution and field relations of the wall rocks.

In brief, before collapse of the present caldera, rhyolite (and minor dacite) flows were erupted, probably from intersecting fractures attending the beginning of collapse of an earlier caldera. They flowed away from the still shallow, subsiding caldera, but were highly viscous and moved for only short distances from their vents. After the rhyolite flows, andesites were erupted and flowed down the flanks of the shield. These platy andesites are found on all caldera walls, and to distances of as much as 6 miles from the caldera rim on Paulina Creek. Next, the eruption of basaltic scoria, probably from the same vents, covered the top of the andesites. By this time the caldera was becoming deep enough to hold a shallow crater lake. Further eruptions from vents beneath the lake were phreatic and intermittent. They deposited layer upon layer of wet airborne mud, forming mafic tuffs with graded bedding. Continued activity in the old caldera deposited a welded tuff on the east wall, basalts and andesites on the west wall, and scoria deposits on the south wall. Faulting on a north-south-trending zone dropped the western part of the summit and a part of the caldera.

With the beginning of collapse of the present (later) caldera, a great volume of rhyolite issued from fissures near the present south wall to form the Paulina Peak rhyolites.

Petrogenesis of Newberry Rocks

Table 1 records five analyses of Newberry rocks. The analyses were done by X-ray fluorescence and are corrected to 100 percent. Although 21 analyses have now been completed on Newberry rocks, only the five will be reported here. Field, petrographic, and chemical evidence indicate that the rocks of Newberry Caldera were derived, by crystal fractionation, from high-alumina basalts like those to the south, east, and southeast (figure 1) (also see Waters, 1962).

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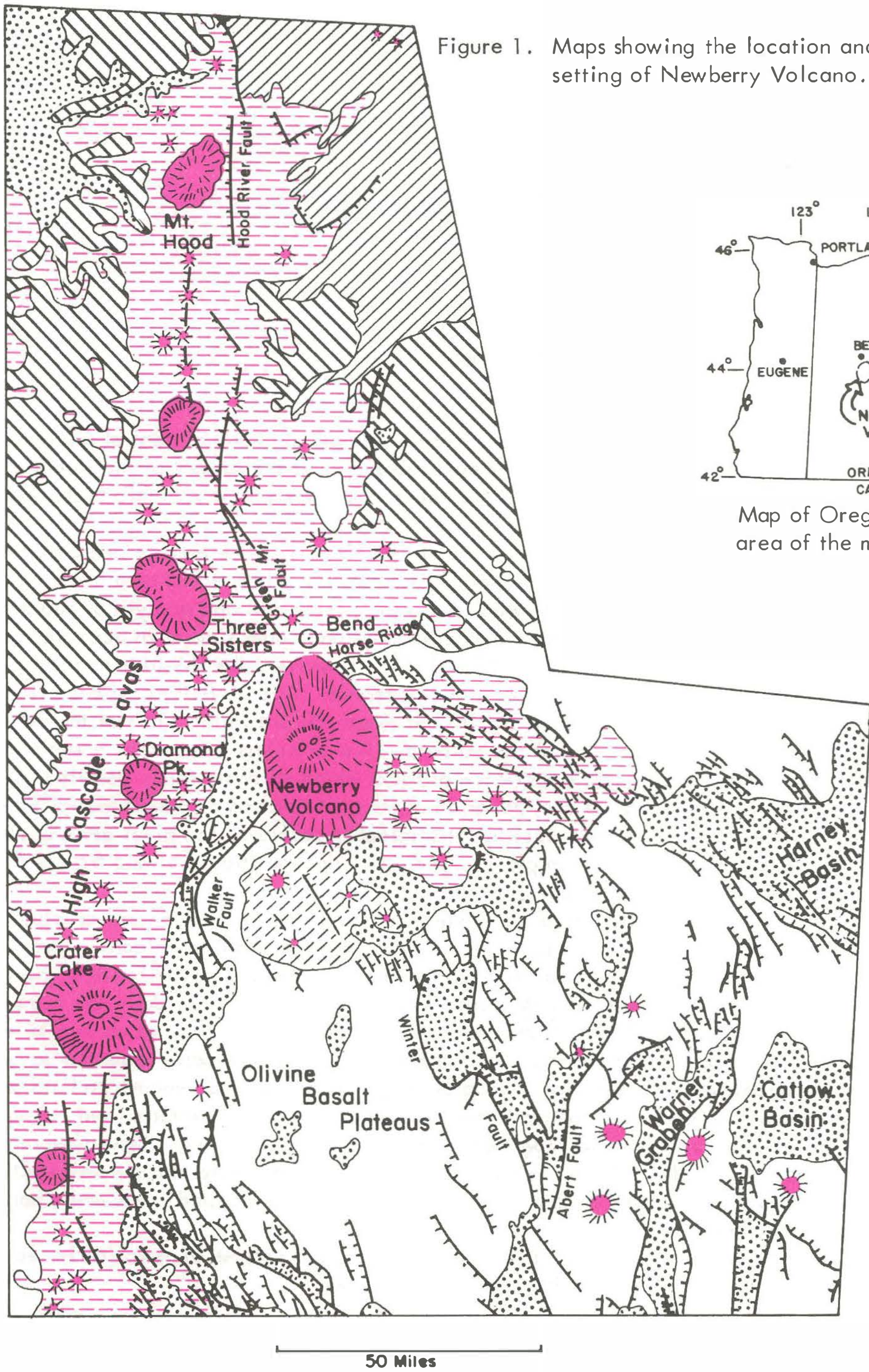
Figure 1. Maps showing the location and generalized geologic setting of Newberry Volcano.



Quaternary and upper Tertiary sedimentary rocks

Quaternary volcanic rocks of the High Cascades

Olivine basalt plateaus

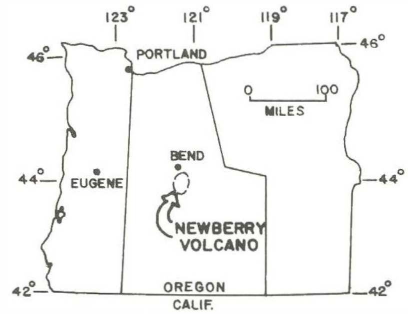
Stams Mountain volcanic complex

Columbia River Basalt plateaus

Miocene and older volcanic rocks

Fault, hachured side down

Volcano



Map of Oregon showing the area of the map at left.

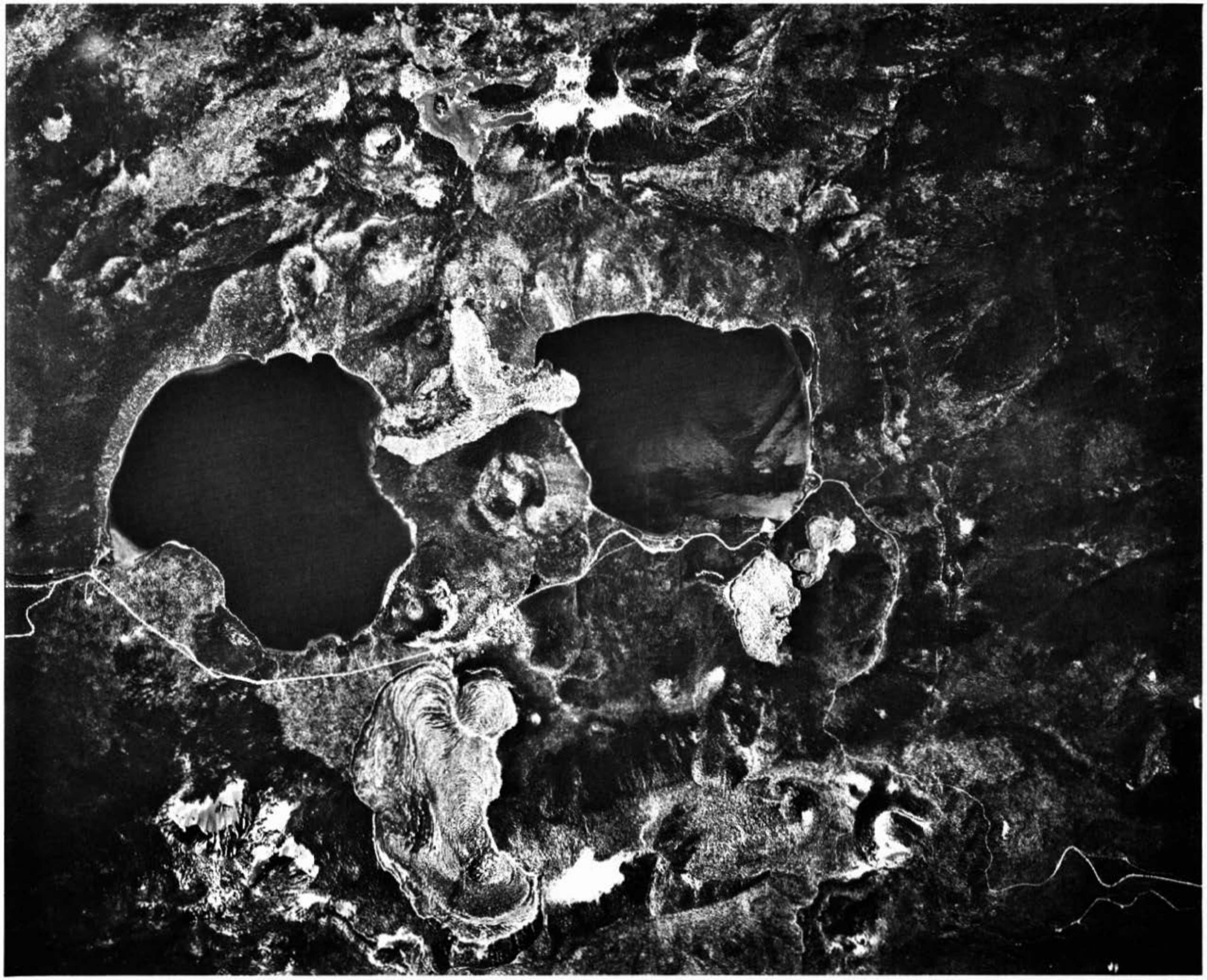
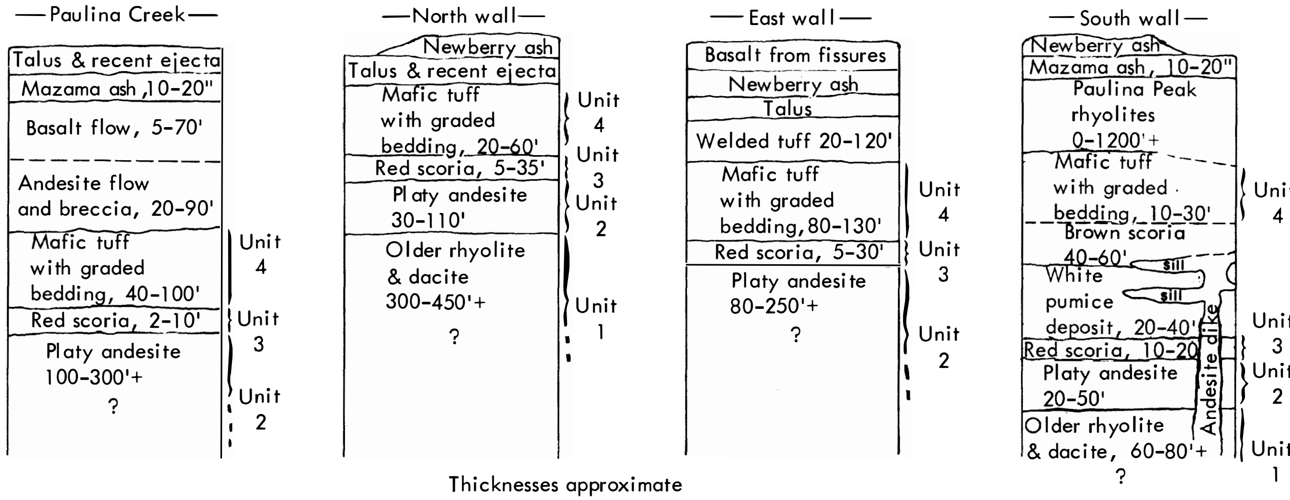


Figure 2. Ortho-photograph of Newberry Caldera. This photograph is base used for the geologic map (figure 4). The geologic nature of the various landforms can be seen by a comparison with figure 4.

Figure 3. Generalized stratigraphic sections, Newberry Caldera.



Thicknesses approximate

Generalized petrographic descriptions of the four main units.

Unit 4. Mafic tuffs with graded bedding:

Field - Buff to brown tuff in graded beds 1 to 4 inches thick. Over-all grading of unit, as well, so that coarse parts of lower beds are coarser than coarse parts of beds near top of unit. Bomb sags and nature of bedding indicate deposition subaerially as a wet mud from phreatic explosions in a caldera lake.

Generalized petrography - Coarse parts of beds consist of 45 to 70 percent lithic fragments; 1 to 4 percent crystal fragments; with matrix of clays, zeolites, carbonates, and palagonite. Of the lithic fragments, 20 to 25 percent are identical to the andesites of Unit 2; 5 to 10 percent are identical to the rhyolites of Unit 1; 30+ percent are coarse-grained olivine basalts like those of the plateaus to the south, east, and southeast. Fine parts of beds consist of 15 to 20 percent lithic fragments; 10 to 15 percent crystal fragments; with a matrix of fine shards of glass in various stages of alteration to clays, zeolites, carbonates, and palagonite.

Unit 3. Red scoria:

Field - Red scoria deposit; commonly agglutinated, suggesting that the hot, pasty lava came from a source near the present outcrops.

Unit 2. Platy andesite:

Field - Gray, platy lavas. Very fine grained and generally nonporphyritic. Stretched amygdules in some horizons are filled with calcite and zeolites. Tops of flows are commonly scoriaceous and reddened; centers are platy; bottoms are locally autobrecciated.

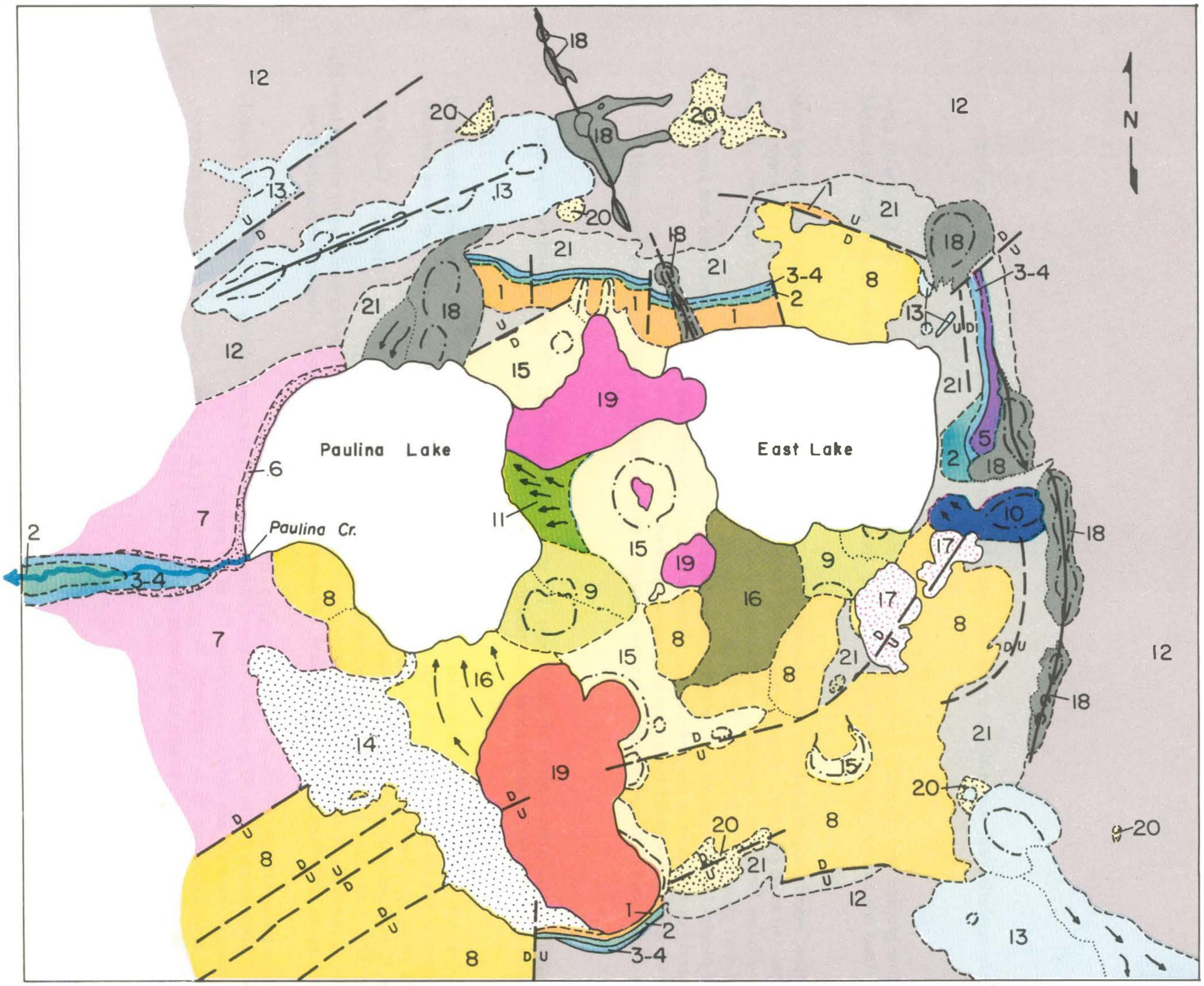
Generalized petrography - Pilotaxitic to trachytic texture, nearly holocrystalline. Groundmass (95 to 97 percent of rock) consists of strongly aligned andesine and oligoclase microlites (40 to 45 percent), augite granules (35 to 45 percent), magnetite granules (4 to 11 percent), glass (2 to 5 percent), and olivine (less than 1 percent). Phenocrysts (0 to 3 percent) are plagioclase (most abundant) -An_{54-83} cores, hypersthene (second most abundant) - 2V's from 56° to 59° indicating En_{65-68}, and magnetite.
Glomeroporphyritic clots of plagioclase or hypersthene, plagioclase and hypersthene, plagioclase or hypersthene and magnetite, or all three minerals, are nearly as abundant as the phenocrysts. Some also have iddingsitized olivine.
Small xenoliths are of same minerals as the groundmass, but are coarser grained.
The presence of groundmass olivine and of olivine basalt inclusions suggests that the andesite is a differentiate from basalt.

Unit 1. Older rhyolite and dacite:

Field - Three main varieties make up the unit, listed in order of abundance: (1) gray, platy rhyolites; (2) white, massive rhyolite; and (3) pink, massive rhyolite. Spherulites, breccia zones, and obsidian layers locally present.

Generalized petrography - (1) Gray, platy rhyolite: Groundmass (92 to 94 percent of rock) is a dense mat of tiny feldspar(?) crystallites and other round and oblong crystallites. Hematite streaks follow platy partings. Microlites of plagioclase (4 to 6 percent) are aligned parallel to platy partings. Most are An_{10-18}. Some magnetite present, and rare alkali feldspar in irregular blebs.
Phenocrysts are plagioclase (2 to 3 percent) mostly in broken crystals, with cores of An_{22-33} and rims of An_{16-30}. Oxidized hypersthene, 2V's of 57° to 59°, indicating En_{65-68} is also present. Augite is a rare constituent.
(2) White, massive rhyolite: groundmass of clear glass (20 to 30 percent) crowded with tiny blebs and crystallites of plagioclase(?). Irregular patches of alkali feldspars and silica minerals are present. Flow-aligned microlites of sodic plagioclase parallel crystallite alignment.
Phenocrysts (1 to 2 percent) are plagioclase, An_{25-30} cores, An_{10-12} rims.
(3) Pink, massive rhyolites: Groundmass (90 to 92 percent). Most (80 to 85 percent) is a mesh of tiny plagioclase (?) crystallites. Regularly dispersed through the mesh are reddish margarites (15 to 20 percent).
Phenocrysts (8 to 10 percent) are plagioclase (6 to 9 percent), An_{20-24} cores, An_{14-18} rims. Orthopyroxenes and glomerocrysts of orthopyroxenes and magnetite or orthopyroxenes and plagioclase comprise 1 to 2 percent. Orthopyroxene has 2V's of 56° to 58° indicating En_{64-66}.

Fig. 4 GENERALIZED GEOLOGIC MAP OF NEWBERRY CALDERA AND THE UPPER PART OF PAULINA CREEK GORGE



BASE MAP FROM AERIAL PHOTO

0 — 1 mile

EXPLANATION and MAP UNITS
(Stratigraphic Sequence Approximate)

- 21 — Talus, landslide material, and other superficial deposits.
- 20 — Pumice flats.
- 19 — Rhyolitic obsidian flows.
- 18 — Basaltic cinder cones and associated flows.

Newberry ashfall – time marker ca. 2000 yrs. B.P.

- 17 — Rhyolitic obsidian flows.
- 16 — Ash-flow and pumice avalanche deposits.
- 15 — Pumice cones and their aprons.
- 14 — Landslide material.
- 13 — Basaltic cinder cones and associated flows.

Mazama ash – time marker ca. 6600 yrs. B.P.

- 12 — Basaltic and andesitic flows and cones of the shield.
- 11 — Interlake Basalt Flow.
- 10 — Resort Lava Flow.
- 9 — Mafic tuff rings and their aprons.
- 8 — Rhyolite domes, flows, and complexes; in part syn-caldera formation in age.
- 7 — Basalt flow of the west wall.
- 6 — Andesite flow and breccia.
- 5 — Welded tuff of the east wall.
- 3-4 — Red scoria and mafic tuff units. (Unit 3) (Unit 4)
- 2 — Platy andesite unit. (Unit 2)
- 1 — Older rhyolite and dacite unit. (Unit 1)

Contact; dashed where approximate.

Crater rim.

Fault with down-dropped block marked "D". (Many faults not shown)

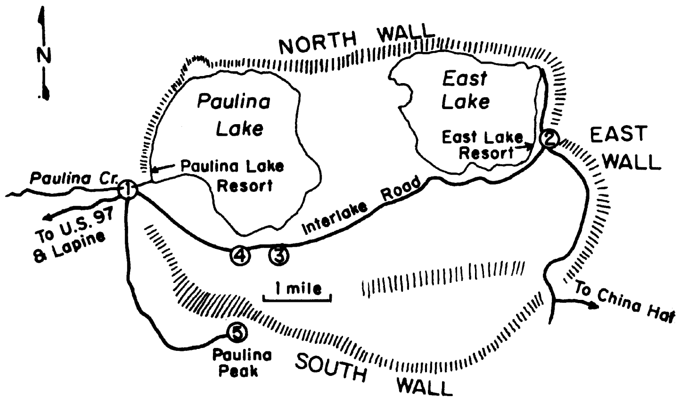
Direction of flow of ash-flows and mafic lavas.

Units 1-4 always dip away from the center of the caldera.

ROAD LOG

OF THE

NEWBERRY CALDERA FIELD TRIP



Sketch map of the caldera showing the stops for this trip.

Stop 1. Paulina Creek Falls

At the falls a red andesite flow and breccia overlie the mafic tuffs of the wall sequence (Unit 3). The tuffs are described in figure 3. The andesite consists of a frothy flow with a basal breccia 20 to 30 feet thick. The breccia is a brick-red granular aggregate of fine ash- to block-sized fragments highly charged with foreign rock fragments. In thin section the lava flow part of the unit is a devitrified, frothy glass charged with tiny specks of magnetite and hematite, and with plagioclase and (less abundant) augite microlites. Phenocrysts (3 to 4 percent of the rock) are plagioclase (2 to 3 percent) with cores of An_{35-37} and rims around An_{32}, hypersthene (less than 1 percent) with 2V's of 60° to 68° indicating about En_{68-74}, and augite (less than 1 percent) with 2V's of 52° to 56° indicating a fairly calcic variety. Glomeroporphyritic clots are also fairly common.

In the breccia, most of the foreign rock fragments are recognizable as coming from the underlying tuff. Others are from units of the wall sequence (figure 3). Some are of coarse-grained olivine basalts. Most of the fragments were probably torn from the walls of the conduit through which the andesite was erupted.

The brecciation at the bottom of the unit and the extreme oxidation and devitrification may indicate that the mafic tuffs were still wet when the andesite flowed across them.

Stop 2. The sequence in the east caldera wall (see sketch below):

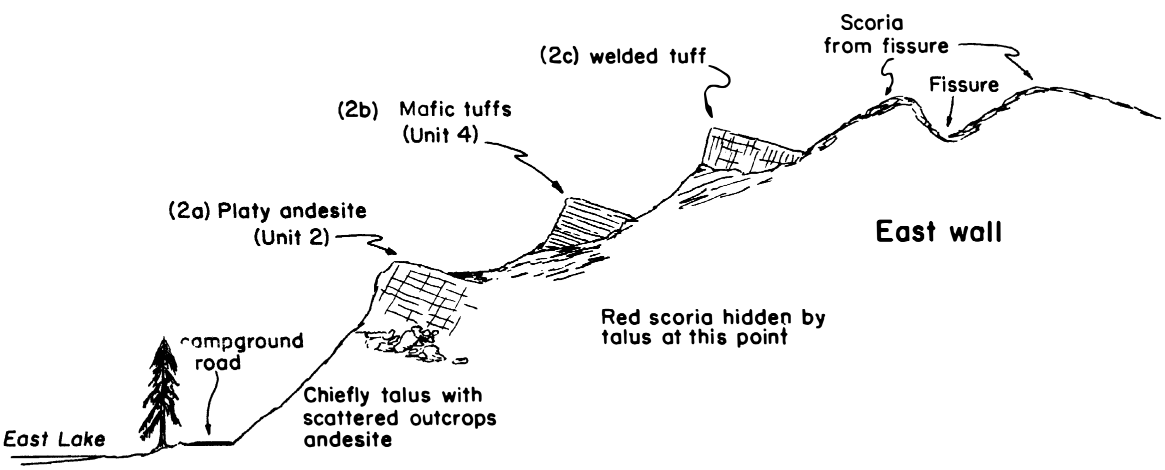


Table 1. Five analyses of Newberry rocks.

Chemical analyses

No.	1	2	3	4	5
SiO_2	54.22	56.23	66.76	72.87	74.09
TiO_2	2.22	2.48	0.76	0.30	0.27
Al_2O_3	14.94	14.53	14.26	13.44	13.36
Total Iron	11.02	9.31	6.03	3.23	2.96
Fe_2O_3*	2.96	2.50	1.62	0.87	0.80
FeO*	8.06	6.81	4.41	2.36	2.16
MnO	0.21	0.16	0.21	0.07	0.02
MgO	3.83	3.72	0.64	0.02	0.05
CaO	8.35	8.20	2.87	0.81	0.56
Na_2O	4.28	4.16	5.81	5.30	4.59
K_2O	0.77	1.17	2.72	4.02	4.03
P_2O_5	0.20	0.07	0.00	0.00	0.12

All total 100 percent.
* Calculated on basis of oxygen from total iron determinations.

Locations

No. 1. Platy andesite, Unit 2, from east wall.

No. 2. Platy andesite, Unit 2, from north wall.

No. 3. Welded tuff, from east wall.

No. 4. Pink, massive rhyolite, Unit 1, north wall.

No. 5. White, massive rhyolite, Unit 1, south wall.

The platy andesites of Unit 2 of the wall sequence are found in the base of the east wall (also see figure 4). It is a short climb to Stop 2a, the lowest ledge, where good outcrops of the andesite can be examined. This andesite is described in figure 3. Analysis No. 1, Table I, is from this exposure. From this ledge one can see the same unit in the north caldera wall.

The red scoria (Unit 3) is obscured at this particular traverse up the wall. It can be found by digging.

A short climb (bearing slightly to the left, or north) leads to the second ledge (Stop 2b) formed by outcrops of mafic tuff (Unit 4) of the wall sequence. These are the same tuffs as those below the falls in Paulina Creek (see figure 3).

A few tens of yards up the hill are good outcrops of welded tuff (Stop 2c). This tuff looks like a rhyolite flow in outcrop, except where long, devitrified pumice lapilli are draped over foreign rock fragments. The tuff is made up of fine ash, broken crystals, and long pieces of flattened pumice lapilli. Because of the large pumice lapilli and the high degree of welding, it is thought to represent an agglutinate-like deposit very near the vent. Chemically it is a dacite (see analysis No. 3, Table I).

Continuing up the wall one sees one of the chain craters (figures 2 and 4) along the fissures at the top of the east wall.

Stop 3. Toe of the Big Obsidian Flow:

This spectacular feature is best viewed and described from the top of Paulina Peak (Stop 5), but a brief stop to collect specimens will be made.

Across the road are excellent exposures of the above-water part of Little Crater, a tuff cone built into ancestral Paulina Lake.

Stop 4. Paulina Lake Ash Flow:

This is a brief stop to see one roadcut through part of the ash flow, and to look at the charred logs which have been dated at 2054 $\pm$ 230 years before present. This ash-flow sheet emerges from under the front of Big Obsidian Flow and covers the area between the obsidian flow and Paulina Lake. Long, shallow grooves and low ridges in the top of the flow, and a progressive lessening in size of largest pumice fragments away from Big Obsidian Flow, indicate that it flowed toward Paulina Lake. The pumice is faintly pink and its tubules are elongated and slightly flattened. There are at least five mappable units younger than this ash flow.

Stop 5. Paulina Peak:

From this vantage point one can see the entire caldera and the wall sequence in the north, east, and south walls. Also visible is the break in the north and south walls which marks the zone on which the western part of the top of the shield was dropped down with respect to the eastern part.

Acknowledgments

The U.S. Geological Survey supplied the ortho-photograph of Newberry Caldera and supported field work during the summer of 1967. Field work during the summer of 1966 was supported by a research grant from the University of California, Santa Barbara. Dr. W. S. Wise was of great help in theory and operation of the X-ray fluorescence.

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Williams, Howel, 1935, Newberry Volcano of central Oregon: Geol. Soc. America Bull., v. 46, p. 253-304.

Figure 5. Explanation of symbols used on figures 6 - 13.

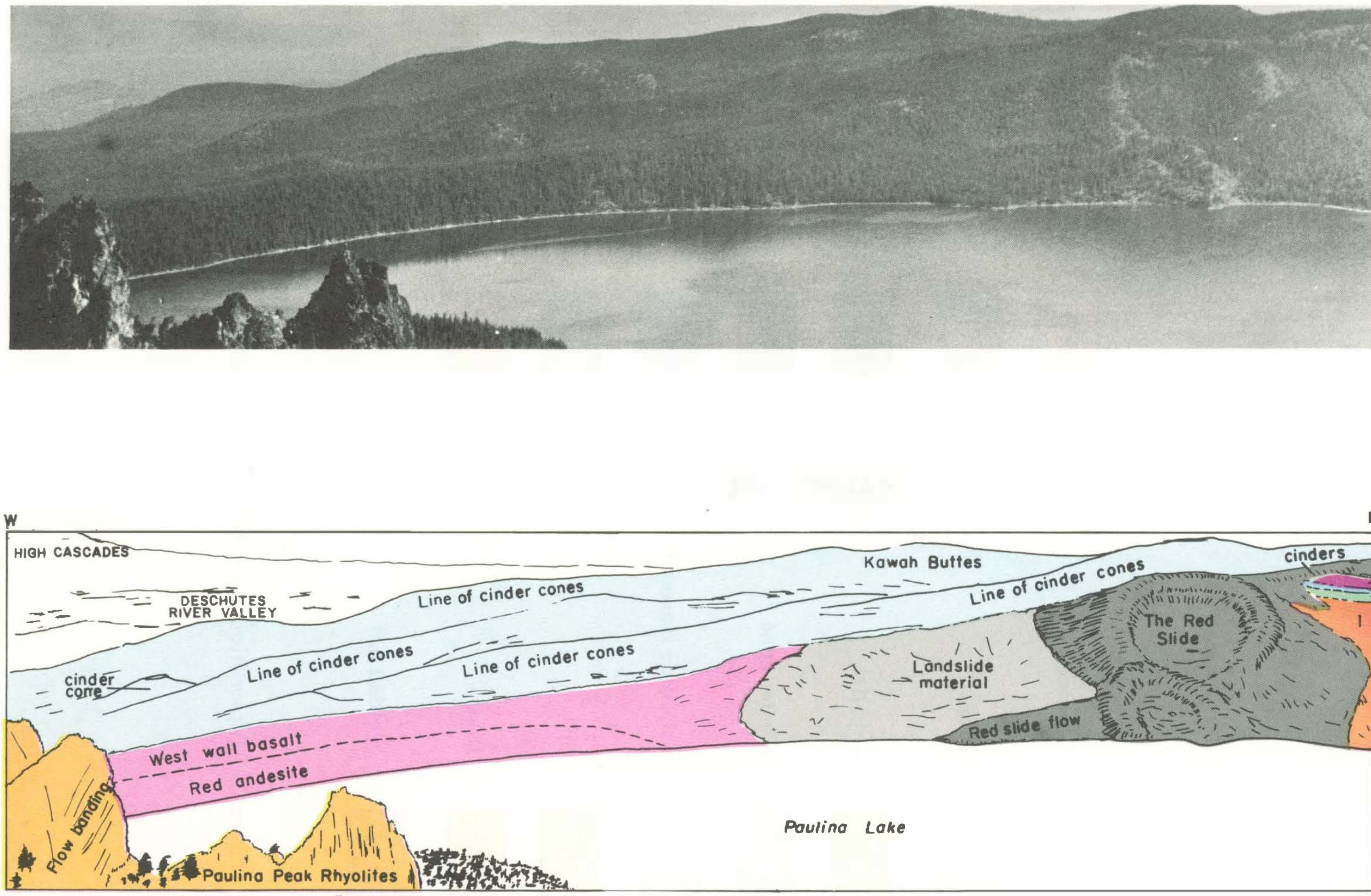

Figure 6 Panorama of part of the north wall of Newberry Caldera, showing geologic and topographic features. (For explanation, see figure 5.)

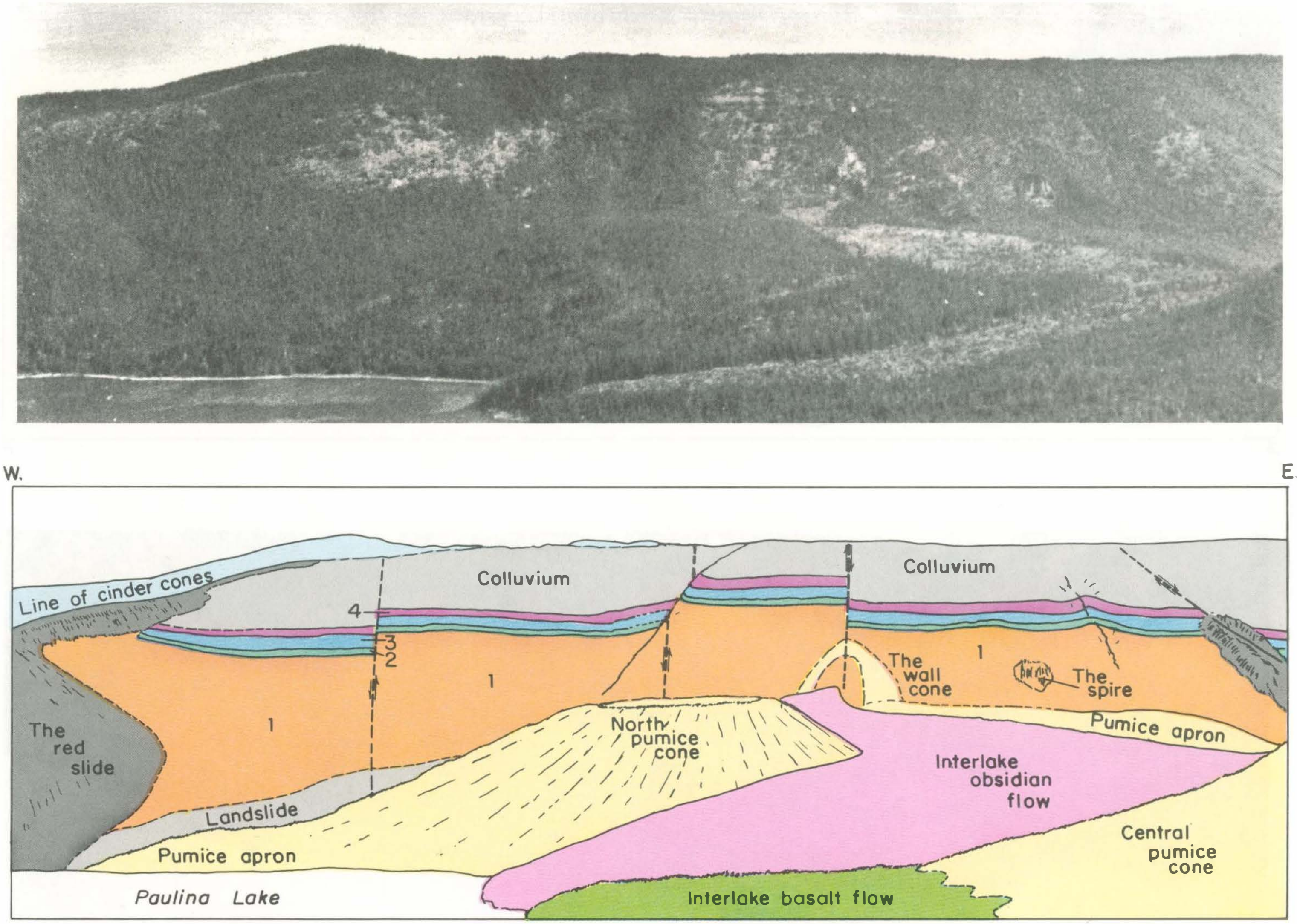

Figure 7 Panorama of part of the north wall of Newberry Caldera, showing geologic and topographic features. (For explanation, see figure 5.)

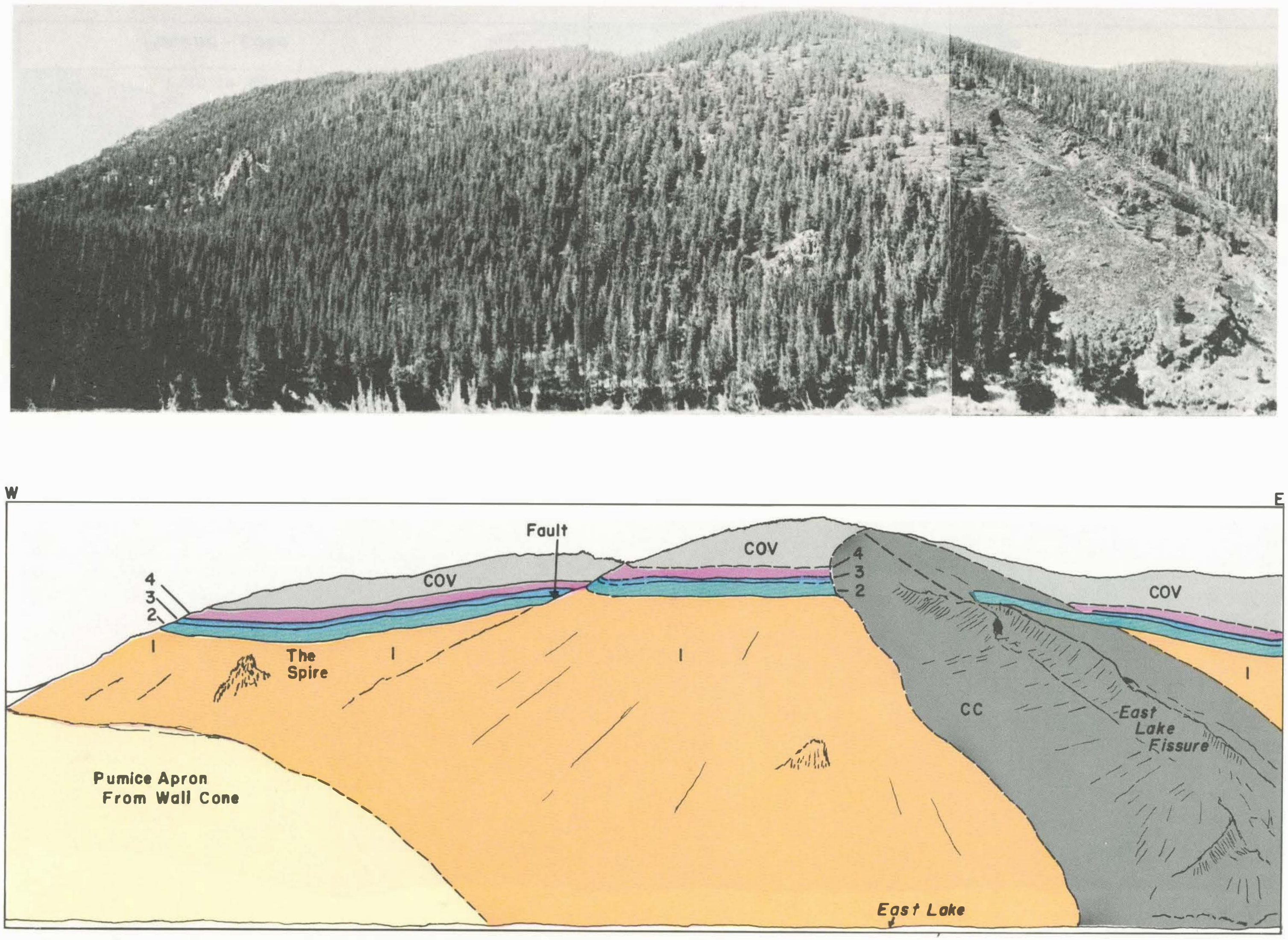

Figure 8 Panorama of part of the north wall of Newberry Caldera, showing geologic and topographic features. (For explanation, see figure 5.)

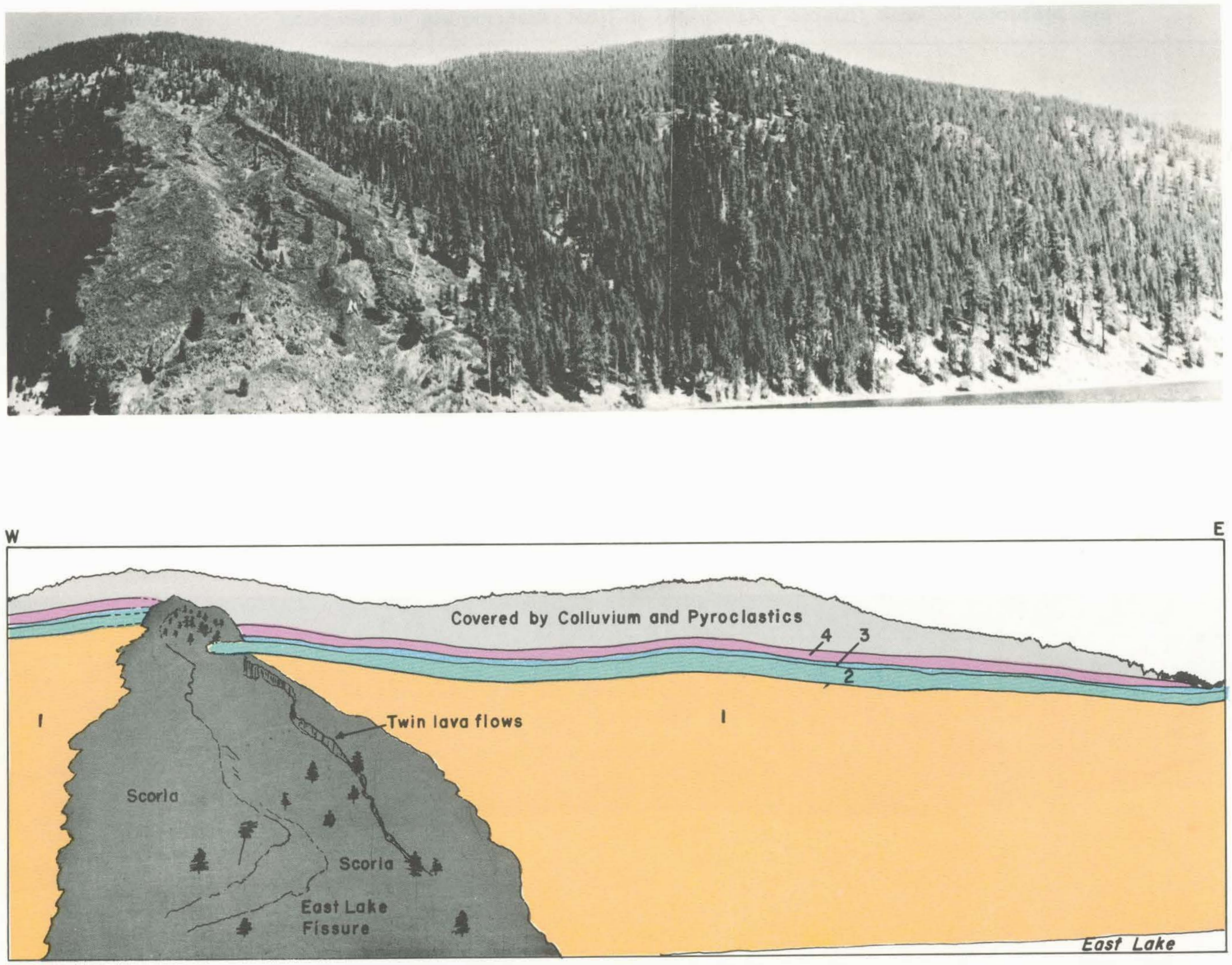

Figure 9 Panorama of part of the north wall of Newberry Caldera, showing geologic and topographic features. (For explanation, see figure 5.)

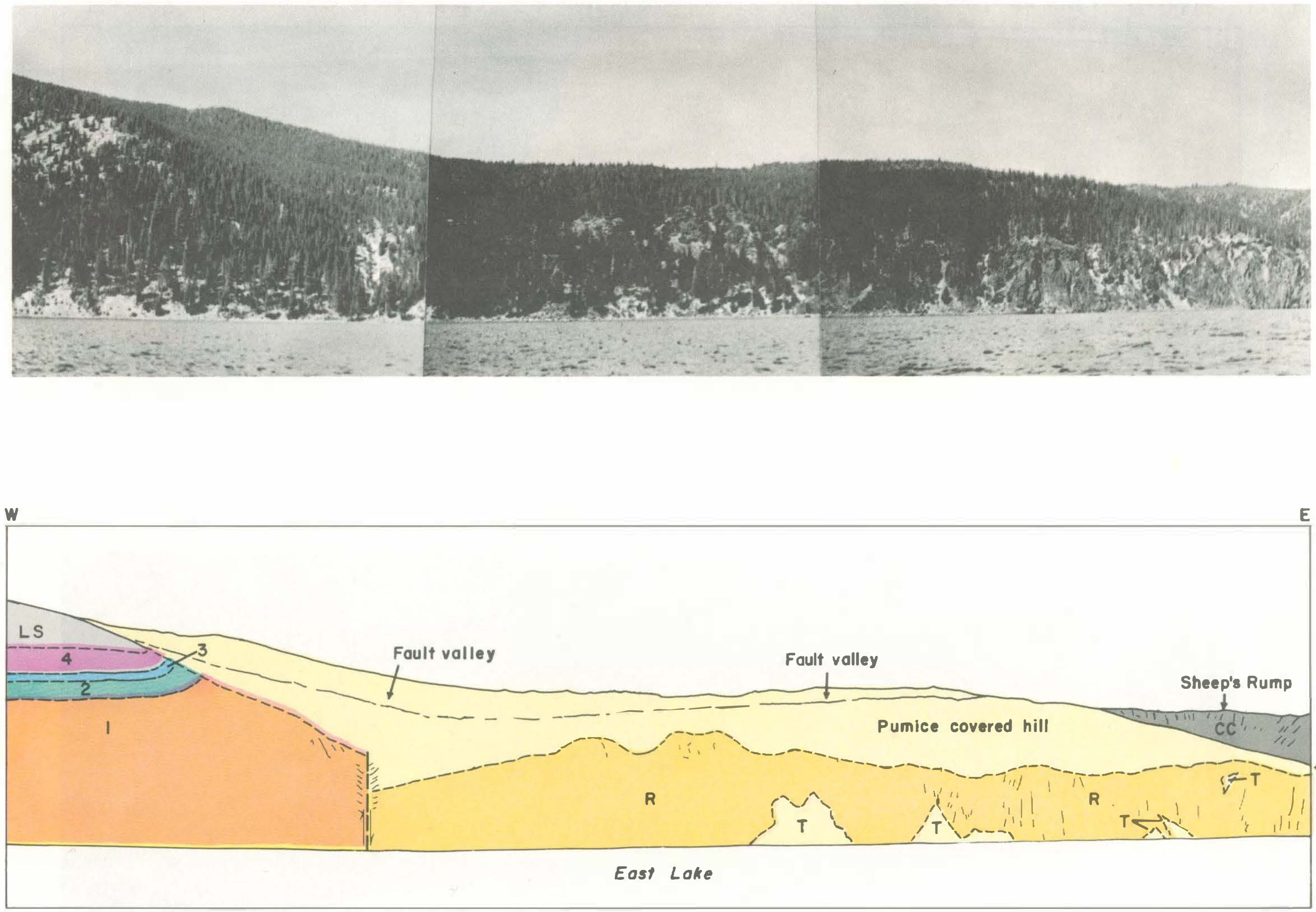

Figure 10 Panorama of the northeast wall of Newberry Caldera, showing geologic and topographic features. (For explanation, see figure 5.)

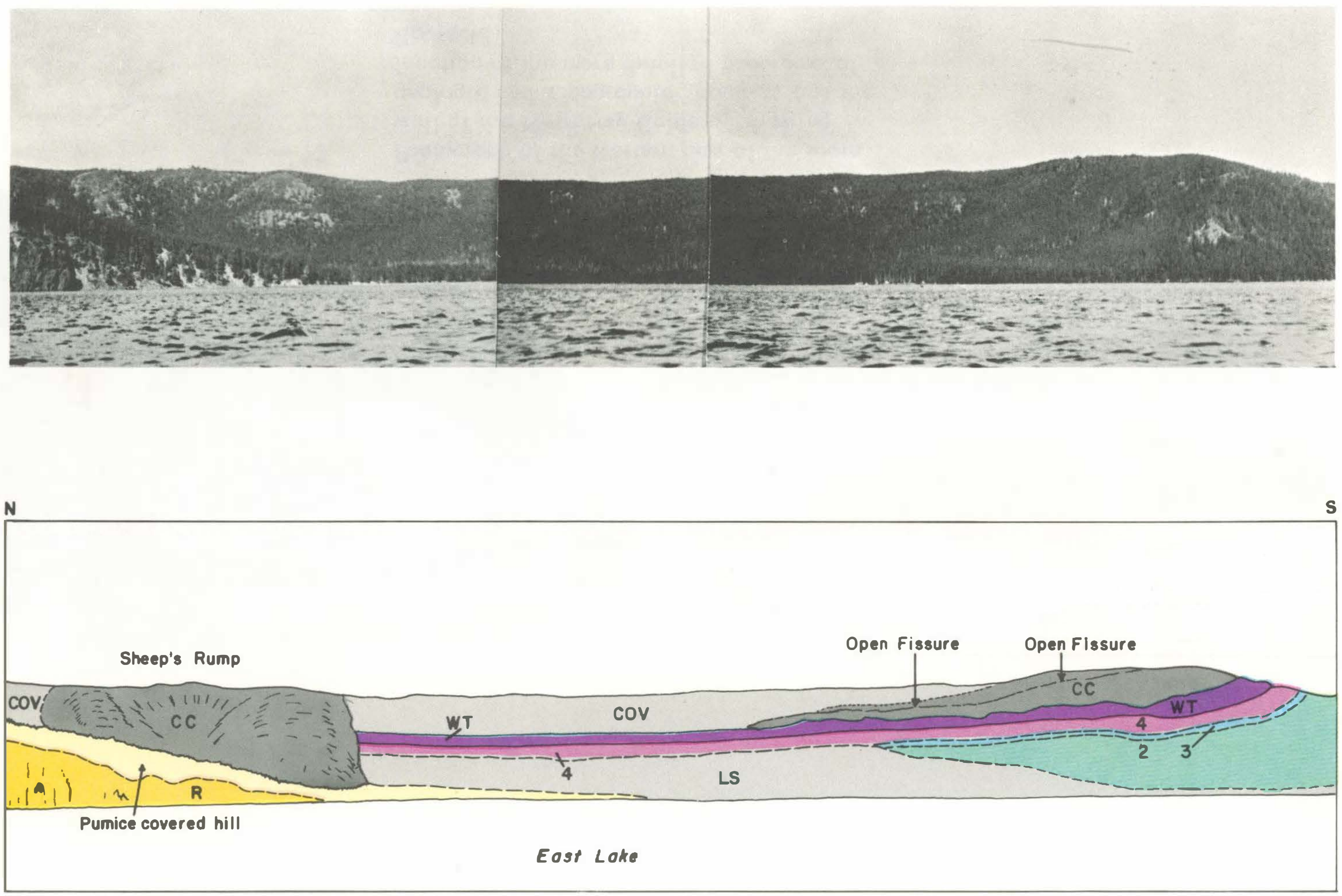

Figure 11 Panorama of part of the east and part of the northeast walls of Newberry Caldera, showing geologic and topographic features. (For explanation, see figure 5.)

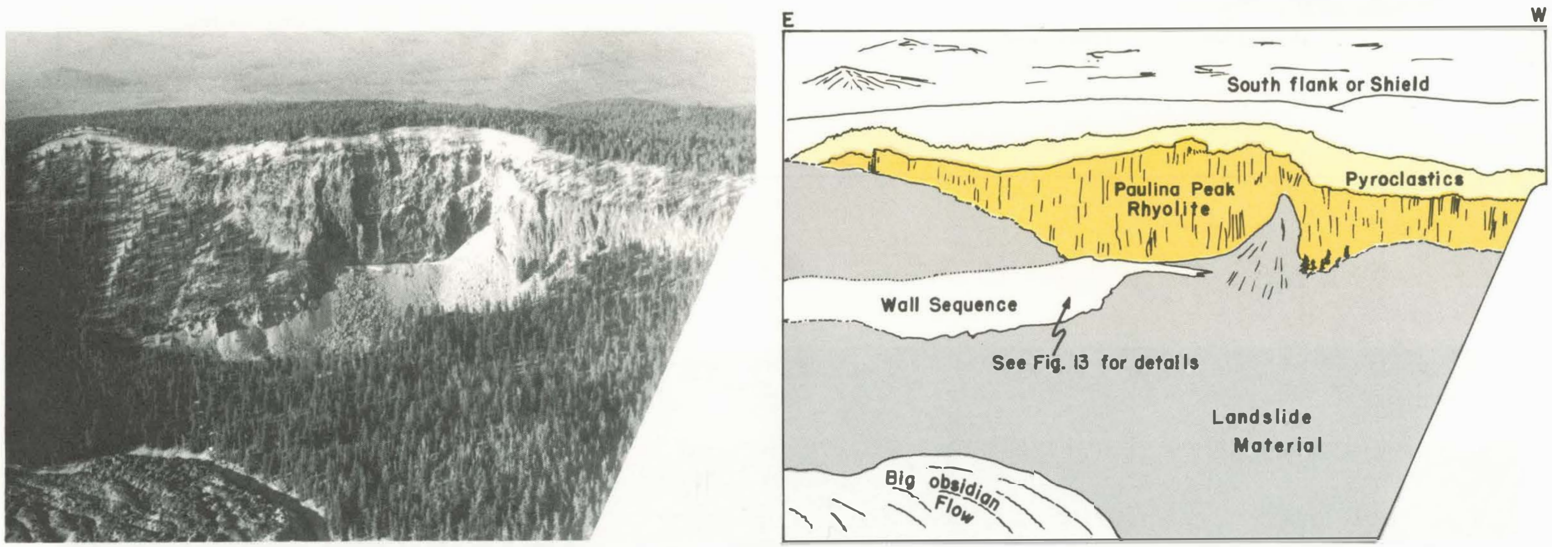

Figure 12 Photograph of the western part of the south wall of the Newberry Caldera, showing geologic and topographic features, and the location of the more detailed panorama of figure 13.

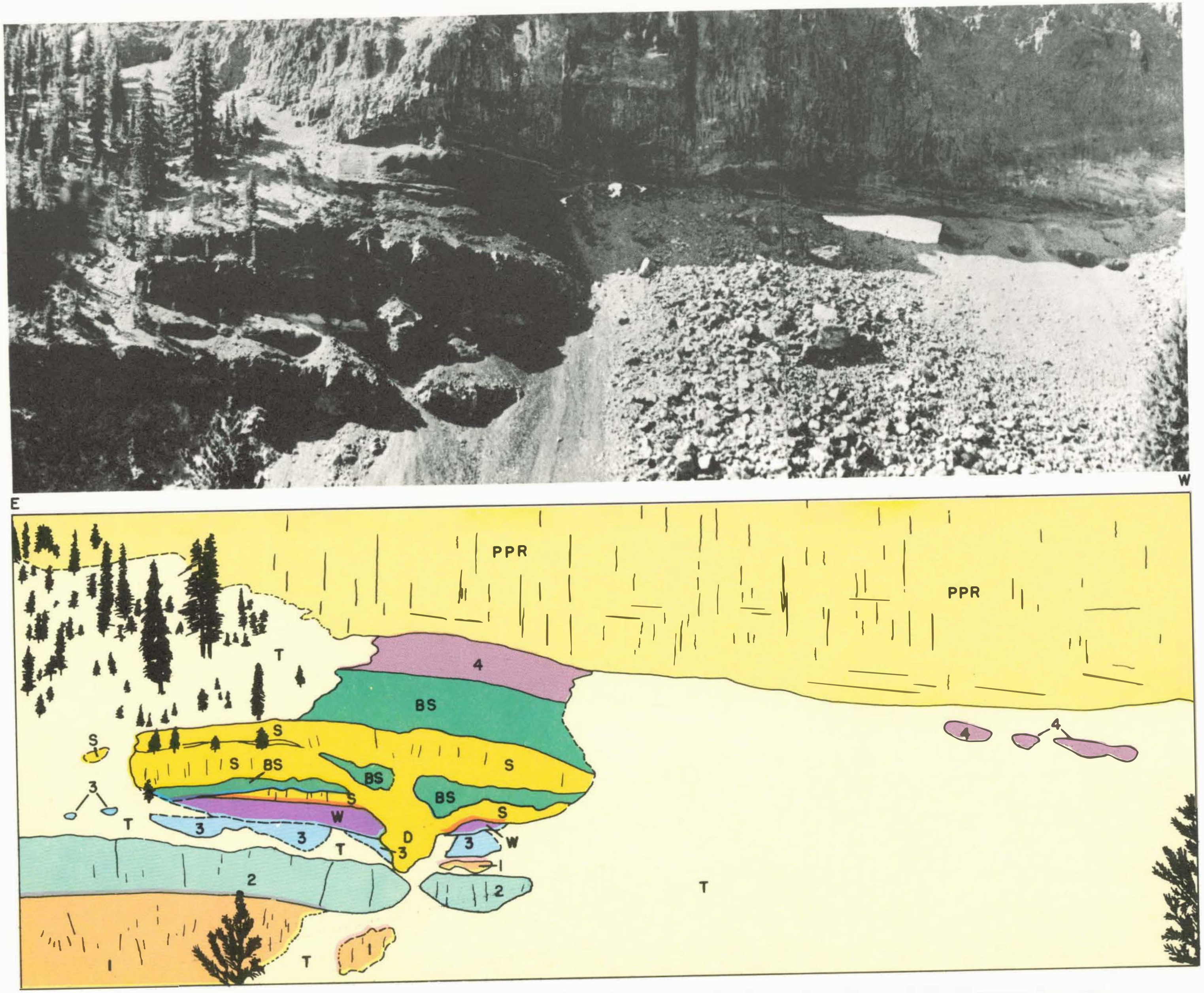

Figure 13 Panorama of part of the south wall of Newberry Caldera (see figure 12), showing the wall sequence, a dike and sills, and the westward down-bending of the wall sequence beds. (For explanation, see figure 5.)

MOUNT HOOD AREA

GEOLOGY OF THE MOUNT HOOD VOLCANO

By William S. Wise*

Introduction

Mount Hood -- 11,235 feet (3,424 m) high -- is the partially dissected cone of a late Pleistocene and Recent volcano. The composite cone is built almost entirely of pyroxene andesite and rises 8000 feet (2400 m) above a platform of Pliocene andesites and basalts. A maximum elevation of nearly 12,000 feet (3650 m) was attained before Fraser Glaciation** (approximately 15,000 years ago). About 2000 years ago activity was renewed with the extrusion of a hornblende andesite plug dome.

This part of the guidebook describes and illustrates the main physical features of the geology of the Mount Hood volcano (figure 1). Details of the geology can be obtained from the accompanying geologic map. Traverse sections (on page 98) are provided to illustrate my interpretations of some individual exposures. A detailed study of the petrology and chemistry is presented elsewhere.

Geology

Early activity

The lowest exposures along Compass Creek, a deep canyon on the north side of the cone, are probably the oldest flows of the volcano. These lavas are olivine pyroxene andesite and appear to be intracanyon flows in north-flowing river valleys. They came from a vent located near the eastern foot of a large, dissected late Pliocene volcano. The new volcano grew until the older cone was completely covered. Erosion has since exhumed part of this older cone, which is now exposed below the terminus of the Sandy Glacier (figures 2 and 9).

Several long intracanyon flows now form the ridges on the lower flanks of the cone. These flows seem to have been erupted when the main vent was less than 7000 feet (2100 m) in elevation. A few of these flows with lengths of as much as 8 miles (13 km) and thicknesses near 500 feet (150 m) represent huge outpourings of lava with volumes close to half a cubic mile (2 cubic km).

Building of the cone

The high part of the cone is built of shorter, thinner flows interbedded with pyroclastic debris. Individual flows, exhibiting a variety of structures and shapes, reveal physical conditions of the cone as the lava poured down its slopes. The six examples of flow exposures shown in figures 3 to 8 indicate that at various times lava flowed down steep slopes or filled canyons or plowed through snow fields.

Platy jointing is developed near the base of most flows (figures 3, 4, and 5). The subparallel arrangement of groundmass plagioclase along shear planes causes the rock to fracture into slabs. Downslope movement of the flow develops the shear planes only where solidification was nearly complete, in most cases near the base. A crude columnar jointing forms in the portion of flows that were subjected to little movement during the final cooling (figures 4 and 5).

Most flows can attain thickness in excess of 50 feet (15 m) only on gentle slopes (less than 8°).

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* Geology Department, University of California, Santa Barbara, Cal., 93106.

** Crandell, D. R., Mullineaux, D. R., and Waldron, H. H., 1958, Pleistocene sequence in southeastern part of the Puget Sound lowland, Washington: Am. Jour. Sci., v. 256, p. 384-397.

GEOLOGIC MAP OF MT. HOOD

Geology by W. S. Wise, 1962-65

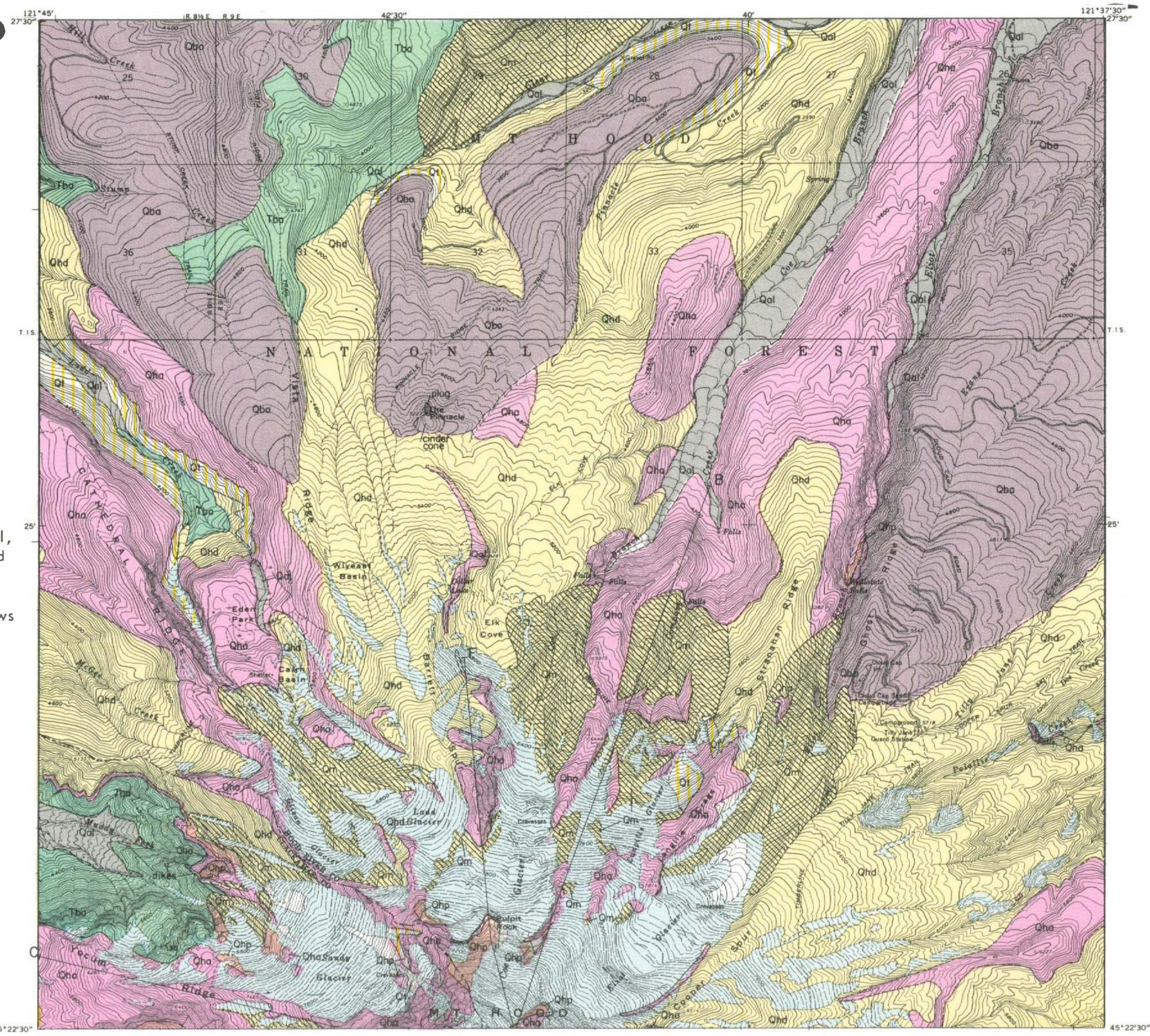
EXPLANATION

Qal	Alluvium and mudflow deposits in river valleys
Qt	Extensive talus slopes
Qm	Moraines, mostly associated with active glaciers
Qba	Post-Mount Hood basalt and andesite

Rocks erupted from the Mount Hood volcano

Qhh	Hornblende andesite debris fan with plug and breccia zone at Crater Rock
Qhd	Reworked debris, post-glacial, partly morainal, partly water-transported detritus
Qha	Mount Hood andesite flows
Qhp	Pyroclastic deposits interbedded with flows

Tba	Pre-Mount Hood andesites and basalts, mostly Pliocene
	Glacier



Base map from Cathedral Ridge, Timberline Lodge, and Government Camp U.S.G.S. 7.5-minute quadrangles.

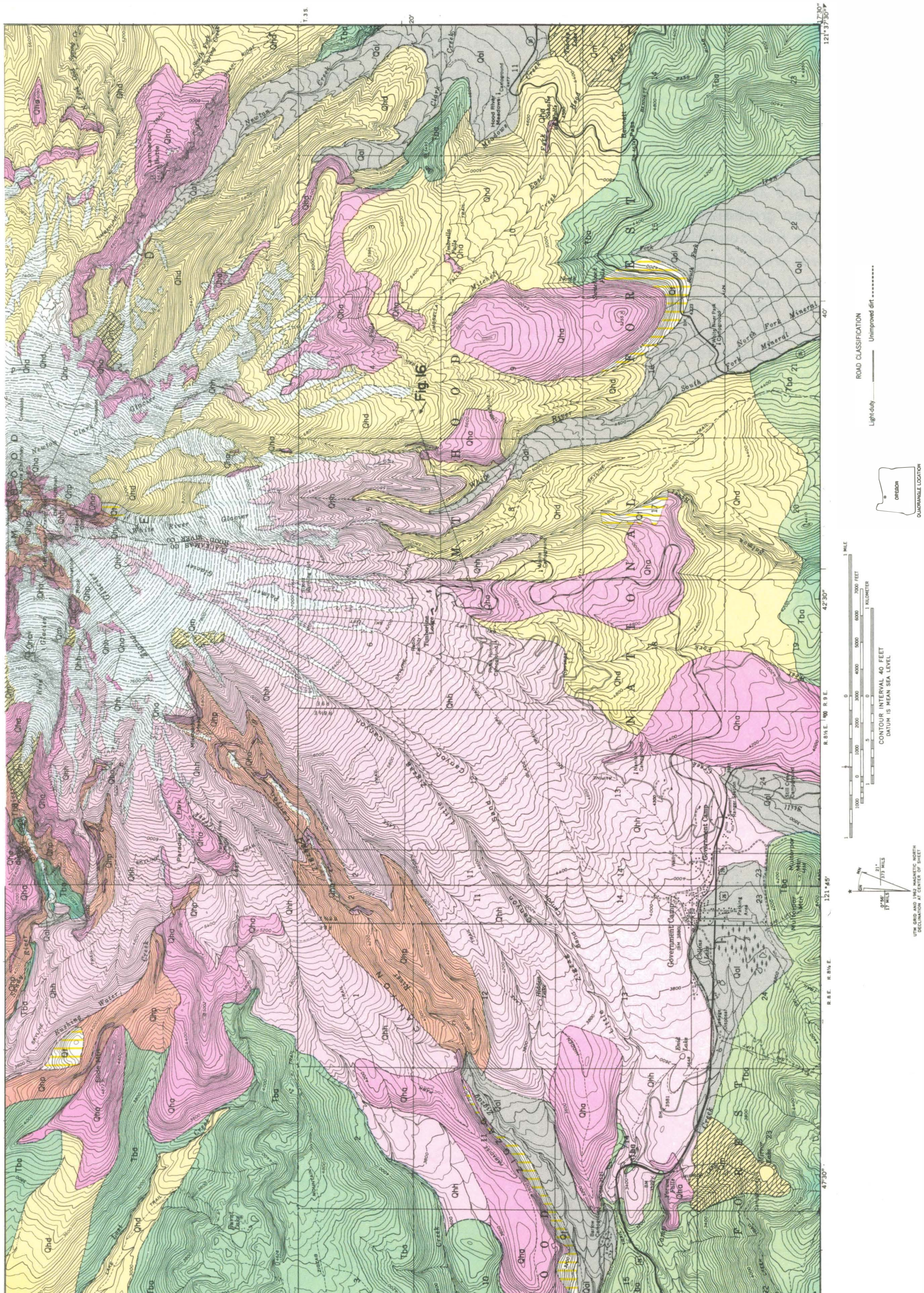
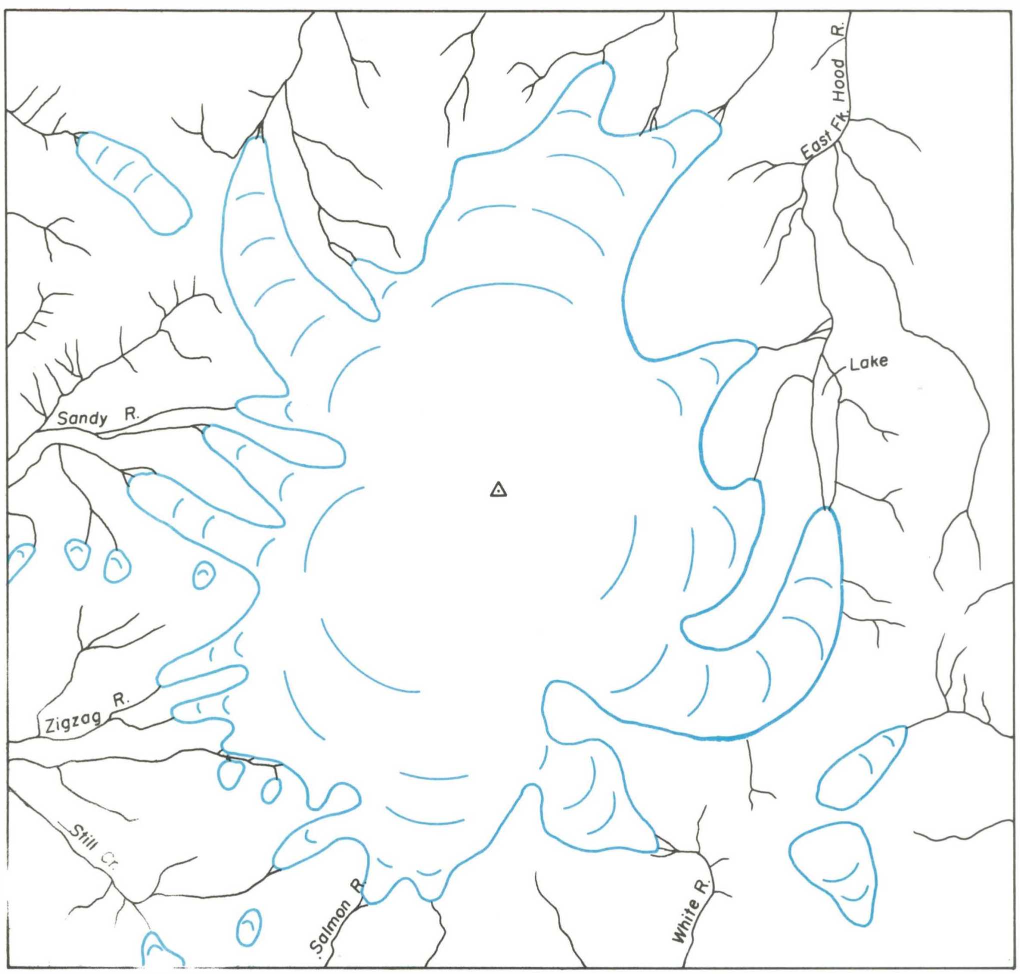


Fig. 16
Government Camp
ROAD CLASSIFICATION
Light-duty
Unimproved dirt
CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL
QUADRANGLE LOCATION
OREGON

The piling up of lava at the bottom of a steep slope produces a characteristic ramp structure. After the front part of the flow stops, later surges of lava are ramped (thrusted) over it. This ramping causes curved shear zones that rise over the front part of the flow. The curved zones of platy jointing in figure 6 indicate that that lava must have piled up in a deep canyon or basin high on the slopes of the volcano.

Large lens-shaped zones of breccia occur near the center of many solid flows lying on steep slopes, greater than 15° (see figure 7). These breccia pods apparently form wherever the lava was too viscous to flow smoothly down a steep gradient. The top-heavy mass developed a shear zone near the center of the flow. This resulted in the fragmentation of the pasty lava, as the upper plate glided over the basal part. The brecciated center was welded together when the movement stopped, leaving a solid flow with a breccia structure in the central part.

The interflow clastic debris in most exposures is at least crudely stratified (figure 5). However, several flows overlie an unbedded breccia in which the clasts have a lithology similar to that of the flow (figure 8). This breccia may have formed when the lava flowed through large snow or ice fields. However, since snow is a good insulator, extensive melting of the snow or ice is required to cause explosive fragmentation of the flow. The necessity of collecting water probably explains why the flow and breccia association is found only on the gentler slopes.



Maximum glacial advance during Fraser Glaciation. The extent of the glaciers shown on this map is based on reconnaissance mapping of tills, outwash, and striated outcrops.

The top part of the cone, the uppermost 2000 feet (600 m), is composed mostly of thin flows that skidded off the top over snow and pyroclastic debris. Remnants of two short, but thick, intracanyon flows form Steel Cliff and Barrett Spur (figure 9 and traverse section E-F).

The remains of the conduit filling are thought to be exposed in the face just north of the summit (figures 10 and 11). Although this exposure was not visited because of its inaccessibility, the interpretation is based on the dips of clastic deposits exposed in the upper 1000 feet of the cone (see the traverse sections).

Satellitic vents and dissection of the cone

Before the extensive glaciation, but after the cessation of the cone building, lava was erupted from two satellitic vents on the north and northeast slopes of the mountain. Several flows of olivine andesite were emitted from each. The plug of one vent forms The Pinnacle and is the source of three flows. The other vent near Cloud Cap Inn has been eroded by Eliot Glacier and covered with moraine. This vent was the source of at least four large flows that are 100 feet (30 m) thick and 5 miles (8 km) long.

Tills, weathered to a depth of less than one meter, occur in all valleys around the mountain, and probably represent a glacial advance during Fraser Glaciation. Reconnaissance mapping of tills and striated outcrops reveals the approximate limits of glacial advance as shown on the small map on the preceding page.

The glaciers retreated to the high levels where they have since carved basins into the cone (figures 9 and 10). This glacial erosion lowered the volcano summit and flanks several hundreds of feet, with most material removed from the north side.

Recent extrusion of a plug dome

The predominant feature of the south and southwest slopes of the mountain is a broad fan of hornblende andesite debris (figures 9, 12, and 14). The fan is crudely stratified with beds of unsorted clasts ranging from sand size to blocks 20 feet (6 m) in diameter. Many of the largest blocks exhibit radial jointing, caused by their cooling as isolated fragments (figure 13). Since it is not possible to move one of these jointed masses without causing fragmentation, they must have been transported while they were hot.

The apex of the debris fan is at Crater Rock, a high outcrop of hornblende andesite. This outcrop is surrounded by a zone of brecciated hornblende andesite.

A large number of trees were buried by the debris fan. Lawrence and Lawrence (1959) have reported radiocarbon ages for several of them, and the oldest (1700 years) provides a minimum age for the fan.

These observations are interpreted as follows: About 2000 years ago a crater was blasted out of the southwest slope approximately 1000 feet (300 m) below the summit of the glaciated mountain. A plug dome of hornblende andesite was extruded from this crater. As the dome grew it came in contact with large amounts of snow and ice, most of which was melted. This excess water helped the normal fragmentation of the cone and mobilized slurry floods, mudflows, and hot avalanches down the slope. Repeated shedding of debris built the smooth debris fan (figure 15).

Normal runoff cut a canyon, ancestral to the upper White River, into the fan (figure 15). Remnants of partial refilling of this canyon can be observed in the White River canyon near Timberline Lodge (figure 16). Contemporaneous erosion also took place in the Zigzag Canyon and Sandy River canyon. These three river valleys are choked with hornblende andesite debris carried by mudflows.

When activity ceased, erosion removed all loose fragments from the dome. The solid portion, Crater Rock, is all that remains. Erosion has also been aided by rock alteration around the plug by fumarolic gases. East and northeast of Crater Rock there are at present at least 20 fumarole vents (figure 17). Temperatures range from 50° to 85° C. Gas analyses by Phillips (1935) average 98.7 percent H_2O, 1.2 percent CO_2, 0.03 percent H_2S, and 0.003 percent H_2.

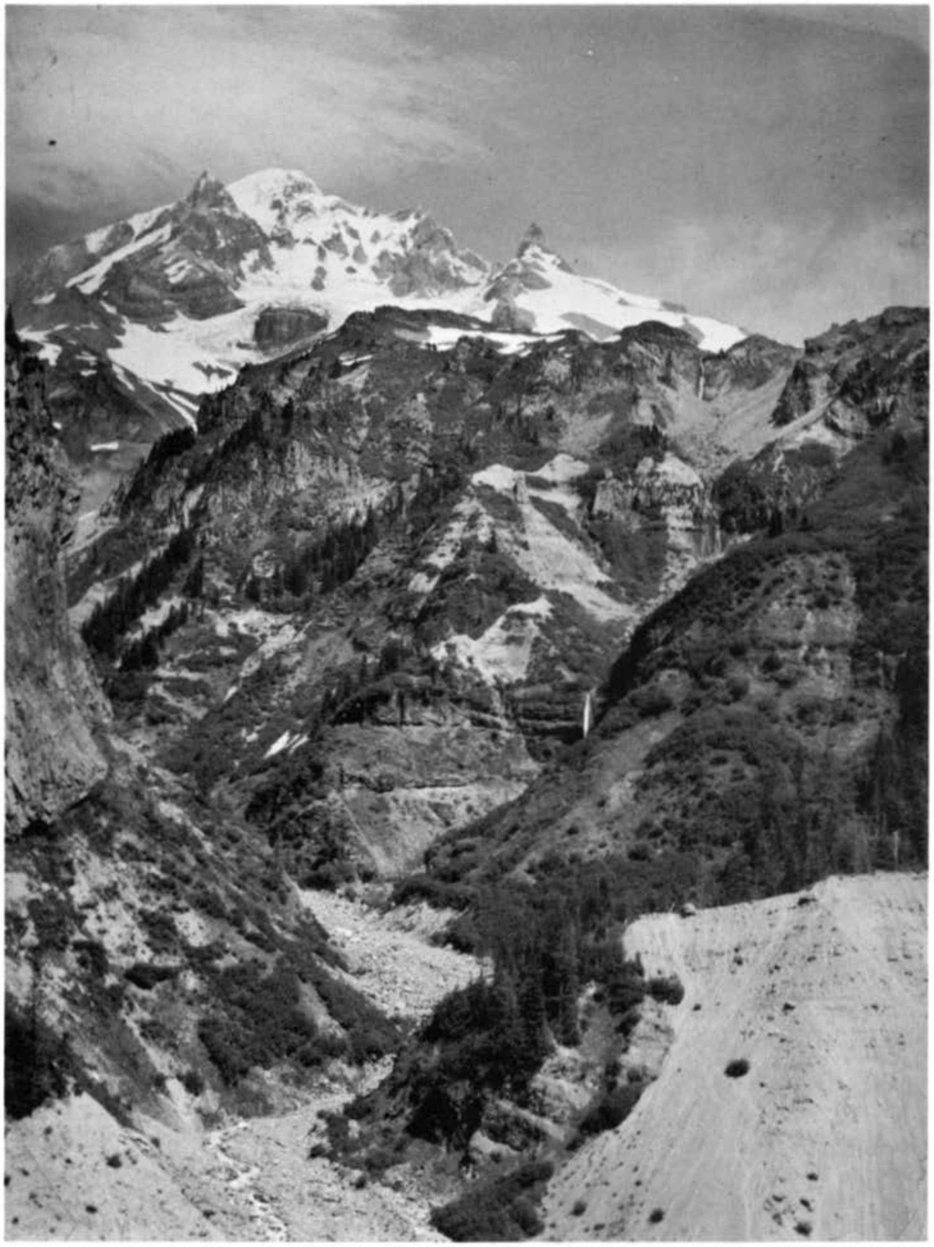


Figure 1. Mount Hood and the upper Sandy River canyon. Thin late Pliocene basalt flows and tuffs crop out in center foreground and under the lowest waterfalls. Overlying the basalts are light-colored Mount Hood pyroclastic rocks (center). Mount Hood andesite flows form all high outcrops. The Reid Glacier breaks over a large outcrop of andesite and feeds the Sandy River. Remnants of the Recent hornblende andesite debris fan form the white bedded deposit in lower right.

Figure 2. Stereo view of the Sandy Glacier volcano and Mount Hood andesite dikes (west side of Mount Hood). The bare slopes and the large exposure in the background expose thin basalt flows and tuffaceous breccias of a late Pliocene volcano. Two large, tabular dikes, cutting the old flows, rise 200 feet (60 m) above the slopes. The upper part of the exposure is overlain by two Mount Hood andesite flows.

Figure 3. Andesite flows exposed under the Newton-Clark Glacier (east side of Mount Hood). Four flows in this view have a total thickness of 200 feet (60 m). The second flow from the top is tentatively correlated with the top flow of figure 4.

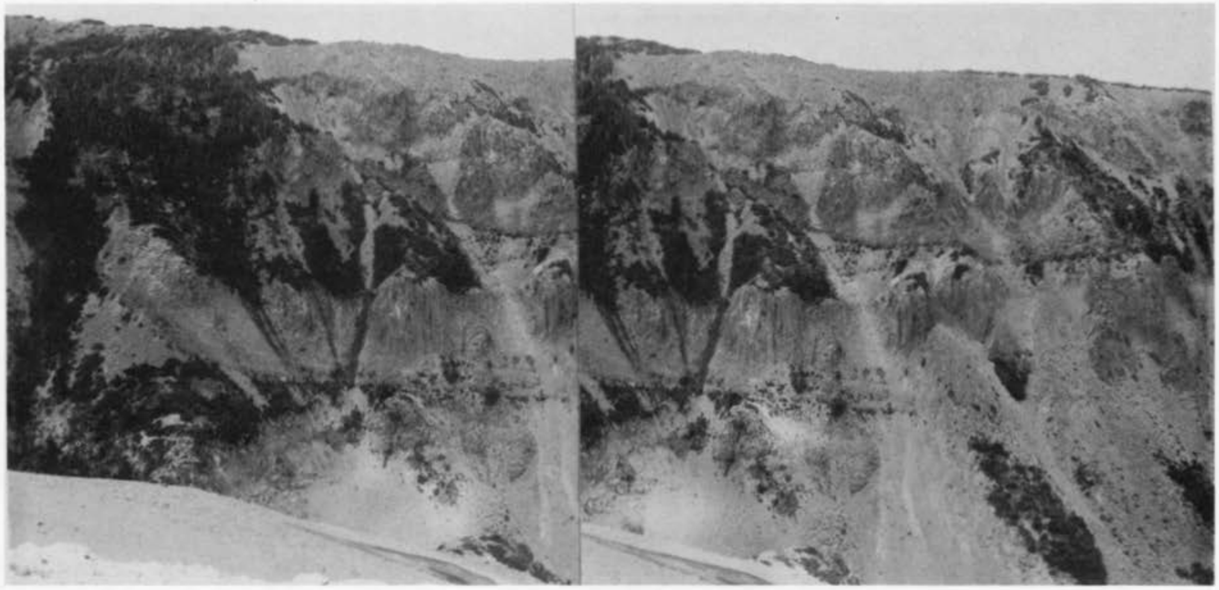


Figure 4. Stereo view of four flows forming Lamberson Butte (east side of Mount Hood). Outcrops of the lowest flow are partially obscured by brush and talus. The second flow has bold outcrops with columnar jointing and a planar lower surface. The third flow crops out in the tree-covered area in upper left. The highest flow has bold outcrops with columnar and irregular jointing. Its contact with the third flow appears curved, because the flow filled a canyon cut into earlier flows. This canyon was situated diagonally to the present one. Each of these pyroxene andesite flows is at least 200 feet (60 m) thick.

Figure 5. Two andesite flows near Slide Mountain (southwest flank of Mount Hood). The large flow has a platy jointed zone 7 feet (2 m) thick between the upper, columnar-jointed part and the basal, blocky jointed part. The larger flow is on a 7° slope. The lower flow (10 feet [3 m] thick) is on a 4° to 8° slope. Interbedded clastics are sands and gravels with few large boulders deposited on 5° to 7° slopes.

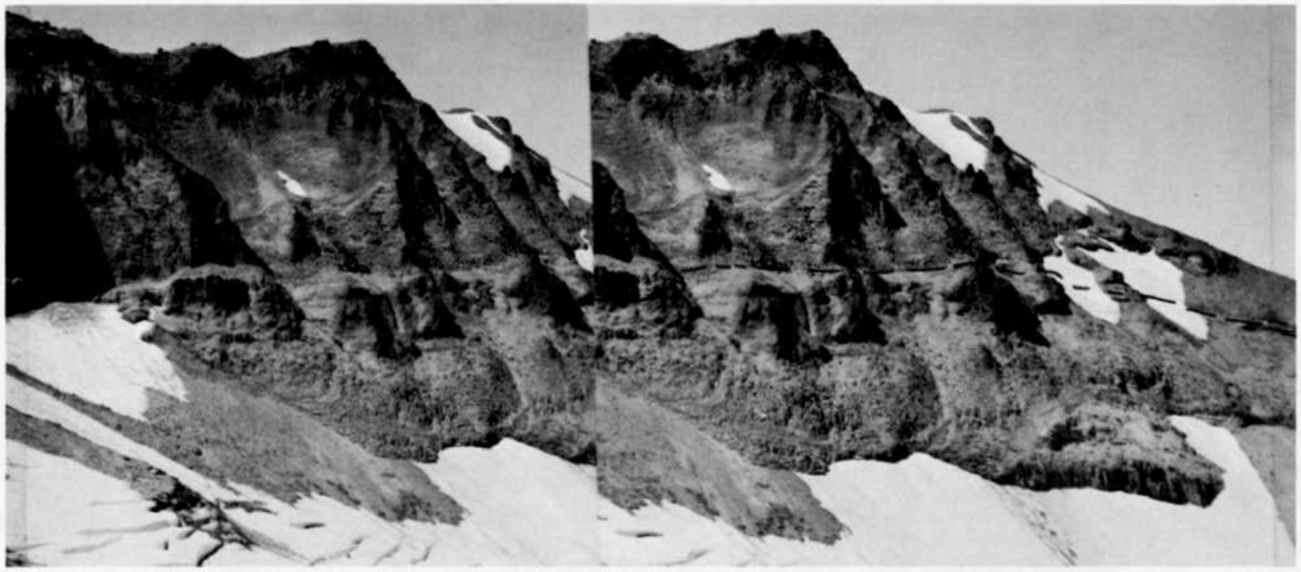


Figure 6. Stereo view of the east side of Barrett Spur (north side of Mount Hood), formed by two late, high-level intracanyon flows. Lava flowed from left to right. The inclined shear surface, cutting across the upper flow, was formed when lava was ramped up and over an earlier part of the flow.

Figure 7. Breccia pod in the center of an andesite flow, north side of Mount Hood. The flow lies on a 15° slope. Lava, when still pasty, fractured along a plane parallel to the flow base. The upper plate of the flow moved rapidly over the base, causing brecciation along the shear plane. When movement stopped all the fragments were welded together, giving a solid flow with an internal fragmental structure.

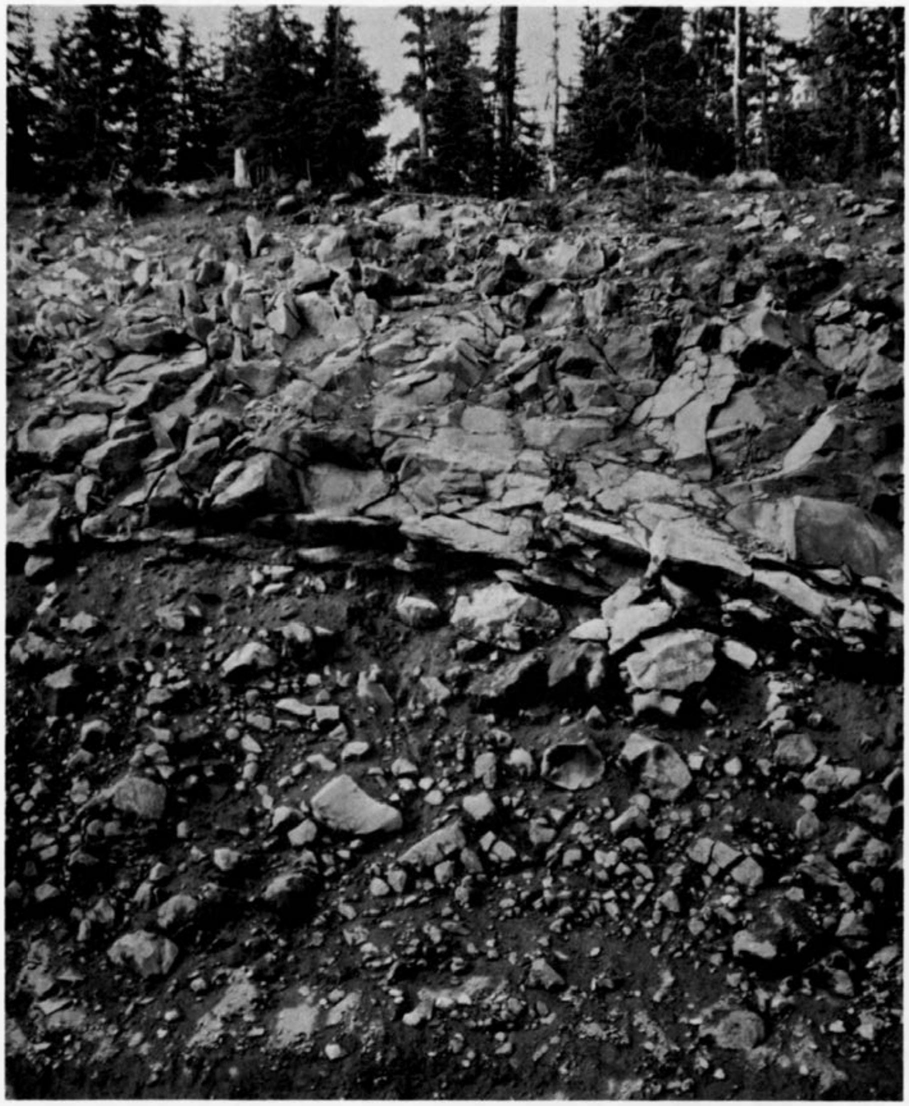


Figure 8. Andesite flow, exposed inroad cut along highway to Timberline Lodge (south slope of Mount Hood). Since breccia is unbedded and has same lithology as the overlying flow, it may have formed from lava exploded by water from the melting of snow or ice.

Figure 9. Aerial view of west face of Mount Hood. The Sandy Glacier (left center) and Reid Glacier (center) have cut basins into the upper part of the cone. The Sandy Glacier volcano (late Pliocene) is exposed under moraines (lower left). The ridges between the glaciers and the face above Sandy Glacier are outcrops of andesite flows. The face above Reid Glacier is mostly pyroclastic deposits with some flows. Most of the south slope (right side) is covered by hornblende andesite debris, which originated from the plug forming Crater Rock. The large cliff exposure to the east of Crater Rock is Steel Cliff, a remnant of a thick, late flow. [Delano Photographics No. 60498]

Figure 10. Aerial view of north face of Mount Hood. Coe Glacier (left) and Ladd Glacier (right) have cut basins into the upper part of the cone. Pulpit Rock (center) and Barrett Spur (lower right) are remnants of late intracanyon flows. The central plug, filling the old conduit, is thought to be exposed in the cliff below and left of the summit. [Oregon Dept. Geology and Mineral Industries photo.]

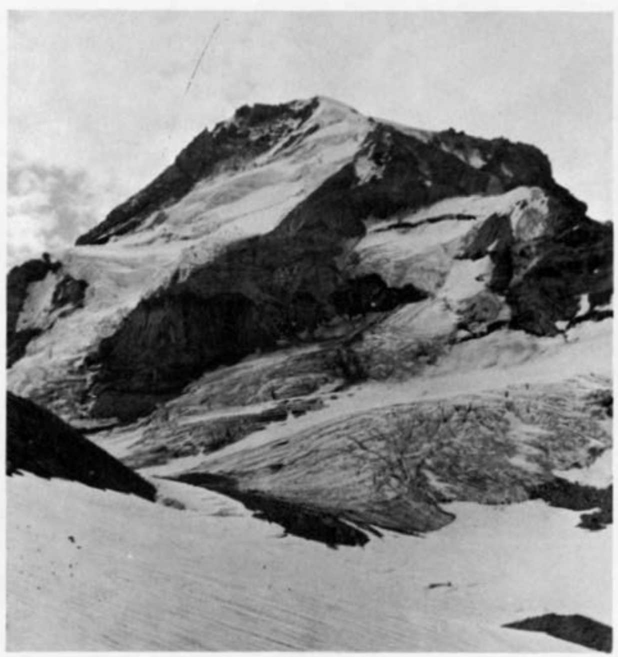


Figure 11. View of north face of Mount Hood from west side of Barrett Spur. Pulpit Rock (left center) is composed of a solid andesite flowoverlying and over-loin by pyroclastic beds.

Figure 12. Aerial view of Zigzag Canyon. The canyon exposes interbedded andesite flows and pyroclastic deposits (compare with Traverse Section A-B). The thickest flow is Mississippi Head. Debris from the Recent plug dome filled the canyon and has been partially removed to exhume the earlier flows. [Oregon Dept. of Geology and Mineral Industries photograph.]

Figure 13. Hornblende andesite debris fan exposed by the Little Zigzag Canyon. The 80-foot (25 m) deep canyon reveals unsorted but crudely stratified layers of mudflow, slurry flood, and avalanche deposits. The large, radially jointed boulder near the bottom was transported to this site while hot. Subsequent cooling produced the radial joints, causing the boulder to fall apart. This type of jointing, common in the debris fan, is the main evidence leading to the conclusion that the debris fan formed from an actively extruding plug dome.

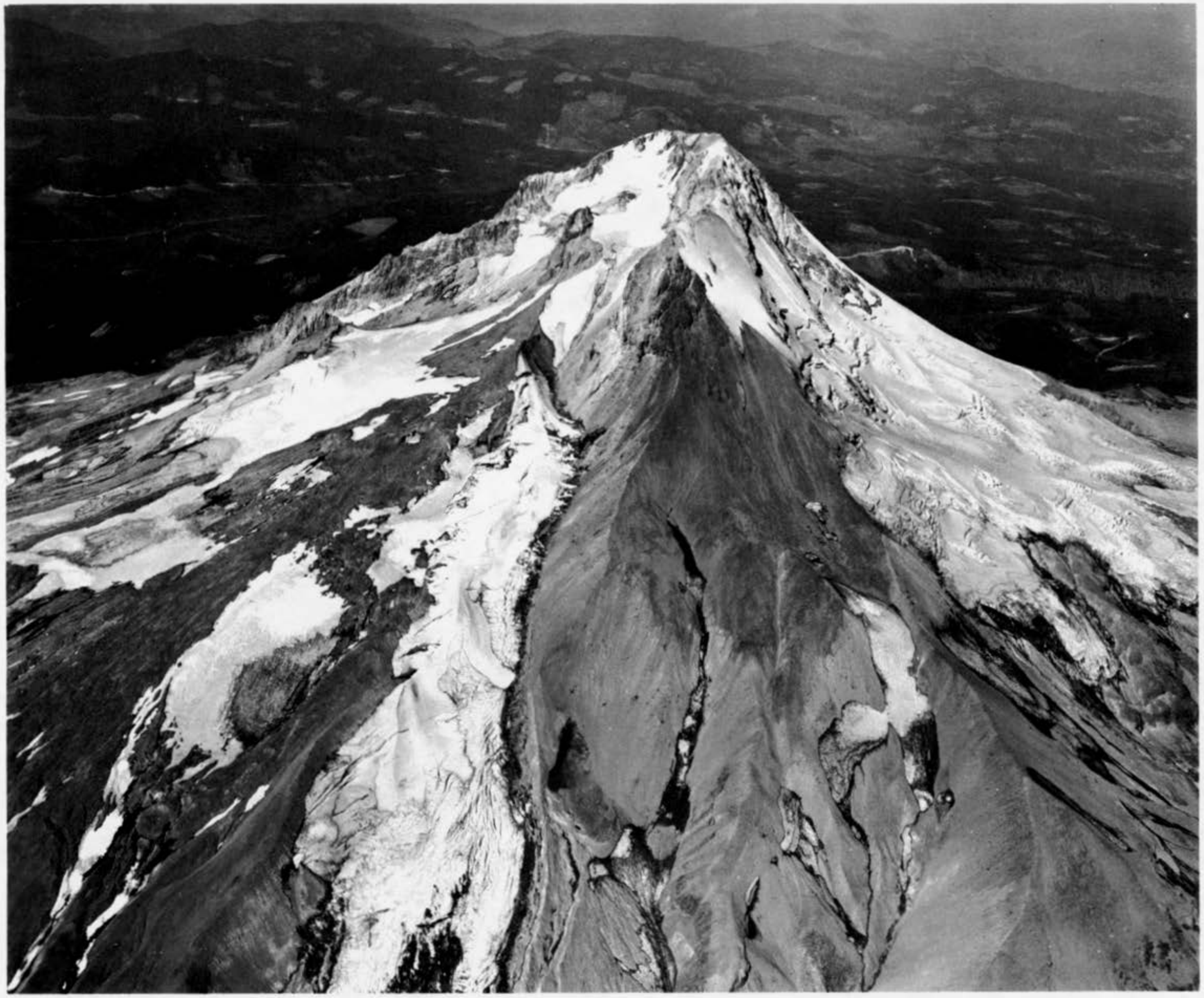


Figure 14. Aerial view of the southeast side of Mount Hood. White River Glacier (just left of center) is cutting into port of the Recent hornblende andesite debris fan, which covers the entire slope west (left) of the glacier. Newton Clark Glocier is on the east slope (right side). Crater Rock is in the center of the pocket southwest of the summit. Hot Rocks (figure 17) ore fumaroles located around Crater Rock, except lower side. Below the solid portion of Crater Rock is a breccia margin. The smooth slopes in the center and lower right ore underlain by crudely stratified debris redistributed after Fraser Glaciation. [Delano Photogrophics, No. 60500.]

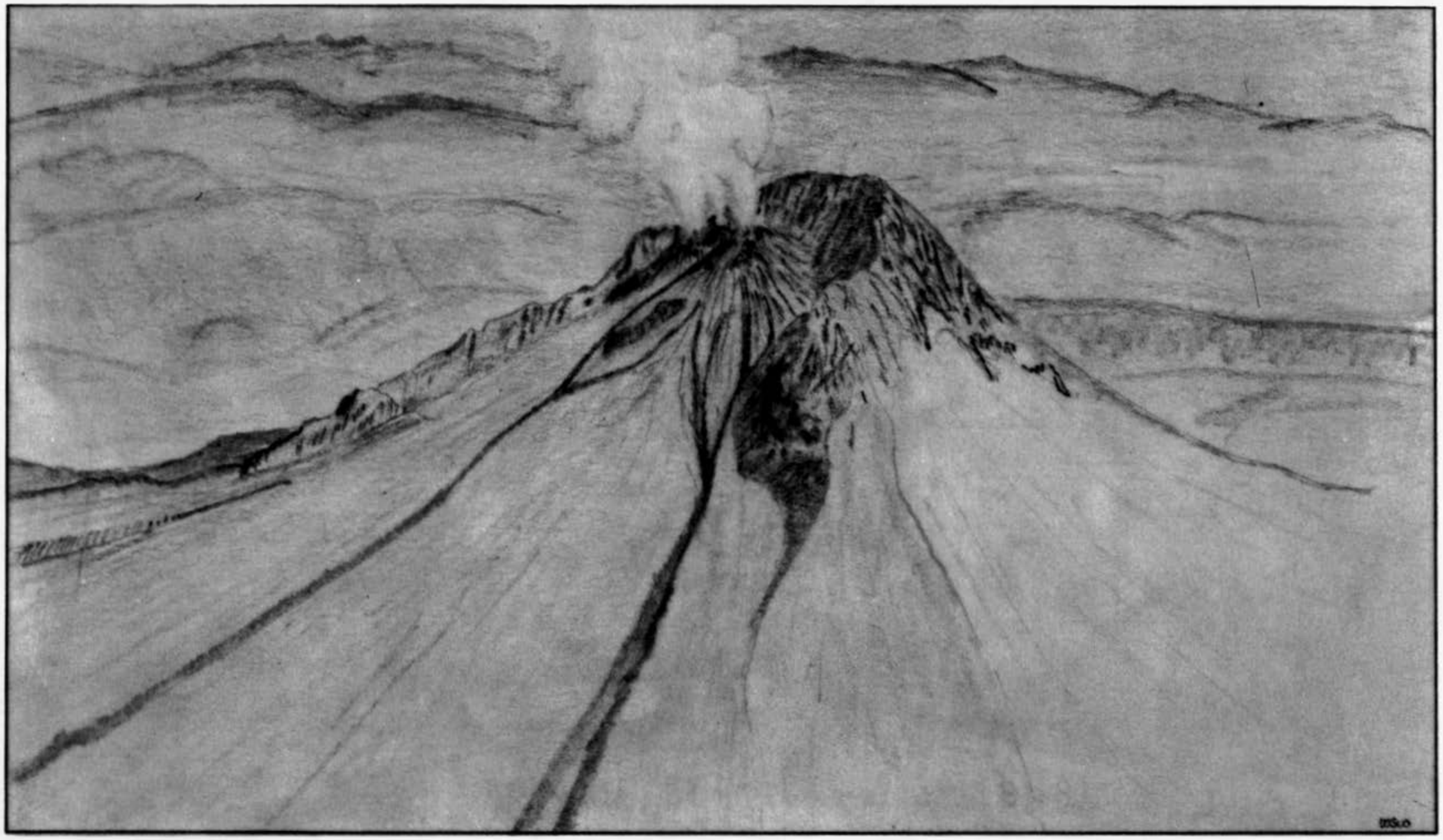


Figure 15. Reconstructed view of Mount Hood, during the activity of the plug dome. Explosive eruptions, preceding the extrusion of the dome, were probably responsible for the formation of the open crater. Slurry floods, mudflows, and hot avalances transported debris from the dome down the slopes forming the broad fan. Normal precipitation runoff into the White River continued to cut deeply into the fan (center foreground).

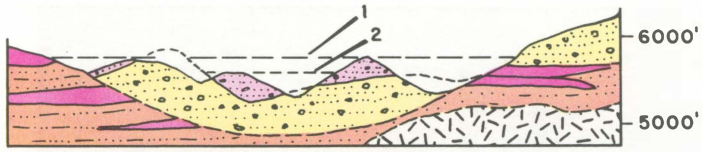


Figure 16. Cross section across the White River canyon near Timberline Lodge (see geologic map). A U-shaped canyon was cut into flows (red) and pyroclastic deposits (orange) by a large glacier during the Fraser Glaciation. The canyon was partially filled by debris (yellow) from the mountain as the glacier retreated. Although debris from the hornblende andesite plug dome (light red) filled the canyon to a high level (surface 1), rapid erosion soon cut the canyon again. A later surge of dome activity was responsible for the partial refilling of the canyon (surface 2).

Figure 17. The Hot Rocks and Crater Rock near the summit of Mount Hood. Gas is emitted from a fumarole on the edge of Crater Rock (lower left), as well as through the hole in the snow. Acids derived from the fumarolic gases have altered most of the rock in the area around Crater Rock.

TABLE I.

Chemical analyses of some representative lavas erupted from Mount Hood.

	1	2	3	4	5
SiO_2	57.04	59.2	60.6	61.07	61.3
TiO_2	0.84	0.92	0.98	0.80	0.80
Al_2O_3	17.94	17.65	16.6	16.96	16.9
Fe_2O_3	2.58	3.18	2.40	2.48	2.26
FeO	4.19	3.63	4.36	3.09	3.08
MnO	0.10	0.10	0.10	0.08	0.08
MgO	4.49	2.8	2.6	2.30	2.1
CaO	7.61	6.6	6.2	5.86	5.95
Na_2O	3.81	3.96	4.15	4.28	4.36
K_2O	1.01	1.60	1.48	1.79	1.44
P_2O_5	0.17	0.18	0.19	0.22	0.18
Total	99.78	99.82	100.05	98.93	98.45
			Molecular Norms		
qz	7.0	10.0	12.1	12.2	13.4
or	5.9	9.5	8.8	10.7	8.7
ab	34.1	35.7	37.6	38.9	39.8
an	28.8	25.8	22.5	22.1	22.7
di	5.1	4.8	5.8	4.7	4.9
hy	15.1	10.5	9.5	8.3	7.5
ol	0.0	0.0	0.0	0.0	0.0
mt	1.9	2.0	1.9	1.5	1.5
il	1.2	1.3	1.4	1.1	1.1
ap	0.4	0.4	0.4	0.5	0.4

Analysts: No. 1, T. Asari; No. 4, H. Asari; Nos. 2, 3, and 5, W. Wise.

1. Olivine pyroxene andesite: Compass Creek, north side of Mount Hood.
2. Pyroxene andesite: Intracanyon flow, west side of Zigzag Canyon.
3. Pyroxene andesite: Flow exposed at parking lot at Timberline Lodge, south side of Mount Hood.
4. Pyroxene andesite: Late flow forming Barrett Spur, north side of Mount Hood.
5. Hornblende andesite: Clast from debris fan, collected near terminus of Zigzag Glacier.

Petrology

All the flows are porphyritic with plagioclase, hypersthene, and magnetite phenocrysts. Augite, olivine, and oxyhornblende are common as phenocrysts but are not present in all flows. The composition of the phenocrysts shows remarkably little variation. Plagioclase, though complexly zoned, ranges from An_{50} to An_{40}, hypersthene is about En_{70}, and augite $Wo_{45}En_{42}Fs_{13}$.

Table I lists the chemical composition of five flows to illustrate the maximum range of compositions.

Evidence being published elsewhere leads to the following conclusions regarding the origin of the Mount Hood magmas: These andesites did not differentiate from a high alumina basalt magma similar to that erupted in the area around Mount Hood. Moreover, the later flows did not differentiate from magmas represented by any of the earlier flows. The variety of compositions, the large volume of andesite magma erupted, the long period of activity, and the lack of differentiation processes are best explained by the repeated generation of magma by some melting process near the base of the crust.

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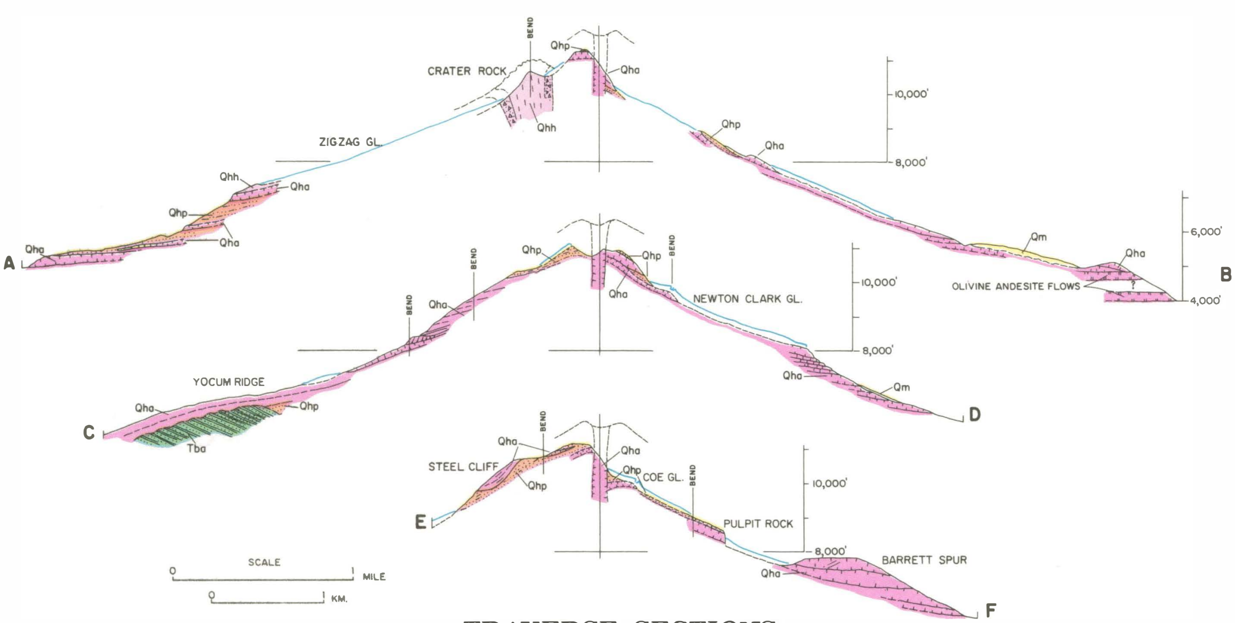
Phillips, K. N., 1935, A chemical study of fumaroles on Mount Hood: Mazama, v. 18, p. 44-46.



TRAVERSE SECTIONS

ANDESITE PETROCHEMISTRY

PETROCHEMISTRY OF THE CASACADE ANDESITE VOLCANOES

By Alexander R. McBirney*

Despite the fact that the Quaternary lavas of the High Cascade volcanoes have long been cited as a 'typical' example of an orogenic volcanic suite, the rocks, until recently, have received only sporadic attention. Apart from a few studies, such as those by Williams at Crater Lake (1942) and Lassen Peak (1932) and Thayer's work at Mount Jefferson (1937), most early studies were of a reconnaissance nature. Within the last few years, however, several geologic and petrologic investigations of major Cascade volcanoes have helped to fill large gaps in our knowledge. Notable among these are the work of R. S. Fiske and his co-workers at Mount Rainier (1963) and W. S. Wise at Mount Hood (in press). Even now, however, several important volcanic centers remain to be studied in detail, and a few have not even been examined in a reconnaissance fashion. The scope of currently available data is indicated by the references compiled on page 107. Additional work now in progress is summarized elsewhere in this guidebook.

Between Mount Garibaldi in British Columbia and Lassen Peak, California, the High Cascade range (figure 1) includes about 20 major Quaternary volcanoes and a host of small cones and deeply eroded necks. The age of the rocks has generally been accepted as Late Pliocene to Recent, but direct dating of the lavas has rarely been reported. Measurements of the magnetic polarity of some of the rocks suggest that the great bulk of the lavas forming the high composite cones may span a relatively short time interval. The entire sequence of rocks at Mount Jefferson, the Three Sisters, and possibly Mount Mazama, for example, appears to be normally polarized and can be presumed to be younger than the last reversal 770,000 years ago.

As data accumulate, it becomes increasingly evident that the lavas vary markedly from one volcano to another and, in some parts of the chain, may even have wide differences within an individual volcanic center. Although one can make certain broad generalizations about the series as a whole, the chemical differences and regional variations within the province may have as much petrogenetic significance as the features that characterize the chain as a whole.

The volcanoes fall into two general types. In the first, the lavas form a coherent series of very uniform composition or, at most, a limited range of continuous variation. In the second type, the rocks are more varied and become increasingly divergent with time. The contrast between these two types is apparent in the variation diagrams of figure 2.

Most of the volcanoes of the Central Cascades -- Baker, Rainier, Hood, and Jefferson -- produced lavas of the first, or coherent, type. Throughout almost all their active histories these volcanoes erupted andesite or andesitic basalt of monotonously uniform composition; rhyolites are conspicuously absent and basalts, if present at all, are minor and grade imperceptibly into the main andesites. At Mount Hood, for example, there is virtually no significant chemical variation, at least in terms of the major elements, from the first lava to the last. The lavas are described in another section of this guidebook.

At Mount Jefferson there is a limited variation from the main lava type, but the degree of differentiation is narrow and continuous, there being no apparent break in the sequence, either in time or in composition. The main cone rises from a thick sequence of Recent lavas erupted from numerous vents scattered over a broad area to the west and south of the present peak. The youngest lavas have been erupted from small cones near the southern base of the main cone. Thayer (1937) noted that despite their mineralogic differences, the great majority of the lavas are remarkably uniform andesitic basalts; subsequent studies have only extended the known range of variation slightly beyond that originally recognized (table 1). The most felsic rocks are dacitic and rhyodacitic tuffs erupted in small volumes and at infrequent intervals. No rhyolites have yet been found, nor are youngest lavas significantly different from the earliest.

Associations of the second, or divergent, type are found at the northern end of the chain and south

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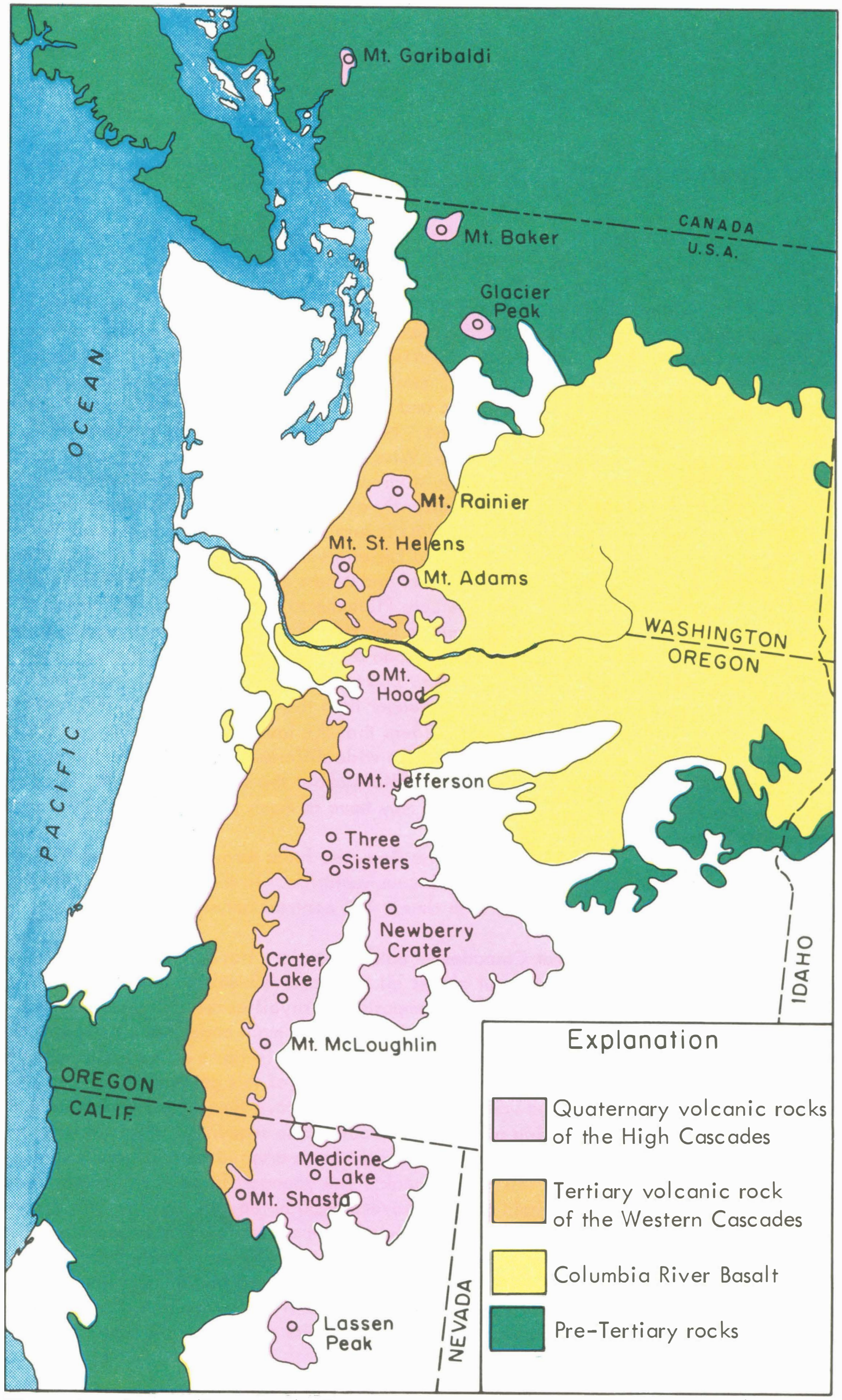

Figure 1. Generalized geologic map of the Cascade Range showing relations to older basement rocks and lavas of the Columbia River Plateau.

of Mount Jefferson. Mount Garibaldi and South Sister (figure 3) are excellent examples. In these volcanoes, the most abundant rocks forming the main mass of the cones are siliceous andesites or dacites of rather uniform composition. These were followed in time by two sharply divergent groups, commonly the products of flank eruptions that produced basalts of erratic composition intermittently with small volumes of rhyolite obsidian or pumice. At South Sister rhyolites were also common at an early stage preceding the main cone, and in other volcanoes of the southern Cascades basalts form a broad shield underlying the main andesitic cone. Thus the rocks of the main cones contrast with both earlier and later rocks of divergent composition. Analyses of representative members of the South Sister suite are given in table 2.

In extreme examples of the divergent type, intermediate rocks may be volumetrically subordinate or grade without a compositional discontinuity into basalts. This seems to be the case at Medicine Lake, for example, where early andesites merge with the late basalts, and dacites grade into rhyolites of the late obsidian domes. At Crater Lake the andesites of the main cone of Mount Mazama merge at their basic end with the more varied basalts of late flank eruptions. In both volcanoes, the effect is to produce two distinct groups of rocks on a variation diagram, one of basic to intermediate composition and the other a siliceous differentiate, but the divergence from earlier intermediate andesites to late contrasting rocks is still apparent, if the series is viewed in the order of its eruption.

Recognizing these marked contrasts in the Cascade volcanoes, one may logically look for a relationship to such features as the regional geologic setting of the different suites or the composition of the principal rock types that may represent a parent magma. At first glance it is evident that almost all the volcanoes with coherent andesitic suites are situated in the central section of the range between central Oregon and northern Washington. It is perhaps significant that it is this same portion of the range that straddles the embayment between areas of pre-Tertiary sialic basement rocks (figure 1); there is no evidence that the sedimentary, metamorphic, and plutonic rocks of Mesozoic and Paleozoic age that visibly underlie the northern and southern ends of the chain also lie beneath this central region. Instead, a very thick sequence of Tertiary lavas and mafic sediment is all that is known or postulated under this area.

On closer scrutiny, however, one sees important exceptions to this apparent relationship. Mount Baker, near the northern end of the chain, is composed of very uniform andesites of the coherent type, but it stands on a basement composed of older sedimentary and metamorphic rocks that include Paleozoic phyllites and greenstone (Coombs, 1939). Its lavas are almost identical to those of Mount Rainier, which rose from a basement series composed of more than 10,000 feet of Eocene basalt and basic volcanic sediments. On the other hand, Mount St. Helens, standing between the uniformly coherent suites of Mount Hood and Mount Rainier, has produced a large proportion of very basic basalts and shows considerable range in the composition of lavas making up the main cone (Verhoogen, 1937). Differences are also seen in the southern Cascades, although all the volcanoes of that region appear to be varieties of the divergent type.

Hopson and his co-workers (1965) point out the close chemical similarity of the andesites of the northern Cascades and the Miocene epizonal plutons in the same region, and they suggest that the andesites may have been derived from the same magma source, which remained active at depth. In figure 4, the principal Late Tertiary stocks and related zones of propylitization are shown in relation to the main vents of the High Cascades. It is clear that the line of intrusions intersects the Quaternary chain in the same region that is characterized by rocks of the coherent type, and there are no reported intrusions in the regions of divergent rock associations to the north and south. This relation suggests that the explanation offered by Hopson and his associates may also explain the differences of the Cascade Quaternary rocks as a whole.

The composition of basalts associated with the different andesitic suites may show regular variations related to the nature of differentiation, but this is difficult to demonstrate. The voluminous tholeiitic lavas of the Columbia Plateau and adjacent parts of the central Cascades are much less common in the southern region, where high-alumina basalt is much more abundant. There are too few Quaternary basalts in certain parts of the range to justify generalization about their regional differences. They are especiallyrare in the northern Cascades. Where data are available, however, the basalts directly associated with andesitic volcanoes are high-alumina types of variable composition. Quaternary alkali-olivine basalts have been found by E. H. Lund among the early High Cascade lavas in the valley of the McKenzie River west of Mount Washington (table 3).

TABLE 1. NEW ANALYSES OF REPRESENTATIVE ROCKS OF MOUNT JEFFERSON.

	1	2	3	4	5	6	7
SiO_2	52.22	52.55	54.31	58.54	60.66	64.13	68.29
TiO_2	2.00	1.53	1.32	0.85	0.81	0.75	0.71
Al_2O_3	16.46	17.01	17.39	18.68	17.70	16.43	15.63
Fe_2O_3	3.62	3.75	2.61	3.32	4.19	2.38	0.69
FeO	5.72	5.79	5.53	2.50	1.53	2.28	2.87
MnO	0.13	0.15	0.13	0.08	0.09	0.08	0.11
MgO	4.31	4.94	5.22	3.53	2.85	1.83	0.86
CaO	7.19	8.71	7.57	6.49	5.72	4.18	1.88
Na_2O	3.35	3.61	3.84	4.11	4.25	4.50	5.90
K_2O	1.05	0.77	0.86	0.80	1.12	1.46	2.22
H_2O+	1.81	0.64	0.61	0.66	0.94	1.42	0.55
H_2O-	1.61	0.23	0.04	0.24	0.06	0.15	0.10
P_2O_5	0.35	0.26	0.32	0.18	0.24	0.25	0.20
other	-	-	-	-	-	-	-
TOTAL	99.82	99.94	99.75	99.98	100.16	99.84	100.01

(Analyses by Ken-ichiro Aoki, Tohoku University, Japan.)

1. Columnar-jointed lava 1½ miles east of Triangulation Peak.
2. Platy andesite lava below Spire Rock.
3. Olivine andesite from fresh flow of Forked Butte, west side.
4. Columnar-jointed flow in northeast part of Cathedral Rocks.
5. Hypersthene-augite andesite from summit of Mount Jefferson.
6. Hornblende-hypersthene dacite from talus slope of neck (?) north of main peak of Jefferson.
7. Vitrophyric dacite in pyroclastic bed 3/4 mile west of Triangulation Peak.

TABLE 2. CHEMICAL ANALYSES OF REPRESENTATIVE ROCKS OF SOUTH SISTER.

	1	2	3	4	5	6	7	8	9
SiO_2	53.23	55.07	57.46	62.98	63.50	65.30	71.94	72.27	73.45
TiO_2	1.48	1.36	1.27	1.15	1.26	1.02	0.40	0.42	0.34
Al_2O_3	18.26	16.52	16.90	16.24	15.93	15.92	14.31	14.47	14.21
Fe_2O_3	2.68	2.19	2.62	2.87	2.01	1.38	0.61	1.11	0.74
FeO	6.45	5.47	4.70	2.94	3.88	3.49	1.77	1.27	1.37
MnO	0.11	0.11	0.12	0.08	0.10	0.07	0.05	0.05	0.05
MgO	4.32	5.83	3.43	1.52	1.55	1.29	0.41	0.18	0.05
CaO	7.52	7.33	6.25	4.04	3.85	3.42	1.75	1.60	1.45
Na_2O	4.20	3.45	4.36	4.86	5.05	4.98	4.69	4.85	4.59
K_2O	0.70	1.22	1.30	2.00	2.05	2.19	3.00	3.04	3.18
H_2O+	0.65	0.71	1.21	0.43	0.36	0.50	0.48	0.48	0.29
H_2O-	0.06	0.18	0.02	0.25	0.13	0.08	0.16	0.10	0.01
P_2O_5	0.28	0.25	0.25	0.28	0.29	0.26	0.07	0.06	0.07
other	–	–	–	–	–	–	–	–	–
TOTAL	99.94	99.69	99.89	99.64	99.96	99.90	99.64	99.90	99.80

(Analyses by Ken-ichiro Aoki, Tohoku University, Japan.)

1. Andesite knob rising above moraine and pumice on south side of Green Lake.
2. Basaltic lava, Leconte Cone, small outcrop of lava north of cone.
3. One of last basaltic flows from summit crater of South Sister, elevation 9460 feet.
4. Platy andesite lava at south edge of Lewis Glacier, elevation 8840 feet, dips northeast away from 6.
5. Platy andesite lava near east base of South Sister west of Green Lake.
6. Vitrophyre from columnar-jointed plug, south slope of South Sister, elevation 8720 feet.
7. Obsidian from north edge of Newberry flow, South Sister, elevation 6800 feet.
8. Glaciated 'andesite' above Skyline Trail on north side of Rock Mesa in Mesa Creek.
9. Glaciated 'andesite' from lower slope, east side of South Sister, elevation 7200 feet.

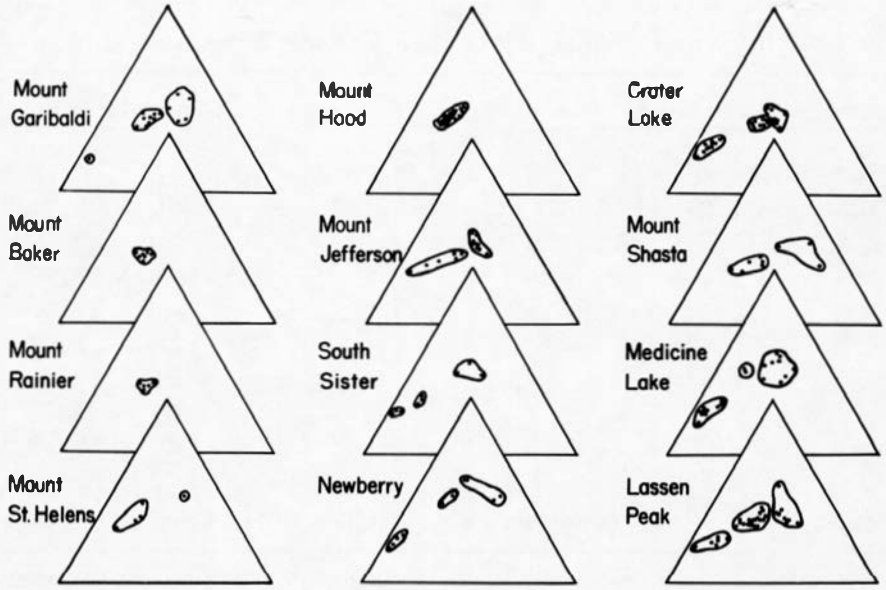

Figure 2. AMF variation diagrams for the principal Quaternary volcanoes of the High Cascades. The points show the proportions of total iron as FeO (top corner), magnesia (lower right) and total alkalies (lower left). Sources of analytical data are listed in the references at the end of this paper. Additional, previously unpublished analyses from Mount Jefferson and South Sister are given in Table I and table 2. Analyses of rocks from Mount Hood are from unpublished data of W. S. Wise.

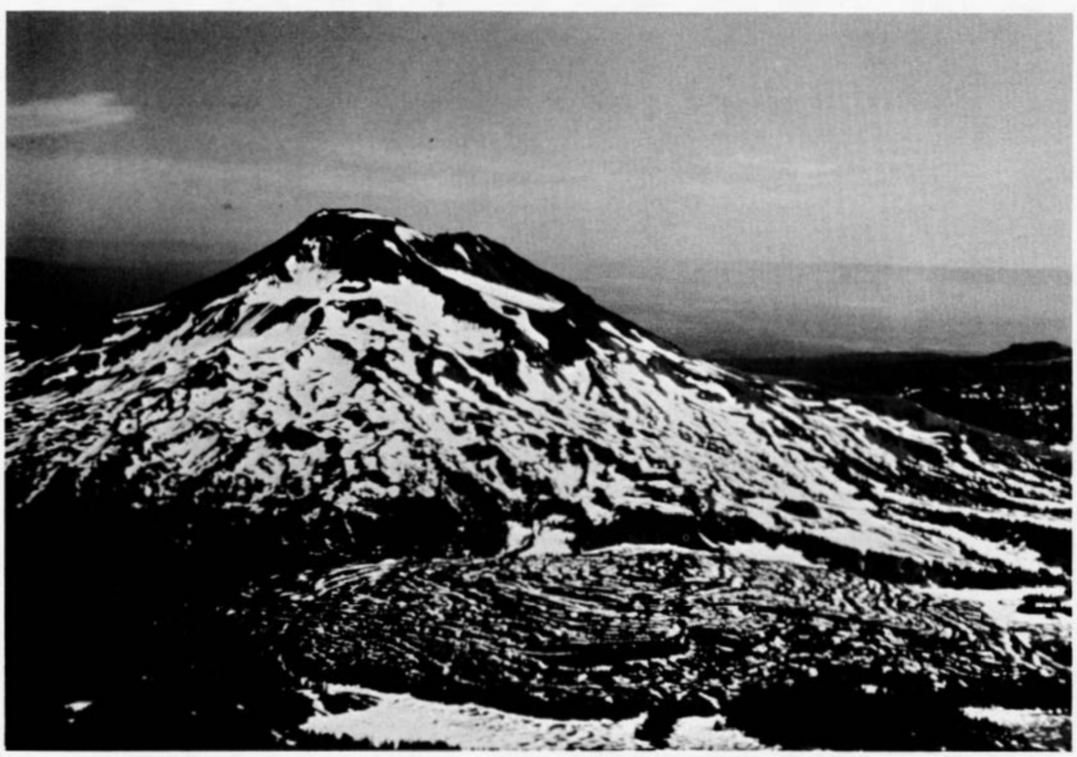

Figure 3. The main cone of South Sister, seen here from the southwest, consists mainly of andesitic lavas and pyroclastic material with a thin veneer of youthful basalts erupted from the summit crater. The most recent eruptions broke out near the base of the main cone. Rock Mesa is a viscous flow of rhyolite obsidian and LeConte Crater, the small cone closest to the camera, was the source of basaltic lava and scoria.

Table 3. Alkali-olivine basalt from the early High Cascade lavas west of Mount Washington.

Chemical composition in weight - %		Molecular norm	
SiO_2	47.48	Ap	0.70
TiO_2	2.28	Il	3.21
Al_2O_3	15.48	Or	2.69
Fe_2O_3	2.49	Ab	27.99
FeO	10.64	An	27.42
MnO	0.20	Mt	2.63
MgO	7.87	Di	12.91
CaO	9.11	Hy	7.12
Na_2O	3.08	Ol	15.32
K_2O	0.45		
P_2O_5	0.33		

(Analyses by Ken-ichiro Aoki, Tohoku University, Japan.)

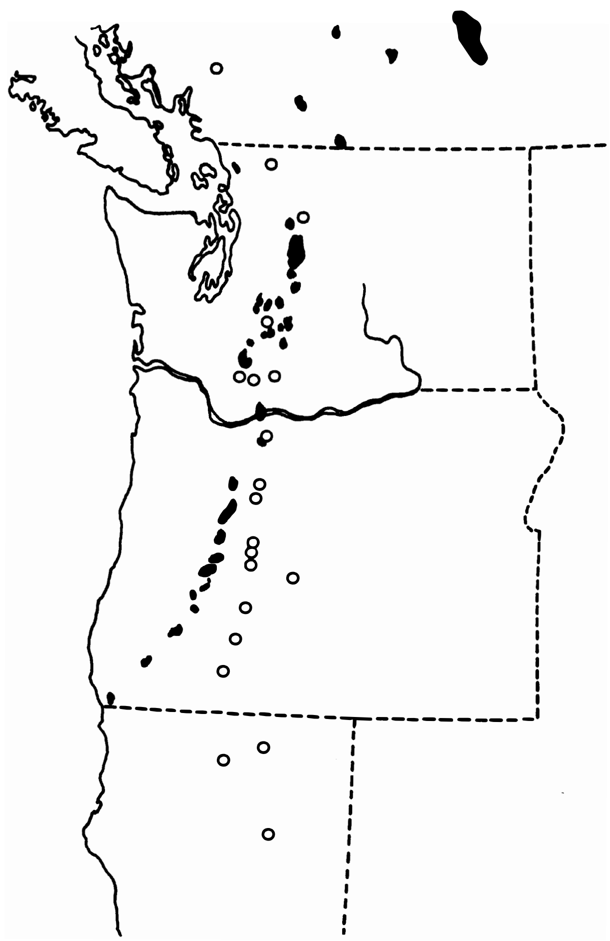

Figure 4. Distribution of late Tertiary plutons and related zones of propylitic alteration and their relation to the principal Quaternary volcanoes of the High Cascades (open circles).

Much additional work is clearly needed before an adequate explanation of the differing andesitic suites will be possible. All that can be said on the basis of current knowledge is that differences in the basement rocks do not provide a consistent correlation with the variations of andesitic rocks from one volcanic center to another.

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