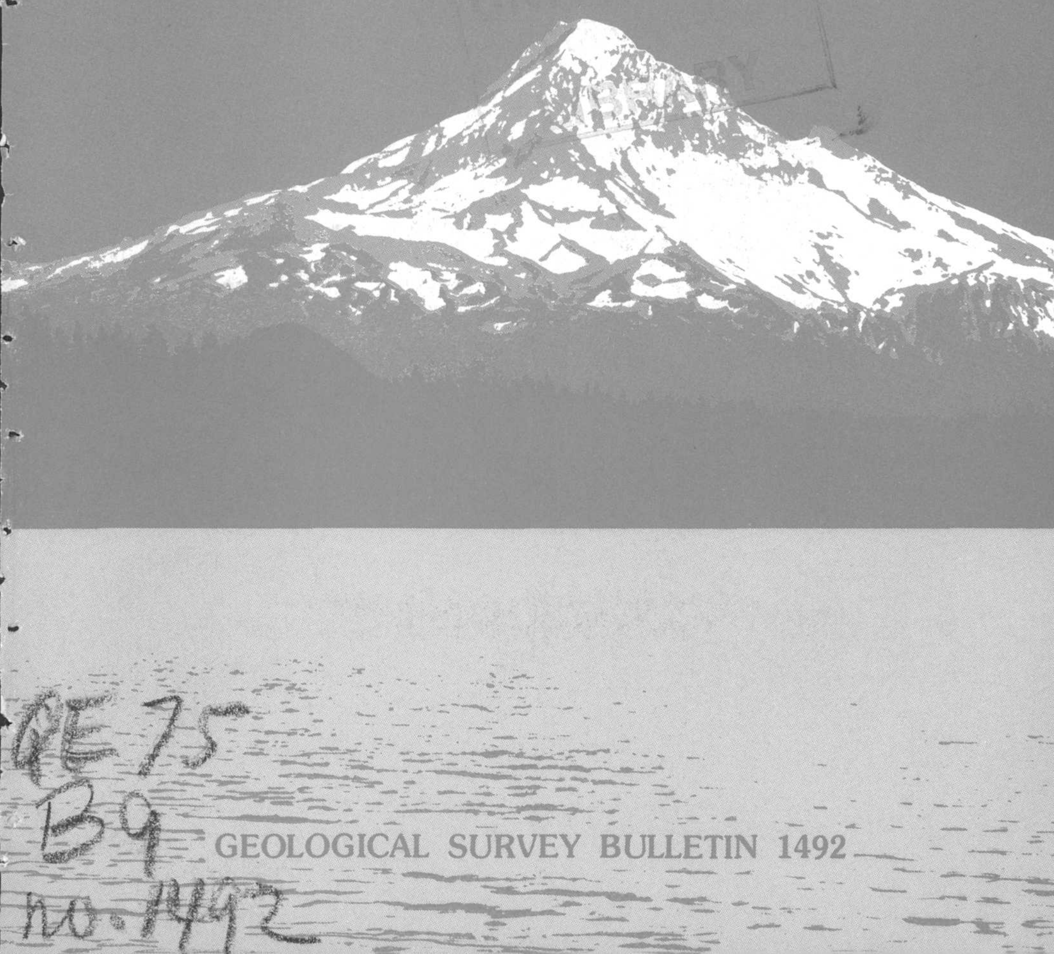
RECENT ERUPTIVE HISTORY OF MOUNT HOOD, OREGON, AND POTENTIAL HAZARDS FROM FUTURE ERUPTIONS



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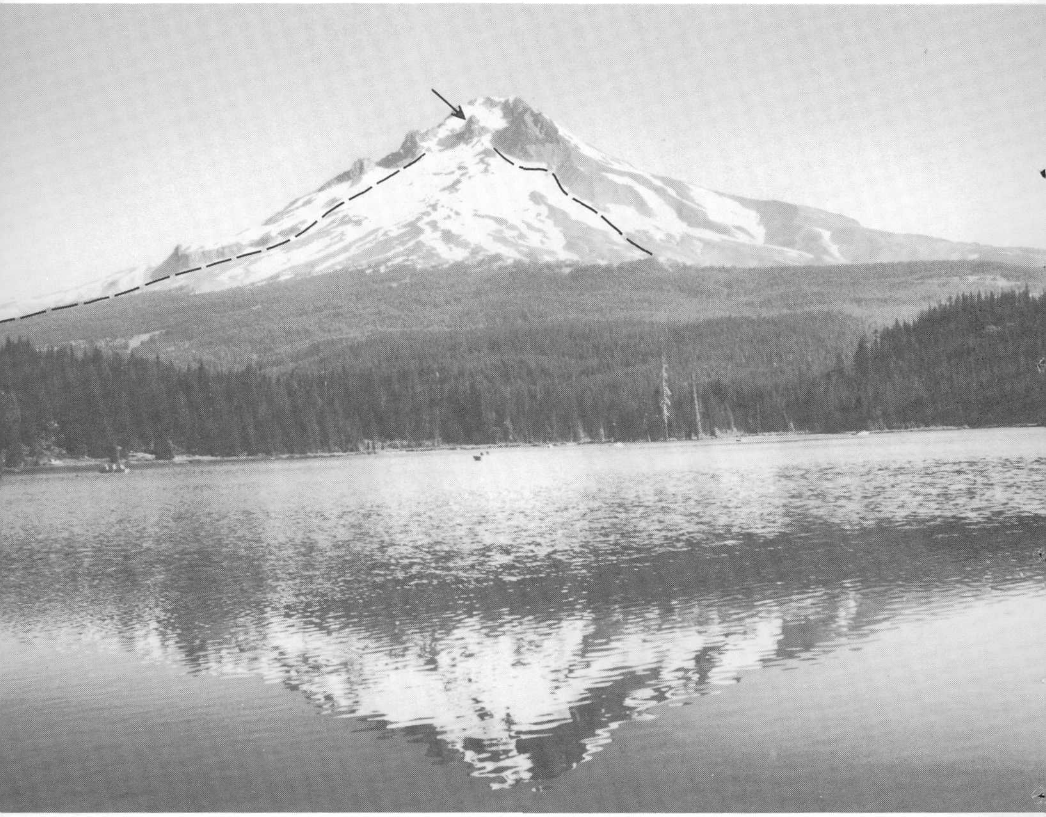

SOUTH SIDE OF MOUNT HOOD. Dashed line outlines the fan of pyroclastic-flow deposits and mudflows formed 1,500–1,800 years ago. In the center of Mount Hood's crater is a remnant of a dome (arrow) that was erupted between 200 and 300 years ago.

Recent Eruptive History of Mount Hood, Oregon, and Potential Hazards from Future Eruptions

By
Dwight R. Crandell

An assessment of expectable kinds of future eruptions and their possible effects on human lives and property based on Mount Hood's eruptive behavior during the last 15,000 years

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United States Department of the Interior
CECIL D. ANDRUS, Secretary

Geological Survey
H. William Menard, Director

Library of Congress catalog-card No. 79-22249

U.S. GOVERNMENT PRINTING OFFICE : 1980

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402
Stock No. 024-001-0333-6-4

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UNITS OF MEASURE AND THEIR EQUIVALENTS

To convert metrics	*Multiply by*	*To obtain*
Millimeters (mm)	0.03937	Inches (in.)
Centimeters (cm)	.3937	Inches (in.)
Meters (m)	3.28	Feet (ft)
Kilometers (km)	.62 (about ⅔)	Miles (mi)
Cubic meters (m^3)	35.31	Cubic feet (ft^3)
Cubic kilometers (km^3)	.2399 (about ¼)	Cubic miles (mi^3)
Kilometers/hour (km/h)	.62	Miles/hour (mi/h)

RECENT ERUPTIVE HISTORY OF MOUNT HOOD, OREGON, AND POTENTIAL HAZARDS FROM FUTURE ERUPTIONS

By DWIGHT R. CRANDELL

ABSTRACT

Each of three major eruptive periods at Mount Hood (12,000-15,000(?), 1,500-1,800, and 200-300 years ago) produced dacite domes, pyroclastic flows, and mudflows, but virtually no pumice. Most of the fine lithic ash that mantles the slopes of the volcano and the adjacent mountains fell from ash clouds that accompanied the pyroclastic flows. Widely scattered pumice lapilli that are present at the ground surface on the south, east, and north sides of Mount Hood may have been erupted during the mid-1800's, when the last known activity of the volcano occurred.

The geologically recent history of Mount Hood suggests that the most likely eruptive event in the future will be the formation of another dome, probably within the present south-facing crater. The principal hazards that could accompany dome formation include pyroclastic flows and mudflows moving from the upper slopes of the volcano down the floors of valleys. Ash clouds which accompany pyroclastic flows may deposit as much as a meter of fine ash close to their source, and as much as 20 cm at a distance of 11 km downwind from the pyroclastic flows. Other hazards that could result from such eruptions include laterally directed explosive blasts that could propel rock fragments outward from the side of a dome at high speed, and toxic volcanic gases. The scarcity of pumiceous ash erupted during the last 15,000 years suggests that explosive pumice eruptions are not a major hazard at Mount Hood; thus, there seems to be little danger that such an eruption will significantly affect the Portland metropolitan area in the near future.

INTRODUCTION

MOUNT HOOD volcano is situated at the crest of the Cascade Range 75 km east-southeast of Portland, Oreg., and 35 km south of the Columbia River (fig. 1). Because of the volcano's proximity to a large metropolitan area, future eruptions have been regarded as a potential threat by geologists and laypersons alike (McBirney, 1966, p. 25; Hammond, 1973; Harris, 1976, p. 264). The principal purpose of this report is to assess the nature and likelihood of this threat to communities around the volcano and to show areas of potential hazard when eruptions occur in the future. The volcanic-hazards map (pl. 1) that accompanies the report can be used for long-range land-use planning around the volcano and for preparing contingency plans for mitigating the effects of future eruptions.

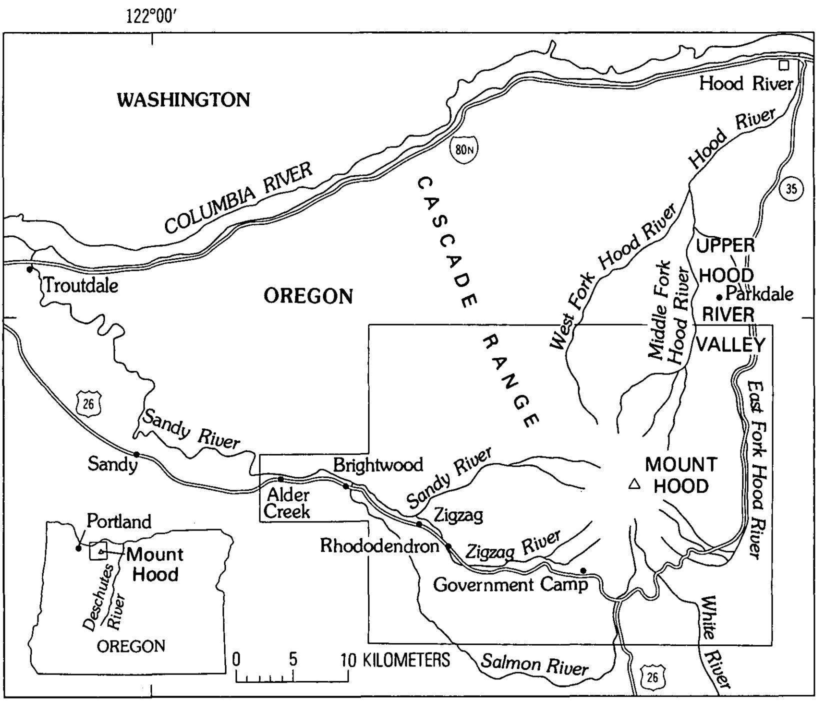

FIGURE 1.—Index map of the Mount Hood area. Rectangular area is shown in detail on plate 1.

If it is assumed that a volcano will continue to behave as it has in the past, a knowledge of its behavior pattern can provide a basis for predicting dangers that could result from future eruptions. Mount Hood lacks a well-documented record of historic eruptions. Thus, its past behavior must be analyzed by studying the geologic evidence of prehistoric eruptions. This is done by examining the rocks and unconsolidated volcanic deposits that resulted from those eruptions. From this examination the kinds, ages, and scales of activity that produced those deposits can be inferred, as well as the ways the eruptions affected the region around the volcano. Such an analysis is made here (part II; pl. 1) in order to anticipate the nature of future eruptions of Mount Hood and the areas they will affect.

The main body of this report is divided into two parts. Part I includes a description of the volcanic deposits that have been formed by eruptions during about the last 15,000 years and the kinds of eruptions that were responsible for these deposits. Part II is chiefly an assessment of volcanic hazards that could result from similar eruptions in the future. Some technical terms used in the report are explained in appendix A for readers who do not have a background in geology; these terms or variations of them are boldface the first time they appear in the following text. Readers lacking geologic background will benefit from reading appendix A before proceeding with the body of the report.

Drainage

THE location and extent of areas affected by some kinds of volcanic phenomena are determined by topography; for example, **mudflows** and floods move along valley floors. Thus, the drainage pattern on and around the volcano is of great importance to the identification of potential hazard zones. Much of the south slope of Mount Hood is a broad, relatively smooth fan that slopes down to the area around Government Camp and is bounded on the east by the White and Salmon River valleys (fig. 1). The White River flows southward and southeastward through a virtually uninhabited region for many tens of kilometers and joins the Deschutes River, a tributary of the Columbia. The Salmon River takes a long circuitous course southwesterly, then northwesterly, through uninhabited country and finally joins the Sandy River. The west side of the fan is bounded by the Zigzag River, which, with its tributaries, drains the southwest slope of Mount Hood. The Zigzag River flows westward to join the Sandy River near the community of Zigzag. The Sandy heads on the west side of the volcano and flows westerly and northwesterly to its confluence with the Columbia River at Troutdale. The north and east sides of the volcano are drained by tributaries of the Hood River, which joins the Columbia at the city of Hood River. The largest concentration of population near Mount Hood is situated along the floors of the Zigzag and Sandy River valleys. These valley floors will be endangered by future eruptions that produce floods and mudflows on the west and south slopes of Mount Hood.

Glaciation

THE extent of glaciers during the last major glaciation is pertinent to the eruptive history of Mount Hood because the presence of glacier ice was partly responsible for the distribution of volcanic deposits formed during the first eruptive period described in this report. Glacier extents shown in figure 2 are approximations based on widely scattered moraines and outcrops of glacial deposits; the downvalley extents shown for some glaciers may be in error by as much as several kilometers.

The last major advance of glaciers in Washington and British Columbia occurred during the Fraser Glaciation. This glaciation began some time before about 29,000 years ago and ended about 10,000 years ago (Armstrong and others, 1965; Armstrong and Clague, 1977). By comparison with glaciers in western Washington and British Columbia, those at Mount Hood probably reached their maximum downvalley extents by 18,000 years ago and then generally retreated until about 11,000 years ago. Glaciers in the mountains probably were not significantly larger by that time than they are today.

Deposits of the Fraser Glaciation at Mount Hood can be recognized by yellowish-brown soil oxidation and by a lack of

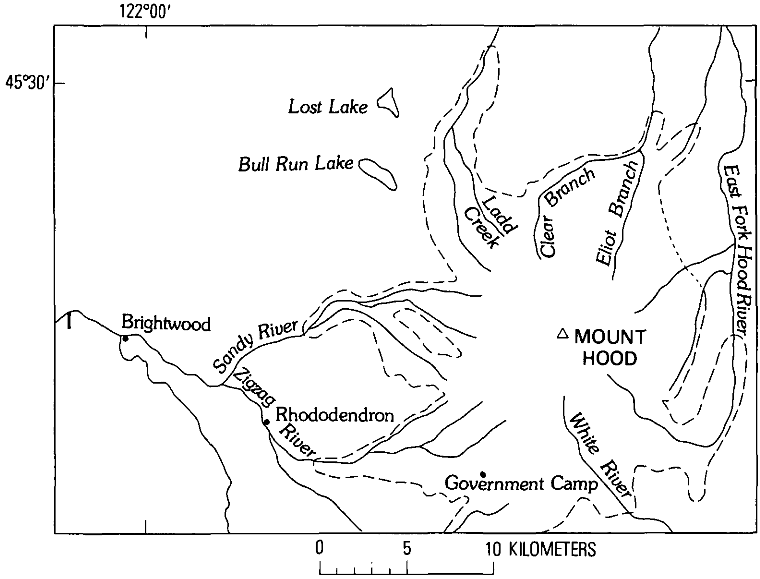

FIGURE 2.—Inferred extent of glaciers at Mount Hood during the Fraser Glaciation (dashed line) and probable maximum extent of glacier in the Sandy River valley during the next older glaciation (short heavy line).

appreciable weathering of stones in soil profiles. The thickness of the oxidized zone on till measured at 17 localities ranged from 35 to 90 cm and averaged 63 cm. These characteristics are similar to those of deposits of the first eruptive period (Polallie) described in this report. Some Polallie deposits, in fact, resemble those of glacial origin because of their coarse, poorly sorted, or unsorted texture. For example, deposits in roadcuts along U.S. Highway 26 about 3 km west of Government Camp resemble till, but they were formed by volcanic mudflows (fig. 3). Similar mudflow deposits on the northeast side of Mount Hood have obscured the extent of glacial deposits of Fraser age; thus, the extent of glaciers is not known in that area.

The average altitude[1] of north-facing cirques near Mount Hood is about 1,030 m (3,400 ft) in the areas north and northwest of the volcano, about 1,250 m (4,100 ft) south of the

[1] Altitudes are given in the inch-pound system because contours on the accompanying topographic map (pl. 1) are in feet.

FIGURE 3.—Bouldery volcanic mudflows of Polallie age in roadcut along U.S. Highway 26 about 3 km west of Government Camp. The largest boulder in the center of the photograph is about 1 m in length.

volcano, and about 1,370 m (4,500 ft) to the east. These cirque floors provide a crude measure of the altitude of areas of ice accumulation during the last glaciation; however, the lower limits of accumulation in areas outside cirques must have been higher because ice was not as protected from the sun there as in the cirques.

When Fraser glaciers were at their maximum extents, the northern slopes of Mount Hood probably were largely covered by ice at altitudes about 1,370 m (4,500 ft), and the southern slopes above perhaps 1,525–1,675 m (5,000–5,500 ft). Most north-facing glaciers today terminate at altitudes of 1,830–1,980 m (6,000–6,500 ft), and the lower limits of perennial snow on the south slope of the volcano seem to be at about 2,150 m (7,000 ft).

Deposits of one or more older glaciations have also been recognized at scattered localities in the Mount Hood area. One such deposit is till that forms a terminal moraine in the Sandy River valley near Brightwood (fig. 2); this moraine probably represents the farthest downvalley extent of a glacier during the glaciation that immediately preceded the Fraser Glaciation. Yellowish-brown soil oxidation extends to a depth of 1.5–2 m in the till, and stones in the soil profile have weathered rinds 1-2 mm thick. Glacial deposits in the Mount Rainier area of Washington that have similar weathering characteristics were assigned to the Hayden Creek Drift of the Salmon Springs Glaciation (Crandell and Miller, 1974).

Till thought to be of Hayden Creek age elsewhere in the Sandy River valley underlies a deposit of distinctive pumice that was erupted at Mount St. Helens in southern Washington between about 35,000 and 40,000 years ago (D. R. Mullineaux, oral commun., 1976). The best outcrop at which the relation of the till to the pumice can be seen is along a road to a rock quarry south of U.S. Highway 26 (appendix B, measured section 1).

At Bennett Pass, on the southeast side of Mount Hood, a large cut along State Highway 35 exposes three tills separated by yellowish-brown oxidized zones that constitute buried soils. The uppermost till forms a lateral moraine of Fraser age; the ages of the underlying tills are not known.

Volcanic Rocks of Mount Hood

THE eruptive history of Mount Hood prior to about 15,000 years ago is chiefly recorded by the volcanic rocks that form the volcano. These rocks were described by Wise (1969), who divided them into four main groups. From oldest to youngest these are **olivine andesite** lava flows that form the base of the volcano, long flows of **pyroxene** andesite that extend down former canyons that headed on the volcano, flows of pyroxene andesite that form the part of the volcano above about 1,800 m (5,900 ft), and a remnant of a young **dome** of **dacite** that forms Crater Rock (Wise, 1969). The bulk of the volcano is made up of andesite in which the silicon dioxide (SiO_2) content ranges from about 57 to 61 percent. Rocks at Mount Hood that were described by Wise (1969) as dacites contain 62-63 percent SiO_2 and are limited to the products of the geologically most recent eruptions, including the deposits of the Polallie, Timberline, and Old Maid eruptive periods described in this report (appendix C). These dacites generally contain the **ferromagnesian** minerals **hypersthene** or **hornblende**, or both, and may include small amounts of **augite**. At some other volcanoes the presence or absence of these and other minerals has been used to distinguish volcanic deposits of different ages, but this was not found to be possible during the present study of Mount Hood.

Several volcanic vents on the lower flanks of Mount Hood or beyond its base have erupted olivine andesite lavas which are chemically similar to one another, but which do not seem to be genetically related to Mount Hood (Wise, 1969, p. 994, 999–1000). One vent is at The Pinnacle on the north flank of the volcano, another is near Cloud Cap Inn on the northeast flank (pl. 1), and a third lies in the valley of the Middle Fork Hood River 11.5 km northeast of the summit of Mount Hood. Wise believed that the lava flows from the vent at The Pinnacle were erupted before the Fraser Glaciation, but regarded those from the vent near Cloud Cap Inn as of post-Fraser age. Lava flows from The Pinnacle are locally overlain by glacial deposits of Fraser age. Soil profiles on deposits that overlie the lavas from the vent at Cloud Cap Inn indicate that these lavas, too, are pre-Fraser and probably are older than the Hayden Creek Drift.

The olivine andesite lava flow in the Middle Fork Hood River valley extends down the valley floor about 6 km from a vent south-southwest of Parkdale[2]. The flow is about 60 m thick (Wise, 1969) and as much as 1.2 km wide. Charcoal from a soil beneath the lava flow had a radiocarbon age of 6,890±130 years (Harris, 1973, p. 66–67; this report, table 1).

Deposits of Old Mudflows and Pyroclastic Flows from Mount Hood

LARGE mudflows from Mount Hood moved westward down the Sandy River valley and northward into the Upper Hood River Valley many times prior to the Fraser Glaciation. The mudflows that extended into the eastern part of the Portland metropolitan area have been mapped and described by Trimble (1963). Some of these old mudflows are exposed at localities in the Sandy River valley between Brightwood and

[2]The length of the lava flow was mistakenly given as 6 miles by Wise (1969).

Alder Creek, and crop out in a roadcut along U.S. Highway 26 about 1.2 km west of Alder Creek. At this roadcut, the mudflow deposit is about 15 m thick and contains, in addition to fragments of basalt and pumice, a predominance of andesitic rocks derived from Mount Hood. The upper part of the mudflow is weathered to clay and is overlain by about 7 m of yellowish-brown loess. The extent of weathering at the top of the mudflow suggests that it is many tens of thousands of years old.

Old mudflows make up much of the southeast bank of the Sandy River in the west center of section 22, about 3 km east of Alder Creek. Wood from one of these mudflows about 3 m above the river had a radiocarbon age of more than 40,000 years (table 1). These deposits are part of a succession of mudflows that is deeply weathered at the top and forms a valley fill whose top is about 30 m above the Sandy River. The Sandy River glacier of Hayden Creek(?) age terminated less than 1 km east of the locality described above (fig. 2), where it built a moraine on top of the valley fill of mudflow deposits.

Old mudflows that resemble till are widespread in the Upper Hood River Valley, where they directly underlie the Parkdale soils deposit. (See p. 19.) The degree of weathering on these deposits suggests that they have a wide age range; some probably were formed during the nonglacial interval that preceded the Fraser Glaciation, and others are of pre-Hayden Creek age. Some of the deposits probably are of the same general age as the old mudflows west of Mount Hood.

Volcanic deposits of pre-Fraser age are well exposed at a locality near the top of the east canyon wall of Eliot Branch Hood River (fig. 2). The outcrop is located at about the 4,880-foot contour (see Cathedral Ridge 7½-minute quadrangle) at a point about 150 m north of a hairpin turn on the road to Cloud Cap Inn. Here, till of Fraser age, 23 m thick, overlies a pyroclastic-flow deposit about 12 m thick which has strong brown oxidation in the uppermost 1.5 m. Most stones in the oxidized zone have weathered rinds 1–2 mm thick. The deposit consists of unsorted and unstratified angular and subangular rock fragments as large as 1 m in diameter in a matrix of loose lithic ash; some rock fragments in the deposit are prismatically jointed. The pyroclastic-flow deposit overlies a mixture of nonvesicular rock fragments as much as 15 cm in diameter and **lapilli** of hypersthene-augite pumice in a matrix of lithic and pumiceous ash. The deposit is about 1.7 m thick and may have been formed by a mudflow. It overlies an andesite lava flow more than 50 m thick. These pre-Fraser deposits probably resulted from eruptive activity during the nonglacial interval that preceded the Fraser Glaciation.

PART I RECENT ERUPTIVE PERIODS AND THEIR PRODUCTS

THREE PRINCIPAL ERUPTIVE PERIODS have occurred at Mount Hood since the maximum of the Fraser Glaciation. The first of these, which is referred to here as the Polallie eruptive period, is believed to have occurred when glaciers on Mount Hood were significantly larger than they are today. The second, which is referred to as the Timberline eruptive period, occurred between about 1,500 and 1,800 years ago; and the third, known as the Old Maid eruptive period, occurred between 200 and 300 years ago. In addition, a very small amount of pumice was ejected at Mount Hood some time during the last 200 years, perhaps in 1859 or 1865.

Polallie Eruptive Period

THE oldest volcanic deposits described in this report were formed during the Polallie eruptive period, which is believed to have occurred some time between 12,000 and 15,000 years ago, during a late stage of the Fraser Glaciation. The deposits of Polallie age were formed chiefly by pyroclastic flows and mudflows and by **ash clouds** generated by pyroclastic flows.

Deposits of Pyroclastic Flows and Mudflows

DEPOSITS of Polallie age occur on all sides of Mount Hood and consist chiefly of mixtures of coarse and fine nonvesicular rock debris that resulted from pyroclastic flows and mudflows. The rock debris probably avalanched from the flanks of dacite domes as the domes were being extruded at or near the summit of the volcano. The Polallie deposits typically occur in three different topographic positions: ridge top, valley side, and valley floor. The topographic positions of the ridge-top and valley-side deposits probably were determined by the presence and thickness of glacier ice in a given valley when the deposits were formed. Deposits accumulated on the tops of ridges when glacier ice still occupied the adjacent cirque or valley. The deposits on valley sides were formed adjacent to glaciers after the glaciers had shrunk in size, and the valley-floor deposits were laid down beyond the ends of valley glaciers during and following both of the earlier stages.

Rock fragments in deposits of Polallie age typically are light- to dark-gray dacite that contains hypersthene and variable amounts of hornblende or augite or both; olivine was not recognized in rocks of Polallie age. Hornblende was more abundant than hypersthene in only a few of the rock fragments that were sampled.

Typical Polallie deposits are exposed on the northeast side of Mount Hood in valley walls at the head of Polallie Creek 0.6–0.9 km southwest of Tilly Jane Guard Station (pl. 1). There, they consist of a succession at least 100 m thick of unsorted bouldery deposits of pyroclastic flows interbedded with mudflows of generally similar appearance. The deposits of pyroclastic flows can be recognized by the presence of reddish-gray tops 1–2 m thick and by the presence of prismatically jointed blocks of dacite. Blocks like these were sampled for chemical analysis from two deposits near the head of Polallie Creek (appendix C).

The Polallie deposits on the northeast side of Mount Hood form a broad triangular apron whose apex is on Cooper Spur, about 825 m (2,700 ft) below the summit of the volcano (pl. 1; fig. 4). The deposits underlie a broad sloping surface north of Cloud Cap Inn, extend northward between Tilly Jane Creek and Eliot Branch, and flank both sides of Polallie Creek


Cooper
Spur
Eliot Glacier
Stranahan Ridge

downstream to its mouth (pl. 1). They also form a fill, now mostly removed by erosion, in the valley of East Fork Hood River at and downstream from the mouth of Polallie Creek. This fill was responsible for forcing the East Fork against its east valley wall downstream from Cold Spring Creek (pl. 1). Temporary damming of the East Fork valley by the fill created one or more short-lived lakes which are represented by deposits of horizontally bedded fine sand and silt. The lake sediments are exposed in cuts along State Highway 35 near Sherwood Campground, where they are interbedded with thin mudflows that evidently moved southward, upstream, into the lake from the thickening Polallie fill. A few scattered lapilli of hypersthene-augite pumice were noted in the lake sediments. The sediments were not seen beyond a few kilometers upstream from the campground.

Deposits of Polallie age were recognized downstream in the Upper Hood River Valley, where a gray, unweathered, sandy mudflow forms a terrace about 20 m above the East Fork Hood River in section 5, about 2 km southeast of Parkdale. This deposit is overlain by the Parkdale soils deposit (p. 21). Seven kilometers farther downstream, correlative gray cobble to boulder gravel of Polallie age is oxidized to a depth of nearly 1 m where the Parkdale deposit is absent.

At Cooper Spur, the presence of the broad apron of loose rock debris that extends as high as 2,600 m (8,500 ft)—in an area on the flank of Mount Hood that should have been covered by ice at the maximum of the Fraser Glaciation (fig. 2)—suggests that the debris was deposited some time after that ice disappeared. At a point about 3 km west-southwest of Tilly Jane Guard Station, the south edge of the Polallie deposits is flanked by a lateral moraine formed at the north margin of Newton Clark Glacier during a late stage of the Fraser Glaciation; and the Polallie deposits are not present south of the moraine. These relations suggest that deposition of rock debris south of the moraine was prevented by the presence of the glacier, which was larger than it is now and which subsequently retreated and built the moraine. The

◁ FIGURE 4.—North side of Mount Hood. Remnants of fans of coarse pyroclastic flows and mudflows of Polallie age underlie Cooper Spur and Stranahan Ridge.

FIGURE 5.—Valley of Newton Creek on southeast side of Mount Hood. Deposits of pyroclastic flows and mudflows of Polallie age form the two light-colored fills in the center of the photograph. The tops of these fills are at heights of about 85 and 220 m, respectively, above Newton Creek. The ridge on the skyline consists of lava flows from Mount Hood that are locally overlain by Polallie deposits.

western limit of the Polallie deposits likewise was determined by Eliot Glacier when it was substantially larger than it is now.

Deposits of rock debris formed during the Polallie eruptive period on other sides of the volcano represent several stages of valley filling that were separated by times of erosion. For example, a high sharp-crested ridge that separates the heads of Newton and Clark Creeks (pl. 1) on the southeast side of the volcano is underlain by rock debris that was deposited by pyroclastic flows and mudflows. Similar deposits within the Newton Creek valley are present in remnants of an intermediate fill whose top is about 100 m lower than the top of the sharp-crested ridge (fig. 5); this intermediate fill was formed after the high fill had been deeply eroded. The lowest and youngest deposits of Polallie age form the flat floor of the valley followed by Newton and Clark Creeks eastward beyond the base of the volcano. At its head, this flat-floored valley lies about 60 m below the top of the intermediate fill terrace. The youngest Polallie deposits consist only of mudflows; these probably were derived chiefly or wholly from the two older deposits as they were being eroded. All three fill deposits, however, have similar soil profiles and thus were formed at roughly the same time, although together they may have been deposited over a period of a thousand years or more.

A similar succession of fill deposits is present at the head of White River on the south side of the volcano (fig. 6). Pyroclastic-flow deposits of Polallie age underlie the high divide that is east of White River and northwest of Mount Hood Meadows (pl. 1). The floor of the basin in which Mount Hood Meadows is situated is underlain by glacially eroded rock and glacial deposits; deposits of Polallie age are lacking, even though they underlie the ridge at the head of the basin, 180–660 m higher. Evidently, the basin was largely filled with glacier ice and thus was shielded from pyroclastic flows and mudflows during the Polallie eruptive period. On the west side of the high ridge, two valley fills adjacent to White River are both lower than the deposit that forms the ridge top, one fill is about 70 m lower than the ridge top, and the other is 160 m lower. The deposits that underlie the high ridge evidently were formed early in the Polallie eruptive period when the White River glacier was much thicker and wider than now,

and when it extended at least 3 km farther downvalley. The two lower deposits of Polallie age were formed after the glacier had retreated and become thinner and narrower. These deposits can be seen overlying glacial deposits in a south-facing cliff 1.7 km directly east of Timberline Lodge. The lack of a soil at the top of the glacial deposits indicates that they were buried by the Polallie deposits soon after the glacier retreated.

Wise (1966, fig. 3; 1968, fig. 16) recognized the multiple origin of the deposits adjacent to the White River, but he regarded the ridge-top deposits as glacial drift and thought that the intermediate deposits were formed during the 1,500- to 1,800-year-old Timberline eruptive period. However, the presence of relatively thick soil profiles on the two lower deposits indicates that they are older than the Timberline period and are of approximately the same age as the Polallie deposits that form the high ridge. The lowest fill in the White River valley was thought by Wise (1966, p. 17) to have resulted from a "later surge of dome activity"; these deposits are now known to consist of mudflows and pyroclastic-flow deposits 200–300 years old (p. 35). Deposits of Timberline age evidently are not present within the White River valley.

Mudflows and pyroclastic-flow deposits of Polallie age underlie much of the area between the White River and Zigzag Canyon. They are exposed in many roadcuts along both the old road and the new highway between Government Camp and Timberline Lodge—and along U.S. Highway 26 west of Government Camp (fig. 3). They crop out beneath younger deposits in Little Zigzag Canyon about 2 km downvalley from the Skyline Trail and are especially well exposed in the walls of Zigzag Canyon where it is crossed by that trail.

On the west side of Mount Hood, deposits of Polallie age crop out on both sides of the Muddy Fork valley along a trail (not shown on pl. 1) that extends from Ramona Falls to Bald

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◁ FIGURE 6.—West wall of White River canyon (left foreground). Deposits of Polallie age underlie the ridge on the right skyline and the flat-topped fill at right center of the photograph, and crop out in the canyon wall in the foreground. The prismatically jointed block indicated by the arrow is about 1 m in diameter.

Mountain. Some of these deposits are as much as 300 m above the valley floor, but there is no evidence, in the form of flat-topped terraces, that the deposits ever filled the valley from side to side to a depth of 300 m. Instead, they seem to be veneers on the valley walls and probably were formed when the Sandy Glacier occupied the Muddy Fork valley. Successive deposits probably accumulated as pyroclastic flows and mudflows moved downslope between the margin of the glacier and the valley wall as the glacier slowly shrank. The volume of the Polallie deposits in the Muddy Fork valley is a very small fraction of the volume of similar deposits in valleys on the northeast, southeast, and south sides of the volcano.

Other deposits of Polallie age were noted on the ridge west of Wiyeast Basin, on Barrett Spur up to an altitude of about 2,210 m (7,300 ft), and on Stranahan Ridge north of Timberline Trail (fig. 4). In addition, a small outcrop of Polallie deposits contains prismatically jointed blocks at the place Timberline Trail crosses the east fork of Compass Creek. With this exception, the deposits of Polallie age on the north side of the volcano all occur on ridge tops and are absent from the floors of cirques.

Wise (1969, pl. 1) showed the deposits that are here assigned to the Polallie eruptive period on his geologic map of the Mount Hood area and referred to them as "Mt. Hood clastic debris, largely pyroclastic but on surface much post-glacial redistributed detritus." The Polallie deposits described in the present report are less extensive than those shown by Wise, whose map unit includes the deposits of the Timberline eruptive period, locally those of the Old Maid eruptive period, some glacial deposits of Fraser age, and some unconsolidated deposits of pre-Fraser age.

Ash-Cloud Deposits and the Parkdale Soils

FINE yellowish-brown lithic ash as much as half a meter thick can be found at many localities east and northeast of the volcano. At some places the ash is present on top of mudflow and pyroclastic-flow deposits of Polallie age, as in the area southwest of Tilly Jane Guard Station (fig. 7), so it evidently is no older than the Polallie eruptive period.

A similar deposit of yellowish-brown ash is present in the Upper Hood River Valley 15–20 km north-northeast of Mount Hood. This deposit, which is known as the Parkdale soils (Harris, 1973), mantles flat to gently rolling, north-sloping surfaces formed by alluvium and mudflows of Pleistocene age derived from Mount Hood. The Parkdale soils thin and pinch out near the east side of the Upper Hood River Valley and also disappear toward the north end of the valley. The deposit is present west of the valley, but its extent in that direction has not been determined. The deposit generally thickens southward; its maximum reported thickness is 4.1 m at a point in the Upper Hood River Valley about 1 km northwest of the community of Parkdale (Harris, 1973, p. 30–33). This site is about 18 km north-northeast of the summit of Mount Hood; Harris (1973, p. 42) reported that the deposit is not present on Middle Mountain, about 6 km north of Parkdale.

Typically, 80–85 percent of the deposit is of sand and silt size (0.002–2 mm). Harris (1973) noted that the sand-size fraction of the Parkdale consists chiefly of feldspars, particles of volcanic rock, and products of weathering; and he reported (p. 107) that ferromagnesian minerals present include pyroxenes and hornblende. A very small amount of pumice and glass was present in the samples studied by Harris.

According to Harris (1953, p. 24), the Parkdale also contains "shot", which consists of pellets, commonly of iron oxides, produced by soil-forming processes. He described the "shot" as being concentrated in the uppermost 20–30 cm, but occurring throughout the Parkdale. The pellets Harris referred to range in diameter from 2–10 mm and consist of aggregates of sand and silt-sized ash. They are made up of particles that include mineral fragments, mineral crystals, rock, pumice, and charcoal. Most pellets lack structure but faint concentric layers can be seen in others. Some pellets are irregular and others are of spherical shape. Some spherical pellets have hollow cores a few millimeters in diameter. The pellets resemble accretionary ash and lapilli which typically are formed when moisture condenses in an eruption cloud or when rain falls through a cloud of ash and causes particles to adhere to one another.

A radiocarbon age of 12,270±190 years (table 1) was determined from a composite sample of charcoal particles taken from a zone 1.7–2.1 m below the surface of the Parkdale soils deposit (Harris, 1973, p. 65). The deposit at the sample locality is about 2 m thick and overlies coarse mudflow deposits in which some boulders are as much as 50 cm in diameter. I collected large fragments of charcoal from a horizon about 0.8 m below the top of the Parkdale at the same locality; these had a radiocarbon age of 4,320±200 years (radiocarbon sample W-3731). The reason for this discrepancy in age is not known. Harris noted that the Parkdale deposit underlies a lava flow west of Parkdale. Charcoal that he collected from the deposit at the base of the flow, which presumably was charred by the lava, had a radiocarbon age of 6,890±130 years (Harris, 1973, p. 65).

The age relation of the Parkdale soils to deposits of Polallie age is illustrated at a roadcut in the Upper Hood River Valley in the center of the NE¼ sec. 5, T. 1 S., R. 10 E. (Hood River 15-minute quadrangle). The yellowish-brown Parkdale deposit at this locality is about 1.6 m thick and directly overlies a gray, unweathered, sandy mudflow that forms a terrace on the west side of the East Fork Hood River and is about 20 m higher than the adjacent flood plain. (See p. 13.) The absence of a soil between the deposits indicates that there was not an appreciable time interval between deposition of the Polallie mudflow and the overlying Parkdale.

One of Harris' principal objectives in his comprehensive study of the Parkdale soils deposit was to determine its origin, which evidently has been the subject of some controversy (Harris, 1973, p. 13–14). Because of the very small amount of volcanic glass in the deposit, Harris concluded that the Parkdale is not volcanic ash. He also noted that the mineralogy of the deposit is different from that of wind-deposited material east of the Hood River Valley and inferred that the Parkdale is not a loess. The predominant volcanic

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◁ FIGURE 7.—Ash-cloud deposits of Polallie age (yellowish brown) underlie those of Timberline age (gray and reddish gray) at the top of the north canyon wall of Polallie Creek 0.6 km southwest of Tilly Jane Guard Station. These deposits overlie pyroclastic-flow deposits and mudflows of Polallie age. Handle of shovel is about 50 cm long.

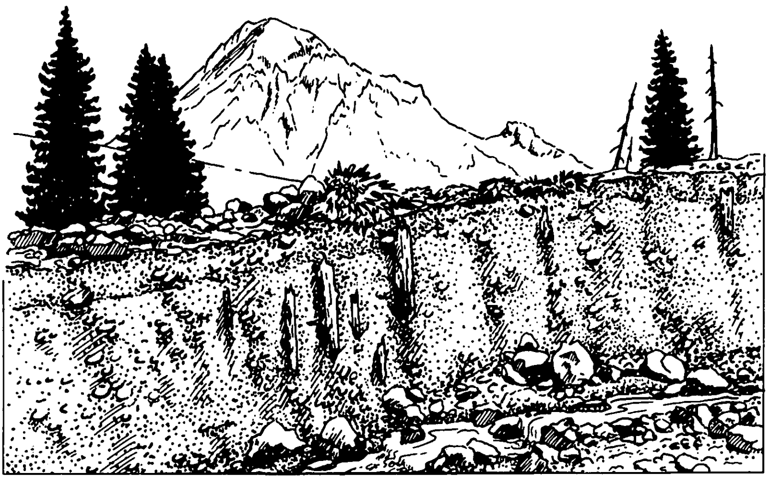
TABLE 1.—*Radiocarbon dates from samples of wood and charcoal in volcanic deposits in the Mount Hood area*

[Dates with W sample numbers were determined by Meyer Rubin and Eliot Spiker in the radiocarbon laboratory of the U.S. Geological Survey. Dates for samples M-898, M-899, and M-900 were determined at the University of Michigan (Lawrence and Lawrence, 1959), and two other samples were dated by Teledyne Isotopes, Inc. Harris, 1973). Symbols: <, less than; >, greater than]

Date (radiocarbon years before 1950)	Laboratory number	Kinds of samples, stratigraphic position, and location
<200	W-3744	Charcoal in forest duff between uppermost two mudflows in roadcut 0.5 km north of Zigzag, in low bluff near confluence of Zigzag and Sandy Rivers (see appendix B, measured section 2).
<250	W-601 and W-661	Wood samples from stumps buried by mudflows in Sandy River valley at Old Maid Flat.
220±150	W-3629	Charcoal from deposit of hot mudflow in north bank of Sandy River about 2 km northwest of Upper Sandy Guard Station.
250±150	W-899	Wood from upright stump buried by mudflows in east bank of White River about 0.8 km east of Timberline Lodge.
260±150	W-3417	Charcoal from lower of two pyroclastic-flow deposits in west bank of White River about 1 km upstream from State Highway 35.
920±150	W-900	Wood from upright stump buried by mudflows in north bank of Zigzag River at Twin Bridges Campground.
1,530±200	W-3407	Wood from log incorporated in mudflow deposits near base of south bank of Sandy River 0.2 km southwest of Upper Sandy Guard Station.
1,610±200	W-3409	Charcoal at base of ash-cloud deposits in roadcut about 2 km northeast of Government Camp.

TABLE 1.—*Radiocarbon dates from samples of wood and charcoal in volcanic deposits in the Mount Hood area*—Continued

Date (radiocarbon years before 1950)	Laboratory number	Kinds of samples, stratigraphic position, and location
1,670 ± 200	W-898	Wood from mudflow about 0.5 km south of Government Camp
1,780 ± 200	W-3742	Wood from mudflow in south bank of Sandy River 1 km west-northwest of Zigzag (see appendix B, measured section 3).
4,320 ± 200	W-3731	Charcoal from depth of 0.8 below top of Parkdale soils deposit in roadcut 2.2 km west-northwest of Parkdale.
6,890 ± 130	Teledyne Isotopes	Charcoal from beneath lava flow about 2.5 km west-southwest of Parkdale.
12,270 ± 190	Teledyne Isotopes	Charcoal from zone 1.7–2.1 m below top of Parkdale soils deposit in roadcut 2.2 km west-northwest of Parkdale.
>40,000	W-3740	Wood from mudflow about 1 m above river level in southeast bank of Sandy River about 4 km west of Brightwood.



Tree trunks buried in mudflow.

lithology of the Parkdale led Harris to conclude that the deposit was formed by a volcanic mudflow from Mount Hood; and, in order to explain the fine texture of the deposit, he suggested that the mudflow was derived from texturally similar material on the flanks of the volcano.

There are some objections to the suggestion that the Parkdale originated as a volcanic mudflow. One is its vertical distribution. If the Parkdale was formed by a mudflow, it should be thicker in the low areas of a valley and thinner or absent in high areas. This relation is not present. Moreover, Harris (1973, p. 42-45) found deposits similar to the Parkdale west of the Upper Hood River Valley on a mountainside at least 200 m higher than the valley. To attain this height, the entire valley would have had to have been filled temporarily by a mudflow at least 200 m deep. This interpretation seemingly is inconsistent with the small range in thickness of the Parkdale deposit across the flat and gently rolling surfaces of the Upper Hood River Valley. Another objection to a mudflow origin is the fine-grained, generally well sorted nature of the Parkdale deposit. Even though mudflows on low gradients typically are incapable of eroding surfaces over which they move (Crandell, 1971), it seems unlikely that large volumes of fine material could have moved down the steep-gradient valleys from Mount Hood without incorporating large amounts of coarse stream gravel. With respect to a possible source, Harris (p. 57) implied that the hypothetical mudflow responsible for the Parkdale deposit could have originated in "Debris * * * shaken down slopes by earthquakes, volcanic eruptions, or other phenomena associated with volcanoes and volcanic activity." This interpretation, however, is inconsistent with the well-sorted character and predominantly fine texture of the Parkdale deposit. Harris (p. 57-59, 161) described a deposit of fine ash near Cloud Cap Inn on the northeast side of Mount Hood as a possible remnant of material that could have provided a source for a mudflow; however, the deposit he described consists chiefly of ash-cloud deposits of Timberline age which are much younger than the Parkdale deposit.

Harris (1973, p. 62) cited the Osceola Mudflow from Mount Rainier as an example of the ability of mudflows to carry material long distances. The Osceola contains abundant material that evidently was picked up as the mudflow moved downvalley from Mount Rainier. The deposit is poorly sorted and contains a wide range of sizes of material at a distance of as much as 100 km from the volcano; thus, the Osceola Mudflow is in no way similar to the Parkdale deposit. Despite Harris' conclusion to the contrary, the size range and areal distribution of the Parkdale deposit seem to be more consistent with transportation and deposition by wind than by a volcanic mudflow.

It has been proposed that the Parkdale soils deposit represents, for the most part, the fallout from ash clouds generated by pyroclastic flows moving down the slopes of Mount Hood (Crandell and Rubin, 1977). If the Parkdale originated in this way, strong winds blowing from the volcano toward the Upper Hood River Valley could have caused the limited lateral distribution of the deposit. In addition, the limited northward extent of the deposit could be explained by the restriction of the ash clouds to relatively low altitudes, so that the ash fell relatively close to its source. The limited extent and excessive thickness of the deposit in the Upper Hood River Valley also could have resulted from locally heavy rainfall which caused most of the ash to be deposited in a relatively small area. The presence in the Parkdale of pellets inferred to be accretionary ash and lapilli seems to support this hypothesis. The abundance of lithic material and scarcity of glass noted by Harris are common characteristics of ash-cloud deposits generated by lithic pyroclastic flows (Crandell and Mullineaux, 1973, p. A6).

Age and Origin of the Polallie Deposits

THE age of the Polallie deposits is suggested by their degree of weathering and by their inferred relation to glaciers on Mount Hood. The thickness of the oxidized zone measured on Polallie deposits at 16 localities ranged from 35 to 85 cm and averaged 60 cm. This similarity to the depth of oxidation on glacial deposits of Fraser age (p. 5) implies that the Polallie deposits are no younger than the Fraser Glaciation; it also provides additional evidence that they were formed during a late stage of the glaciation rather than at some later time. The inferred relation of the Polallie deposits to glaciers on the flanks of Mount Hood suggests that the deposits were formed after glaciers had withdrawn to the flanks of the volcano following their maximum stand about 18,000 years ago (p. 4); however, the glaciers were still larger than they are today. In the absence of radiometric dates on the Polallie deposits, the best estimate that can be made with the evidence available is that the deposits were formed at some time between about 15,000 and 12,000 years ago.

Evidence described previously indicates that a succession of domes of hypersthene-hornblende dacite was formed at or near the summit of Mount Hood during the Polallie eruptive period. Avalanches of hot rock debris from the flanks of these domes produced pyroclastic flows on all sides of the volcano at a time when glaciers were still substantially larger than they are today. Mudflows generated by the remobilization of debris in pyroclastic-flow deposits probably extended tens of kilometers from the volcano down the valley floors of the East Fork Hood River as well as the White, Salmon, and Sandy Rivers. At the end of the eruptive period, Mount Hood probably lay buried by aprons of rubble; beyond the volcano these aprons merged with long unbroken fills that extended down each major valley. The lengths of these fills are not known, but one north of the volcano reached at least as far as the Upper Hood River Valley and may even have extended to the Columbia River.

Clouds of ash generated by pyroclastic flows on the volcano during at least part of the Polallie eruptive period deposited fine ash north of Mount Hood and probably as far north as the Upper Hood River Valley to form the Parkdale soils deposit.

Timberline Eruptive Period

DEPOSITS of the Timberline eruptive period were formed by pyroclastic flows and mudflows between about 1,500 and 1,800 years ago and by ash clouds that accompanied the pyroclastic flows. The pyroclastic-flow deposits are restricted to the area between the Sandy and White Rivers, but mudflows extend down the Sandy River to its mouth.

Deposits of Pyroclastic Flows and Mudflows

TYPICAL Timberline deposits are exposed in Little Zigzag Canyon where Skyline Trail crosses the canyon (fig. 8). There, in the sides of the canyon, a series of bouldery mudflows and pyroclastic-flow deposits, each a meter to several meters thick, can be seen interbedded with lenticular layers of fine to coarse lithic ash a few centimeters to several tens of centimeters thick.

Rock fragments in the Timberline deposits consist chiefly of gray and red dacite that contains hypersthene and hornblende in variable proporitons. A chemical analysis of a sample of this rock, taken from a prismatically jointed block along Skyline Trail just east of Little Zigzag Canyon, is given in appendix C. The overall color of the Timberline deposits is generally redder than that of either the Polallie or Old Maid deposits. The depth of yellowish-brown soil oxidation on the Timberline deposits ranges from 20 to 40 cm and averages between 25 and 30 cm.

The easternmost valley on Mount Hood in which mudflows of Timberline age were recognized is that of the Salmon River. East of Timberline Lodge the deposits can be seen burying a soil-oxidation zone at the top of Polallie deposits. Mudflows of Timberline age were noted in the Salmon River valley near the intersection of U.S. Highway 26 and State Highway 35, but were not traced farther downvalley.

A thick succession of mudflows forms a terrace whose top is about 60 m above the Sandy River southwest of the Upper Sandy Guard Station (fig. 9). The height of this terrace decrease downstream, and the mudflows are buried by deposits of Old Maid age (p. 35) beyond a point about 1 km northwest of the guard station. Logs as much as 1 m in diameter are present in a mudflow near the base of the valley wall opposite the guard station. Wood from one of these logs had a radiocarbon age of 1,530±200 years (table 1).

Deposits of Timberline age underlie much of the south flank of the volcano north and west of Timberline Lodge and extend downslope to the base of Multorpor Mountain. Prismatically jointed blocks of dacite are abundant on the broad fan upslope from, and west of, Timberline Lodge (fig. 10). Wood from a mudflow exposed along a drainage ditch in

FIGURE 8.—Deposits of pyroclastic flows and mudflows of Timberline age exposed on west side of Little Zigzag Canyon near Skyline Trail. Man standing on snow at bottom of photograph shows scale.

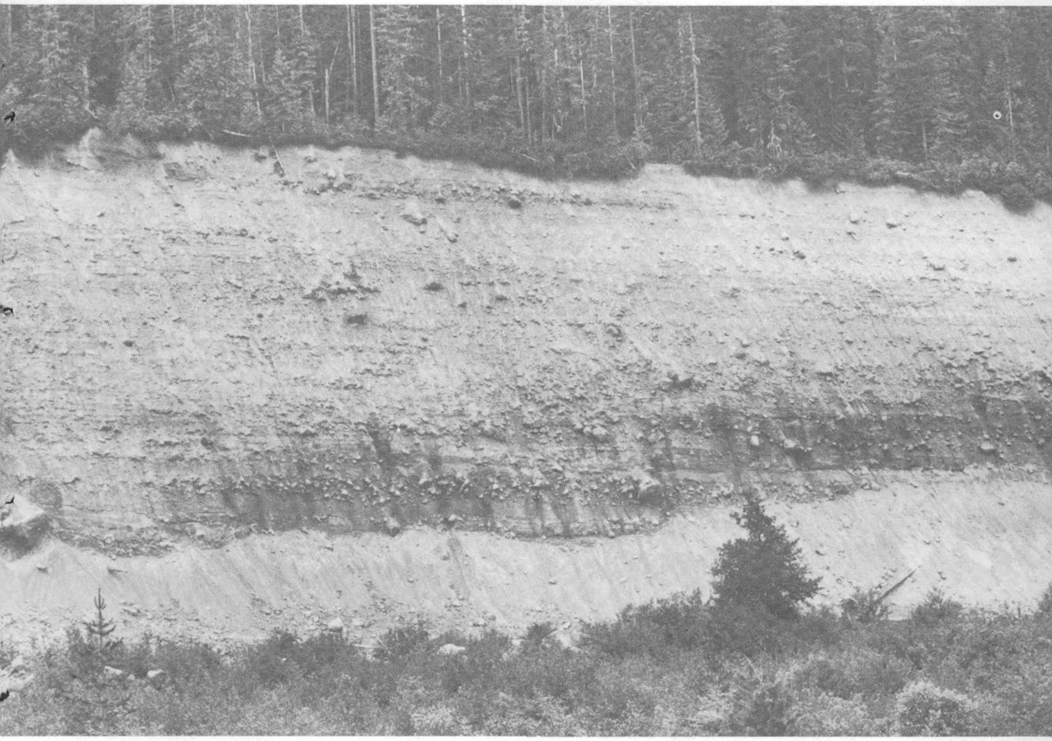


FIGURE 9.—Fill terrace formed by mudflows of Timberline age in the Sandy River valley near the Upper Sandy Guard Station. The height of the terrace is about 60 m.

the meadow south of Government Camp, near the southern margin of the fan, had a radiocarbon age of 1,670±200 years (table 1; Lawrence and Lawrence, 1959). Mudflows that moved down Zigzag and Little Zigzag Canyons underlie the floor of the Zigzag River valley from Twin Bridges Campground westward beyond the community of Zigzag. Wood from a log in a mudflow exposed in the south bank of the Sandy River about 1 km west-northwest of Zigzag had a radiocarbon age of 1,780±200 years. (See appendix B, measured section 3.) The mudflow is about 5 m thick and is overlain by two other mudflows each about 1 m thick. The entire valley floor between the Sandy River and the Salmon River is underlain by mudflow deposits, but some of these are at least as old as the Polallie eruptive period. Downstream from the mouth of the Salmon River, mudflows of Timberline

age crop out intermittently along the Sandy River valley as far as Troutdale, at the mouth of the river.

The mudflows of Timberline age near Troutdale are of special interest because of their downstream distance of about 80 km from the volcano. The deposits are exposed in the front of a terrace on the west bank of the Sandy River near a sewage-disposal plant, about 150 m south of Interstate Highway 80. The lowest mudflow is 1.5 m thick and consists of rock fragments as much as 5 cm in diameter in a silty sand matrix. It overlies river-deposited sand and gravel that probably extends below river level. The mudflow is overlain by about 4 cm of silty sand, above which is a mudflow about 0.6 m thick that contains rock fragments as large as about 1 cm in diameter in a silty sand matrix. These poorly sorted deposits are overlain by 1.3 m of sand that forms the top of the terrace about 6.5 m above the Sandy River.

Ash-Cloud Deposits

FINE ash of Timberline age blankets much of the lower slopes of the volcano. Most of it consists of fine particles of rock, feldspar, and glass; ferromagnesian minerals in the ash are mainly hypersthene and hornblende, rarely accompanied by augite. The origin of the ash is inferred from an exposure at a locality about 2 km northeast of Government Camp. There, a cut along the old road to Timberline Lodge exposes about 1 m of ash on top of mudflows of Polallie age (fig. 11). A sample of charcoal taken from the contact between the ash and the mudflows had a radiocarbon age of 1,610±200 years. Although the deposit is not stratified, the upper 50 cm is reddish-gray ash that contains irregular masses of texturally similar gray ash. The lower half of the deposit is gray to yellowish gray. These colors probably are the original colors of the ash, or were formed by oxidation soon after the ash was deposited, and are not related to subsequent weathering. The outcrop is about 30 m east of the east margin of coarse mudflows and pyroclastic-flow deposits of Timberline age, on

◁ FIGURE 10.—Large prismatically jointed block of dacite in fan deposits of Timberline age upslope from Timberline Lodge. Ice axe is about 80 cm long.

which the ash is absent. Because of these relations and the radiocarbon age at the base of the ash, the ash is inferred to be genetically related to pyroclastic flows of Timberline age and to represent airborne material that was carried downwind from those flows.

Ash deposits east and northeast of the locality just described are correlated by the presence of reddish-gray and yellowish-gray material, by stratigraphic relations to overlying light-gray ash inferred to be of Old Maid age, and, locally, by their relation to underlying Mazama ash, which originated in eruptions at Crater Lake, Oreg., about 6,600 years ago. The lack of well-defined marker beds at many localities makes it difficult to distinguish ash of Timberline age from lithic ash that may be older. In general, however, ash thought to be of Timberline age generally is 15–60 cm thick on the south, east, and northeast sides of the volcano at distances of as much as 10 km from the summit. West of Mount Hood, 20 cm of Timberline ash was noted on Yokum Ridge at a distance of 4 km from the volcano's summit.

Lapilli of white hypersthene-hornblende pumice were noted in the ash of Timberline age at Hood River Meadows, at Mount Hood Meadows, near Sherwood Campground in the East Fork Hood River valley, and near Cloud Cap Inn. Nowhere do the pumice lapilli form a continuous layer. At Mount Hood Meadows the lapilli are as much as 4 cm in diameter and occur within the lower 10 cm of the ash deposit which is about 40 cm thick. (See appendix B, measured seciton 4.) The presence of these scattered pumice lapilli in the ash-cloud deposits suggests that a pumice eruption of very small volume occurred during a period that was otherwise characterized by the eruption of nonvesicular dacite.

Within a few hundred meters of the edges of deep canyons on the flank of Mount Hood, ash of Timberline age is underlain and overlain by loose, brown, fine to medium sand as

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◁ FIGURE 11.—Light-reddish-gray ash-cloud deposit of Timberline age overlying dark-yellowish-brown mudflow of Polallie age at a roadcut about 2 km northeast of Government Camp. Dashed line marks the approximate base of the ash-cloud deposit. The tape measure is resting on a boulder in the mudflow. Charcoal from the base of the ash-cloud deposit had a radiocarbon age of 1,610±200 years.

much as 1 m thick. The sand decreases in thickness and generally disappears within a kilometer of the canyons. The sand deposits probably originated when avalanches of loose material fell from the canyon walls and produced local clouds of fine-grained material. Winds then carried the sand short distances from the canyon.

Age and Origin of the Timberline Deposits

BECAUSE their distribution is limited to the south and southwest flanks of Mount Hood, the mudflows and pyroclastic-flow deposits of Timberline age are believed to have resulted from an eruption at the present south-facing crater of the volcano. The nonvesicular nature of the rock debris in these deposits suggests that the material was derived from a dacite dome that was being extruded within the crater; as the flanks of the dome collapsed, some of the hot rock debris rushed downslope as pyroclastic flows. Melting of snow by the hot debris produced water that remobilized both hot and cold rock material as mudflows that moved into the river valleys draining the south and west sides of the volcano. Some mudflows probably were also caused by runoff during rainstorms. Clouds of ash generated by pyroclastic flows were carried away by winds and were deposited on all flanks of the volcano, but principally on the south, east, and northeast sides. Pumice was erupted some time during the Timberline period, but the quantity was so small that only scattered lapilli can now be found on the east and northeast sides of Mount Hood.

Radiocarbon dates on samples of Timberline age range from 1,530±200 to 1,780±200 years. However, because of the range of possible error indicated in these dates, the exact duration of the eruptive period is not known. At one locality some evidence suggests that a brief dormant interval occurred during the Timberline period. At the top of the White River canyon east of Timberline Lodge, two deposits of reddish-gray ash are separated by brown windblown sand and a thin layer of forest litter. If both deposits of ash are of Timberline age, as is suggested by their color, their formation evidently was separated by an interval of a few decades or perhaps as much as a century.

Old Maid Eruptive Period

ROCKS and unconsolidated deposits of Old Maid age include a dacite dome in Mount Hood's crater, a pyroclastic flow, and many mudflows in the White and Sandy River valleys. These products of volcanism probably are all between 200 and 300 years old, and represent Mount Hood's last major eruptive period.

Deposits in the Sandy River Valley

DEPOSITS of Old Maid age in the Sandy River valley consist of coarse mudflows that underlie the valley floor and adjacent terraces between the Upper Sandy Guard Station and the community of Zigzag; these deposits form Old Maid Flat. Old Maid Flat is underlain by a succession of mudflow deposits, each generally less than 2 m thick, rather than by a single very large mudflow. Rocks in these mudflows typically are light-gray hypersthene-hornblende dacite, some of which contains rare augite. Blocks of this rock are abundant on the surface of the mudflow deposits and are as much as several meters in diameter on the upvalley portion of Old Maid Flat.

Old Maid deposits form terraces at several heights in the Sandy River valley near the Upper Sandy Guard Station. The highest and widest terrace is about 45 m above the Sandy River flood plain and about 15 m lower than a terrace on the south side of the valley that is underlain by mudflows of Timberline age. Three lower terraces in this part of the valley, at heights of 3.5, 7.5, and 18 m above the flood plain, also are underlain by mudflows of Old Maid age. These surfaces evidently were formed during times of mudflow deposition that were separated by longer periods of downcutting by the Sandy River.

Large stumps of trees that were buried by mudflows of Old Maid age indicate that a mature forest was growing on the valley floor at the beginning of the Old Maid eruptive period. Upstream from the Upper Sandy Guard Station, buried tree stumps near the base of the Old Maid deposits are rooted in underlying mudflows of Timberline age. Downstream, at a site just south of Muddy Fork (near the junction of Portage and Timberline Trails), partly buried stumps project from mudflow deposits of Old Maid age. Some have toppled and lie rotting on the ground. Other buried trees have rotted away entirely and have left large vertical "tree wells" that are open at the ground surface. Buried stumps can also be seen in the banks of Muddy Fork at least as far downstream as the junction of the Lolo Pass and Muddy Fork Roads and adjacent to Lost Creek along the south side of Old Maid Flat. Wood samples from two stumps at the margins of Old Maid Flat yielded radiocarbon ages of less than 250 years; according to Rubin and Alexander (1960), the wood may be about 200 years old. Growth-ring counts of the stumps of trees that grew on top of the mudflows indicated an age of at least 176 years (Rubin and Alexander, 1960, p. 161).

One of the most interesting deposits of Old Maid age in the Sandy River valley is a mudflow that carried some hot rock fragments (fig. 12). This deposit crops out in the north bank of the Sandy River at a point about 0.3 km southeast (upvalley) of the junction of the Portage and Sandy River Trails. At this locality, the mudflow is 0.5–1 m thick and contains blocks of dacite as much as 50 cm in diameter in a matrix of fine to coarse sand. Eight rock fragments 10–20 cm in diameter from this deposit were examined with a portable magnetometer. Four of these fragments, each of nonvesicular dacite, had random directions of remanent magnetism, which suggests that they were not at a high temperature when the mudflow came to rest. Three samples of slightly vesicular dacite, each of which were taken from prismatically jointed blocks, as well as one sample of nonvesicular dacite, all had directions of remanent magnetism that coincide with the Earth's present magnetic field; thus, these blocks probably were at temperatures of at least several hundred degrees Celsius when the mudflow came to rest.

The mudflow also contains abundant wood fragments that are partly or wholly charred, as well as many that are uncharred. Selective charring like this probably can be attributed to the proximity of wood to hot rock fragments during movement of the mudflow or after it came to rest. Despite this evidence of heat, the presence of uncharred wood suggests

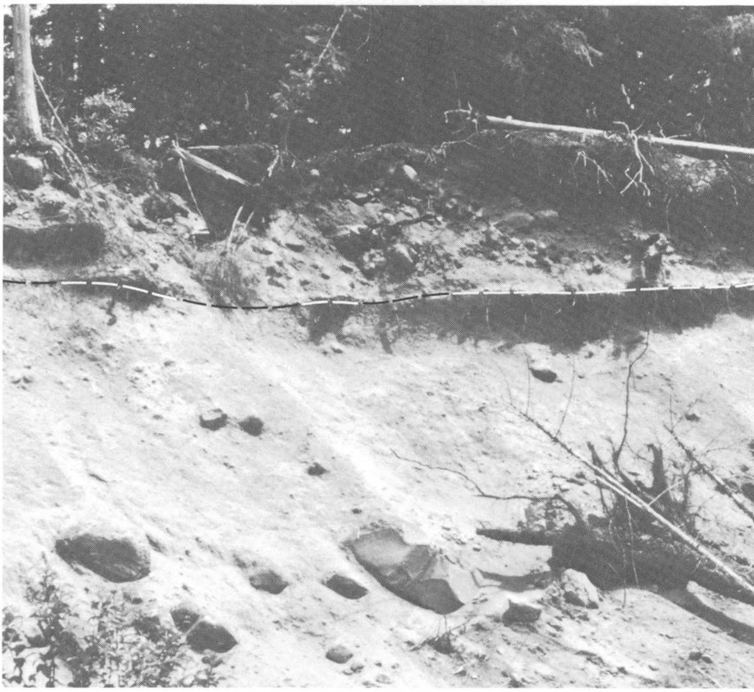


FIGURE 12.—Mudflow of Old Maid age (above dashed line) overlying mudflows of Timberline age in north bank of the Sandy River 0.3 km southeast of the junction of the Portage and Sandy River Trails. The Old Maid mudflow is about 1 m thick.

that the deposit was formed by a hot mudflow rather than a pyroclastic flow. In the deposit of a hot pyroclastic flow, all wood fragments are completely charred.

Charred wood from the mudflow has a radiocarbon age of 220±150 years (table 1). Correction of this date by known variations in atmospheric radiocarbon (Stuiver, 1978) indicates that the mudflow probably occurred between A.D. 1660 and 1790.

The hot mudflow probably occurred during an early part of the Old Maid eruptive period; it was followed by erosion by the Sandy River, then by deposition of the voluminous mudflows that form Old Maid Flat.

Deposits in the White River Valley

DEPOSITS of Old Maid age in the White River valley include two groups of units of slightly different age: an older group of pyroclastic-flow deposits and mudflows, and a younger group of mudflows. The older deposits crop out in the face of a terrace along the west side of White River upstream from State Highway 35 (fig. 13). They include a basal deposit more than 3 m thick that contains dacite fragments mostly less than 0.5 m in diameter in a loose matrix of fine to very fine gray sand. The presence of both charred and uncharred wood in this deposit suggests that it was formed by a mudflow carrying some hot rock fragments. The deposit extends below the level of the White River and is overlain by a pyroclastic-flow deposit 5–20 m thick (fig. 14). The pyroclastic-flow deposit consists of a mixture of dacite fragments as much as 1.5 m in diameter in a semicompact matrix of gray, reddish-gray, and grayish-brown sand. Blocks of dacite as much as 6 m in diameter, many of which are prismatically jointed, litter the terrace. Examination of samples of several jointed blocks using a portable magnetometer gave directions of remanent magnetism that coincide with the Earth's present magnetic field; thus, these blocks probably were at a temperature of at least several hundred degrees Celsius when they came to rest. A chemical analysis of one such block is given in appendix C.

The pyroclastic-flow deposit contains abundant fragments of wood, all of which are charred. A sample of one of these fragments yielded a radiocarbon age of 260±150 years (table 1). Correction of this date by known variations in atmospheric radiocarbon (Stuiver, 1978) suggests that the pyroclastic flow occurred about A.D. 1640.

At its top, this deposit has a reddish-gray to yellowish-brown zone, 0.5–1.5 m thick, in which many stones are coated with yellowish-brown to reddish-brown iron oxides (fig. 15). The coatings are most common and conspicuous on the lower sides of stones. In addition, small areas of the matrix in this zone are also permeated with yellowish-brown coatings on sand grains. This discoloration at the top of the deposit is not part of a soil profile because deposits this young typically are virtually devoid of soil oxidation. Thus, both the reddish-gray

FIGURE 13.—Terrace along the west side of the White River about 1 km upstream from State Highway 35. The conspicuous planar textural break in the Old Maid deposits that form the terrace is at the contact between a mudflow (below) and a pyroclastic-flow deposit. (See fig. 14.) The terrace is at a height of about 25 m above the White River flood plain in the foreground.

FIGURE 15.—*Zone of reddish-gray to yellowish-brown oxidation at the top of the pyroclastic-flow deposit of Old Maid age in the White River valley about 0.7 km north of State Highway 35. This zone, as well as the yellowish-brown to reddish-brown iron oxides that coat many of these stones, evidently was discolored by iron-bearing gases after the pyroclastic flow came to rest.*

zone and the coatings are inferred to have resulted from deposition of iron-bearing material that was being carried upward by hot gases after the pyroclastic flow came to rest and as it cooled.

The pyroclastic flow that forms the terrace is locally overlain by four lenticular mudflows that thin and disappear from the terrace in a downstream direction. The individual mudflows are each as much as 1.5 m thick; they are interbedded with sand a few centimeters to several tens of centimeters thick. Some of the mudflows contain prismatically jointed blocks of dacite.

◁ FIGURE 14.—Pyroclastic-flow deposit of Old Maid age (foreground) forms a terrace that is about 25 m above the White River. (See fig. 13.) A lower terrace in the right center of the photograph is underlain by slightly younger mudflows. (See fig. 16.)

The gradient of the terrace formed by the Old Maid deposits steepens downvalley at a point about 0.4 km from State Highway 35 (about 7.5 km from Mount Hood's crater), and the terrace merges with the White River flood plain between that point and the highway.

Near the point at which it begins to steepen downstream, the Old Maid terrace is about 25 m above the White River. The terrace does not slope as steeply as does the adjacent flood plain; consequently, the height of the terrace decreases upstream and is only a few meters above the White River at the upstream point where the terrace disappears. The pyroclastic-flow deposit was not recognized in the valley farther upstream. It is possible that the pyroclastic flow did not leave thick deposits in the upper part of the valley because the steeper slopes there gave it greater mobility.

The younger part of the Old Maid deposits in the White River valley consists of a succession of bouldery mudflows. these formed a valley fill, now trenched by the White River, whose surface is about 100 m above the river east of Timberline Lodge (fig. 16). The fill surface slopes more steeply than does the White River and merges downvalley with the flood plain at a point about 1.5 km from State Highway 35. A fan of mudflows and river deposits downstream from the highway probably is in part the downvalley correlative of the mudflow fill.

No prismatically jointed blocks of dacite were seen in the young succession of bouldery mudflows, no reddish-gray zones were noted at the top of any of the individual deposits, and upright tree stumps buried at the base of the deposits are not charred; thus, these mudflows evidently were carrying only cold rock debris. The radiocarbon age of a sample of one of the stumps at the base of the mudflows was 250 ± 150 years (table 1).

Topographic relations between the older and younger Old Maid terrace deposits in the White River valley indicate that, after the older deposits were formed, the White River cut down at least as far as the level of the present flood plain. The resulting valley subsequently was partly filled by the mudflows that underlie the younger, lower terrace. The close

FIGURE 16.—View south-southeastward down the White River canyon of a fill terrace formed by mudflows of Old Maid age. Note stumps (indicated by arrows) at base of the fill deposits; one of these had a radiocarbon age of 250±150 years. At this locality, the terrace is about 60 m above the bottom of the gully to the right.

correspondence between the radiocarbon dates on the two groups of deposits suggests, however, that an appreciable amount of time did not elapse between formation of the two parts of the Old Maid deposits.

Crater Rock Dome

MOUNT Hood's crater contains a dome of hypersthene-hornblende dacite called Crater Rock. The dome is about 300–400 m across its base and about 170 m high on its south side (fig. 17). According to Wise (1969), the solid rock of the dome is surrounded by a zone of brecciated rock of the same composition. A chemical analysis of the dome rock is given in appendix C.

FIGURE 17.—Crater Rock (arrow), in the center of Mount Hood's crater, is a remnant of a dacite dome that was erupted between 200 and 300 years ago. The top of Crater Rock rises about 170 m above its base.

Crater Rock is believed to be a remnant of a dacite dome that was formed 200–300 years ago. This age assignment is based on the ages of the pyroclastic-flow deposits and mudflows in the White and Sandy River valleys described above, which are inferred to have been formed as the dome was being extruded. No large-volume source of dacitic rock debris other than the dome exists at the heads of these two valleys. Such a relatively young age assignment is consistent with the extensive fumarolic activity that persists today at and adjacent to Crater Rock. Although Wise (1966, 1969) believed Crater Rock to be the source of the broad fan of rock debris on the south side of the volcano (Timberline deposits of this report), that debris evidently originated at another dacite dome at the same location.

The masses of Old Maid rock debris in the Sandy and White River valleys that were derived from the dome greatly exceed Crater Rock in volume. If it is assumed that the deposits of Old Maid age in the Sandy River valley upstream from Zigzag have an average thickness of 10 m, their total volume is a little more than 100 million m^3. A similar volume can be calculated for similar deposits in the White River valley if it is assumed that they have an average thickness of 25 m, which is the maximum height of the terrace formed by pyroclastic-flow and mudflow deposits. If the volume of all these deposits is arbitrarily reduced by 30 percent to allow for the greater porosity of these deposits than of solid rock and for possible inclusion of material that was not derived from the dome, the resulting volume of the rock mass from which these deposits were derived is about 140 million m^3, which is about 20 times the estimated volume of 7 million m^3 of Crater Rock. A cylinder of rock with a diameter equal to that of the base of Crater Rock and a volume of 140 million m^3 would have a height of a little more than 1,000 m. However, as the dome was extruded, it probably was never significantly larger and higher than it is today, because rockfalls and avalanches probably lowered it as quickly as it was formed.

Ash-Cloud(?) Deposit

A deposit of light-gray lithic ash mantles much of the lower slopes of Mount Hood. At most places the ash directly underlies the ground surface and is covered only by recent forest litter. The ash consists chiefly of fine particles of rock, feldspar, and other mineral fragments; ferromagnesian minerals in the ash include hypersthene, hornblende, and augite in variable proportions. Pumice was not observed in the ash. Most of the ash ranges in size from silt to medium sand, although at some localities there are scattered rock fragments as much as 5 mm in diameter. The maximum observed thickness (about 17 cm) was seen in a roadcut about 150 m north of Tilly Jane Guard Station on the northeast side of the volcano, and a thickness of 14 cm was noted on Yokum Ridge 4 km west of the summit of Mount Hood. The ash is as much as 10 cm thick on the lower slopes of Cooper Spur and near the mouth of the Polallie Creek. Elsewhere, the ash seems to range from less than 1 cm to about 7 cm. A thickness of about 1 cm was observed in a trail cut on Bald Mountain a little more than 7 km west-northwest of the summit of the volcano.

This ash evidently is the same layer as that described by Lawrence (1948), who reported thicknesses of as much as about 15 cm and, on the basis of observations at about 30 localities, drew tentative lines of equal thickness around the volcano (fig. 18). With few exceptions, the thicknesses that I observed generally agree with those of Lawrence. The distribution of the ash on all sides of the volcano suggests that it was transported and deposited by winds blowing in various directions during an extended period of time.

Lawrence believed that the ash was deposited between 1760 and 1810 and most probably about 1800. This age estimate was based on the presence of the ash on a lateral moraine believed by Lawrence to have been formed about A.D. 1740; the lack of a soil between the ash and the underlying moraine was interpreted by him as evidence that the ash is not much younger than the moraine. However, he presented no conclusive evidence that the ash was deposited as recently as 1800.

Lawrence suggested that the ash was erupted at a vent in Mount Hood's crater in the vicinity of Crater Rock. If so, the ash could have originated in repeated steam explosions like those at Mount St. Helens in late March and early April, 1980. Variable winds during that period carried small amounts of ash away from the volcano in nearly every direc-

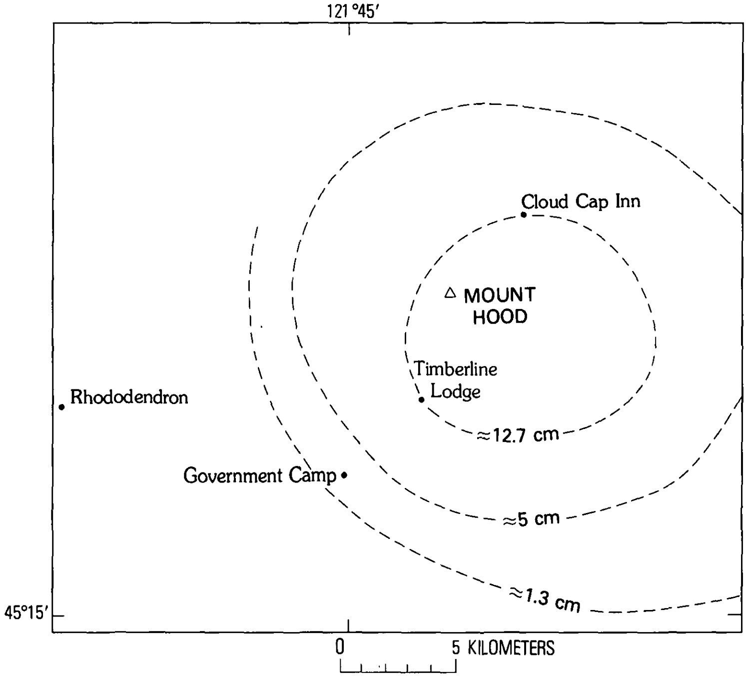


FIGURE 18.—Map showing approximate isopachs (lines of equal thickness) of ash-cloud(?) deposit of Old Maid age (from Lawrence, 1948, fig. 2).

tion. This ash was not derived from new molten rock, but resulted from the explosive disruption of older rocks within the volcano.

It is also possible that the deposit was formed during the extrusion of the Crater Rock dome and that it represents fine-grained airborne dust that was produced by rockfalls and avalanches of debris from the flanks of the dome as it was being extruded.

Recent Flood Deposits

A very coarse, gray, and unweathered deposit of sand and boulder gravel forms a fan in the East Fork Hood River valley at the mouth of Polallie Creek and is preserved farther downstream in a terrace that is between 5 and 10 m above river level. Abundant blocks of gray andesite as large as 5 m in diameter are scattered on the surface of the fan and terrace.

The oldest tree found on the fan is represented by a recently cut stump that has 150 annual growth rings at a height of 40 cm above the ground surface. The light-gray ash described previously could not be found on the fan, and it is concluded that the flood deposit was formed some time during the early 1800's.

At Tucker Park, 32 km downstream from the mouth of Polallie Creek and 6 km southwest of the community of Hood River, similar unweathered bouldery deposits form terraces at heights of about 5, 7, and 9 m above the Hood River. Although the deposits were not traced from Polallie Creek to Tucker Park, it seems likely that they are correlative. The deposits at Tucker Park contain abundant boulders 1-2 m in diameter, and the 7-m terrace has a block of andesite that is nearly 6 m in diameter. A core taken at a height of 60 cm from one of the largest trees growing on the 5-m terrace had 100 annual growth rings.

Although these coarse deposits must have resulted from some kind of unusual event in the Polallie Creek valley, no evidence was found that they were caused by volcanism. Polallie Creek heads in coarse pyroclastic-flow and mudflow deposits of Polallie age and is flanked by these deposits throughout its course. The bouldery deposits downstream from Polallie Creek evidently resulted from exceptionally high discharge in the Polallie Creek valley, which undercut unconsolidated deposits in its banks, and this high discharge probably was caused by unusually heavy precipitation.

Recent (Historic?) Pumice

SCATTERED lapilli of gray pumice are present at the ground surface on the south, east, and northeast sides of Mount Hood, but nowhere do the lapilli form a continuous layer. The largest fragment noted on the ridge 1.3 km west of Mount Hood Meadows was 1.9×2.5×2.3 cm in dimension, and one on a ridge 1.5 km north-northeast of Mount Hood Meadows was 3×4×5.5 cm. The lapilli are generally less than a centimeter in diameter in the areas west of Timberline Lodge, along the East Fork Hood River valley, and near Cloud Cap Inn. Ferromagnesian minerals in the pumice are hypersthene and hornblende; augite is very rare. The chemical composition of a sample of the pumice is given in appendix C.

The recent pumice can be found on top of the pyroclastic flow of Old Maid age in the White River valley; thus, the pumice probably is less than 200 years old. The pumice may have been erupted during the middle of the 19th century.

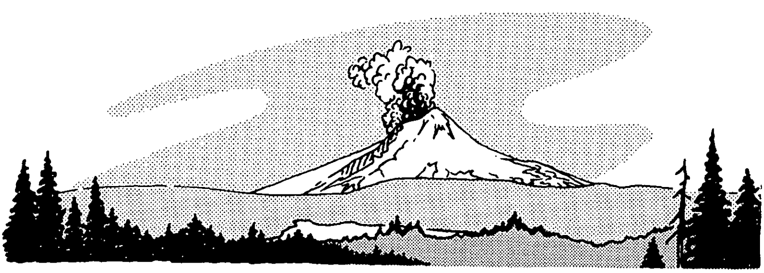
A minor eruption of Mount Hood in September 1859 was witnessed by W. F. Courtney (letter to Everett, Wash., Record, May 1902, quoted in Harris, 1976, p. 147), who reported the following:

> We were camped on Tie Ridge about thirty-five miles from Mt. Hood. It was about 1:30 o'clock in the morning * * * when suddenly the heavens lit up and from the dark there shot up a column of fire. With a flash that illuminated the whole mountainside with a pinkish glare, the flame danced from the crater * * * For two hours, as we watched, the mountain continued to blaze at irregular intervals, and when morning came Mt. Hood presented a peculiar sight. His sides, where the day before there was snow, were blackened as if cinders and ashes had been thrown out.

An event that probably was another minor eruption of Mount Hood was witnessed in 1865 by John Dever, a soldier stationed at Fort Vancouver, Wash., 80 km west-northwest of the volcano. He reported (letter to Portland Oregonian, September 26, 1865) that he saw between 5 and 7 a.m. on September 21,

> * * * the top of Mount Hood enveloped in smoke and flame * * * real jets of flame shot upwards seemingly a distance of fifteen or twenty feet above the mountain's height, accompanied by discharges of what appeared to be fragments of rock, which I could perceive fell immediately after with a rumbling noise not unlike distant thunder.

Although the recent pumice that is scattered on the slopes of Mount Hood could have been erupted either in 1859 or 1865, it also could be the product of more than one eruption.



Mount Hood as seen from the northeast.

PART II
VOLCANIC HAZARDS ASSESSMENT

Potential Volcanic Hazards

POTENTIALLY HAZARDOUS PHENOMENA that could result from an eruption at Mount Hood include pyroclastic flows, lateral blasts caused by volcanic explosions, mudflows, and floods. In addition, a small amount of **tephra** could fall on the flanks of the volcano and adjacent areas.

Lava flows evidently have not been erupted at Mount Hood volcano during the time since the last glaciation, and there is no reason to believe that flows will be erupted in the foreseeable future. If a lava flow were to be erupted, however, its source vent could be located anywhere on Mount Hood, or even beyond the base of the volcano, as is the source vent for the lava flow west of Parkdale. Fortunately, lava flows that have chemical compositions like those of rocks erupted at Mount Hood during the last 15,000 years do not constitute a major risk to lives because such flows are highly viscuous and typically move very slowly. Furthermore, when a lava flow is erupted, the general area of potential hazard will be known immediately because lava moves away from its source in a downslope direction, and its extent will thus be determined by the topography and by the volume of lava that is erupted.

Possible dangers that could be associated with eruptive phenomena other than lava flows at Mount Hood are described in the following section.

Pyroclastic Flows and Associated Ash Clouds

THE repeated formation of domes during several geologically recent eruptive periods at Mount Hood and the relative rarity of other types of volcanic activity indicate that the type of eruption most likely in the future will be the eruption of another dacite dome, probably at or near Crater Rock. Such an eruption almost certainly will produce avalanches of hot rock debris which, if large enough, will move far down the flank of the volcano as pyroclastic flows. Such flows are especially dangerous because they travel at high speed and tend to bury and incinerate everything in their paths. Because of the relatively steep slopes on Mount Hood pyroclastic flows probably will move at speeds of 50 to more than 150 km/h.

If a large volume (0.1 km^3 or more) of lava is erupted in the form of a dome, pyroclastic flows and mudflows from the dome will tend to fill topographically low areas and may form deposits tens of meters thick in the valleys they follow. This is the behavior shown by pyroclastic flows and mudflows of previous eruptive periods. By analogy with domes that have been formed elsewhere during historic time, it should be assumed that the extrusion of a dome will continue for an extended period of time, perhaps many months or even several years, and it should be assumed that pyroclastic flows could occur at any time during dome formation.

Clouds of ash that are generated by pyroclastic flows can form extensive deposits downwind from flows. Although the deposit associated with any one pyroclastic flow may be no more than a few centimeters thick, recurring flows may result in much thicker accumulations, especially in the direction of the prevailing winds. The area covered by an ash-cloud deposit will be determined by the length of the pyroclastic flow, the height of the ash cloud above the flow, and the direction and strength of winds.

Ash clouds constitute a hazard to human life because of their possible high temperature, especially within a few kilometers downwind from the pyroclastic flow. Such clouds may cause asphyxiation and burning of the lungs and skin, as well as abrasion of objects in their paths. The resulting deposits will blanket and perhaps kill vegetation and may block highways. Other potential hazards are similar to those of tephra, discussed subsequently.

Explosive Lateral Blasts

THE formation of domes commonly is accompanied by volcanic explosions that can throw rock debris laterally outward at high speeds to distances of many kilometers. Such a lateral blast during the eruption of a dacite dome at Mount St. Helens about 1,100 years ago carried hot fragments of the dome outward to a distance of at least 10 km (D. R. Mullineaux, oral commun., 1978). A similar explosion occurred during the eruption of a highly viscous lava flow at the summit crater of Lassen Peak in 1915. The resulting hot blast destroyed a mature forest at the north base of the volcano to a distance of about 5 km, and individual rock fragments were carried even farther.

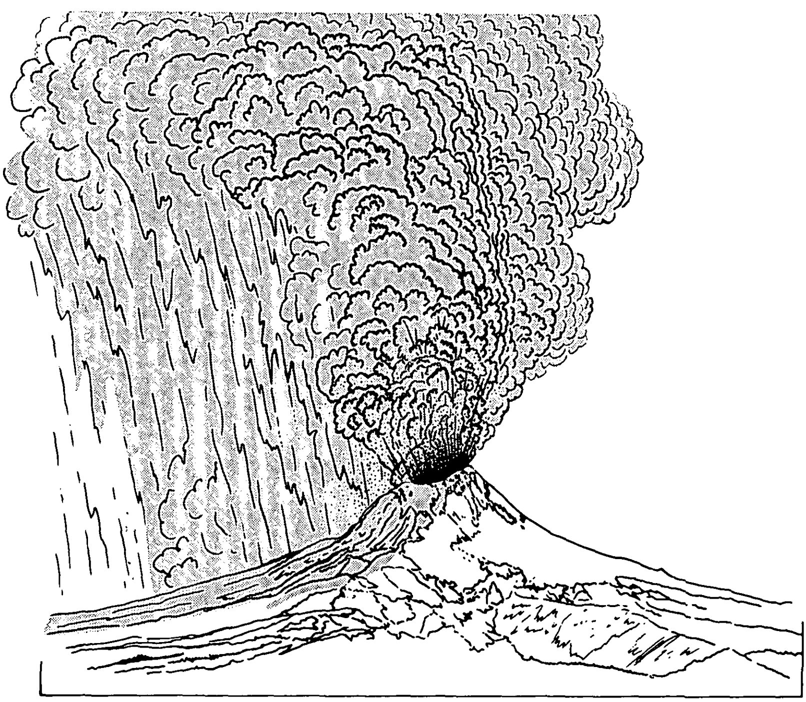
The principal dangers from lateral blasts are from airblast and the impact of rock fragments moving at high speed.

Tephra

TEPHRA usually is projected high above a volcano by the force of the eruption and by hot ascending gases. Typically, winds then carry the material away from the volcano, and it falls to the ground at a distance determined by the height to which the tephra was erupted, by the size of the fragments, and by wind directions and speeds. Large blocks fall close to the vent or may be thrown, like projectiles, onto the flanks of the volcano. If a large volume of tephra is erupted, a continuous layer will accumulate in the fallout area. At Mount Hood, however, eruptions of pumiceous tephra during the last 15,000 years have been of such small volume that only scattered fragments can now be found, rather than continuous layers.

Although the likelihood of a voluminous tephra eruption in the near future seems very low at Mount Hood, the effects of such an eruption could be very serious. Falling tephra can endanger lives and property by the force of the impact, by forming a blanket covering the ground, by producing a suspension of fine particles in air and water, by carrying acids, and, close to the vent, by heat. People can be injured by breathing tephra-contaminated air, by the collapse of tephra-laden roofs, and by fires started by the hot fragments. Tephra can block roads if it is thick enough, can cause darkness, can increase acidity in exposed water supplies, and can interrupt telephone, radio, and electrical services. Damage to property can result from the weight of tephra, from its smothering effect, from abrasion, and from corrosion. Machinery is especially susceptible to damage from abrasion and corrosion both during the initial fall of the material and later, while the material is still loose enough to be redistributed by wind.

The probable extent of future tephra falls at Mount Hood, like those of the geologically recent past, will be within the hazard zones shown on plate 1 for ash clouds and lateral blasts.

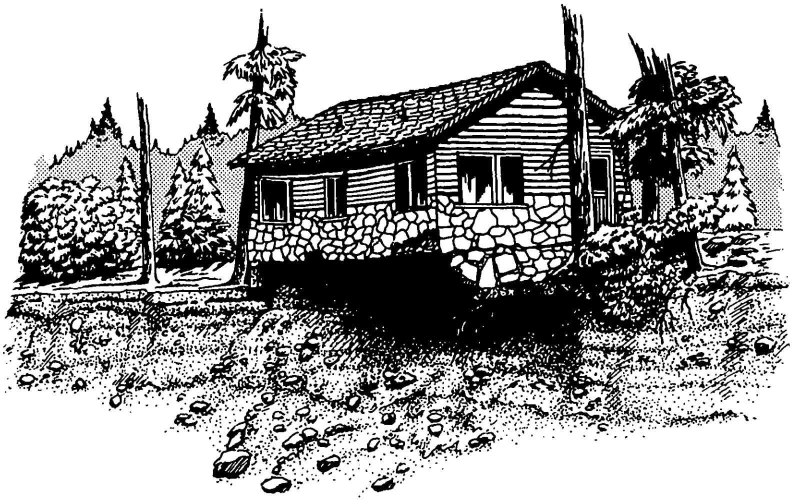


Mount Hood as seen from the east.

Mudflows and Floods

AMONG the many ways mudflows can originate (Crandell, 1971, p. 8–10), the most likely origin at Mount Hood is a pyroclastic flow moving across snow. The rock debris in mudflows can be hot or cold or both. Mudflows can travel distances of many tens of kilometers, and their velocities depend chiefly on volume, fluidity, and the gradient of the surface over which they move. Speeds of as much as 180 km/h have been reported on very steep slopes, and speeds of 20–40 km/h can be expected even on gently sloping valley floors. Mudflows tend to move along stream channels, but those of large volume may overtop streambanks and spread across entire valley floors.

The chief dangers to human life are those due to burial and to the impact of boulders carried in mudflows. In addition, mudflows carrying hot rock debris can cause scalds or severe burns. Buildings can be buried, smashed, or moved. Because of their high viscosities, mudflows can sweep away bridges and other massive structures in their paths. Natural and artificial constrictions that impede flowage in a valley, such as narrow gorges and road embankments, cause mudflows to pond and to attain thicknesses (depths) far greater than those in areas where they can spread freely.



The dangers presented by floods caused by volcanism are similar to those in floods having other causes. Floods can wash out bridges and erode unprotected natural and artificial embankments, thereby causing structures adjacent to river channels to collapse. Floods related to volcanism probably will carry unusually large amounts of rock debris, and deposits of sand and gravel many meters thick may accumulate on valley floors where the carrying power of the water decreases for any reason. If pyroclastic flows were to melt snow on the volcano during a time of flooding, unusually high discharge rates could be expected in streams and rivers.

Volcanic Gases

VOLCANOES emit variable amounts of gases during eruptions. These gases consist chiefly of water vapor, carbon dioxide, carbon monoxide, and compounds of sulfur, chlorine, and nitrogen. Quiet emission may result in gas concentrations near a vent, especially in topographic depressions, but gas generally is diluted and dispersed rapidly by wind. Gases erupted under great pressure may be driven laterally away from a vent at high speed, but they quickly lose speed and then disperse. Dilute gas odors have been reported many tens of kilometers downwind from volcanoes.

Some volcanic gases can be dangerous to health or life as well as to property (Wilcox, 1959, p. 442–444). Gases are potentially injurious to people, mainly because of the effects of acid and ammonia compounds on eyes and lungs, and enough carbon dioxide and carbon monoxide can collect in basins to cause suffocation. Certain gases can harm plants and can poison animals that eat the plants. The cumulative effect of dilute volcanic gases over a long period may cause substantial property damage at distance of many tens of kilometers downwind from a volcano.

No historic basis exists for predicting the specific extent of potential gas-hazard zones at Mount Hood in the event of an eruption; however, the effects of gases can generally be assumed to be greatest close to the volcano and immediately downwind from the active vent.

Hazard Zones

AREAS OF POTENTIAL HAZARD around Mount Hood are subdivided into four main groups according to whether the hazard is the result of pyroclastic flows, lateral blasts, ash clouds, or mudflows and floods. Each of these groups, except that related to ash clouds, is subdivided according to whether the eruption will occur at the present crater or at some other location high on the volcano. In addition, the mudflow and flood hazard zone related to an eruption at the present crater is further subdivided into areas of initial and immediate danger, and additional areas that will be affected if the eruption continues and involves a large volume of material. Each of these subdivisions is discussed in the following paragraphs and is shown on plate 1.

Pyroclastic-Flow, Mudflow, and Flood Hazard Zones PA and PB

THE extent of zone PA is based on the assumption that a dome will be erupted within the present crater of Mount Hood at the site of, or adjacent to, Crater Rock. The zone is limited to areas that are downslope and downvalley from the crater to a distance of 8 km, which is the approximate length of a pyroclastic flow of Old Maid age in the White River valley. The extent of zone PB is based on the assumption that a dome will be formed at some point on the volcano above about 2,750 m (9,000 ft), but not within or downslope from the present crater. The zone includes areas downslope and downvalley to a distance of 8 km from the 9,000-ft contour.

Although zones PA and PB include hazards from mudflows and floods, the extents of the zones are based chiefly on the anticipated behavior of future pyroclastic flows because they are regarded as potentially the most dangerous type of hazard. The lateral boundaries of the zones are based on the assumption that a pyroclastic flow will locally rise as much as a few tens of meters on the sides of the valley it descends and to greater heights in areas where the valley is constricted. The areas adjacent to the basal part of the pyroclastic flow can be affected by clouds of initially hot ash whose effects will rapidly diminish in a downwind direction. Boundaries between pyroclastic-flow hazard zones and adjacent ash-cloud hazard zones are transitional over perhaps as much as 1 km.

Mudflow and Flood Hazard Zones MA, MB, and M

THE area included in zone MA consists of part of the lower south flank of the volcano and the channels of streams and rivers that head on the part of the volcano that is downslope from the present crater. These channels probably will be the first areas to be affected by mudflows and floods resulting from an eruption in the present crater; consequently, the channels are more hazardous that are adjacent, higher areas of valley floors. Zone MB includes the floors of valleys that head on the part of the volcano that is downslope from the present crater; it also includes surfaces that are 5–15 m above present rivers. These areas may not be affected initially by floods and mudflows caused by future eruptions, but they could be endangered if an eruption continues and causes deposits of floods and mudflows to fill existing river channels. Zone M includes the floors of valleys downslope from parts of the volcano that do not head within the present crater.

The lateral boundaries of zones MA and M are based partly on contours shown on the topographic map and partly on an inspection of aerial photographs which show areas of recent flood devastation along valley floors. Lateral boundaries of zone MB are based on the topography of valley floors as indicated by contours. Because the sizes of future mudflows and floods can not be predicted, the boundaries are approximations and, in places, may be accurate only to within a few hundred meters.

Highways and bridges that are located in mudflow and flood hazard zones MA and M are especially susceptible to damage or destruction not only by phenomena associated with eruptions but also by floods caused by weather conditions.

Such floods can erode the banks of rivers and undermine adjacent houses and other structures, as in December 1964, when the Zigzag River washed out bridges or their abutments along U.S. Highway 26 and temporarily isolated the community of Rhododendron. On December 29, 1964, the Portland Oregonian carried the news that:

> The Zigzag, in many places hundreds of feet from its former bed is lined with houses hanging crazily over the undercut banks. Many of the stream-side homes are entirely gone—no one yet knows how many—along with the soil on which they were built.

Areas that are susceptible to the effects of flooding along the branches of the Hood River are identified on a geologic-hazards map of the Hood River quadrangle and are discussed in an accompanying report (Beaulieu, 1977).

Lateral-Blast Hazard Zones LA and LB

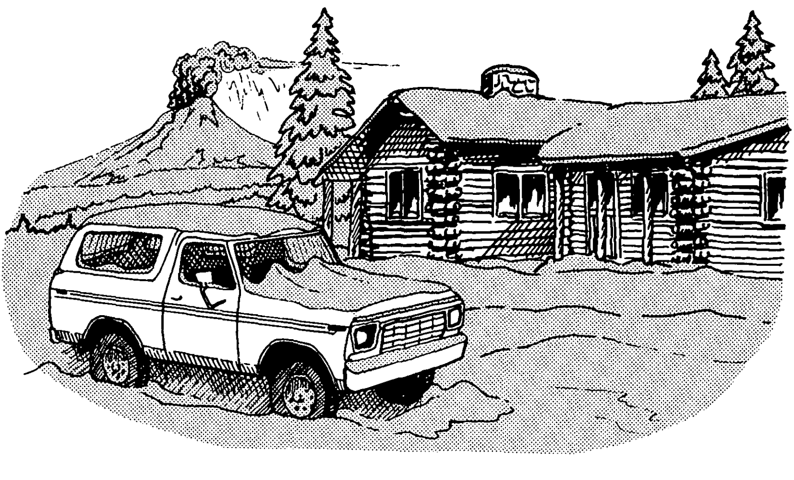
HAZARD zones LA and LB are subject to the effects of lateral blasts caused by volcanic explosions during an eruption. The extent of zone LA is based on the assumption that an explosion may occur during the extrusion of a dome within the present crater, and the extent of zone LB is based on the assumption that an explosion may occur during the formation of a dome elsewhere high on the volcano. The outer limits of the zones, about 10 km from the summit of the volcano, are based on the distance rock fragments were thrown by an explosion during the eruption of a dome at Mount St. Helens about 1,100 years ago. The risk to life and property from rock debris thrown outward by a lateral blast decreases progressively with distance from the summit of the volcano.

Ash-Cloud Hazard Zone

THE ash-cloud hazard zone includes areas that could be covered by 20 cm or more of ash generated by pyroclastic flows. The distribution and thickness of ash probably will be determined by the location, number, and size of pyroclastic flows, and by the direction and speed of winds that carry the ash away as the pyroclastic flows move downslope. This zone could also be affected by ash and lapilli erupted directly from a vent high on the volcano, but if future eruptions are like those of the recent past, the resulting deposits will not form a continuous layer of appreciable thickness.

The extent of the ash-cloud hazard zone is based on the distribution and thickness of ash-cloud deposits of Timberline age relative to the probable sources of those deposits. In determining the limit of the zone (pl. 1), it was assumed that ash-cloud deposits at least 20 cm thick can accumulate at a maximum distance of 11 km from hazard zones PA and PB. The limited westward extent of the ash-cloud hazard zone is based on the assumption that winds will be blowing to the east in a sector defined by 22½° east of north and 22½° east of south.

In the discussion of the Parkdale soils (p. 25), it is suggested that the deposit was formed by ash clouds carried by winds northward from pyroclastic flows descending the northeast slopes of the volcano. If this is true, what is the chance that ash-cloud deposits as much as 4 m thick will accumulate in the Upper Hood River Valley as the result of future volcanic activity? The distribution of ash-cloud deposits probably is controlled by winds at altitudes lower, rather than higher, than the top of the volcano. At Salem, Oreg., the nearest point at which wind records are available, only 5 percent of winds at an altitude of about 2,500 m are from the south. (See fig. 20.) Thus, if it can be assumed that wind directions in the Mount Hood region are similar to those at Salem, the risk of thick ash accumulating in the Upper Hood River Valley in the future seems very low.



Discussion of Hazard Zones

THE hazard-zone boundaries shown on plate 1 can be used only in a very general way to anticipate the extent of a potential hazard. For example, the actual volume of a future pyroclastic flow or mudflow cannot be predicted; thus, its width, depth, and length will not be known until after it occurs. Moreover, possible inaccuracies in the location of the zone boundaries shown on plate 1, small inaccuracies in the base map, and changes in river courses and the location of highways and other manmade features since the base maps were made all combine to make the map useful only as a rough guide to possible hazard areas. Furthermore, an inverse relation exists between the size of mudflows and their frequency—mudflows of small volume are far more common than very large ones. Thus, the risk from mudflows at any one place within a valley decreases progressively with increasing height above a river and generally becomes negligible above a height of several tens of meters (fig. 19). For the same reason, the risk from mudflows also becomes progressively less in a downstream direction, but this decrease occurs over a distance of several tens of kilometers. The same relations are generally true for pyroclastic flows that move down valley floors, although the ash clouds that accompany them can affect adjacent valley walls to heights of hundreds of meters. The boundaries shown for the lengths of future pyroclastic flows are based on an actual event, but many future flows probably will be shorter, and some will be longer.

It cannot be emphasized too strongly that the degree of risk from volcanic phenomena is gradational: the greatest risk is on the upper slopes of the volcano, and from there it diminishes with distance and, in the case of pyroclastic flows, mudflows, and floods, with increasing height above valley floors. Lines that delineate zones of potential hazard on plate 1 are based on the assumption that future eruptive events will be similar to those of the last 15,000 years; however, there can be no assurance that areas beyond those lines are devoid of risk.

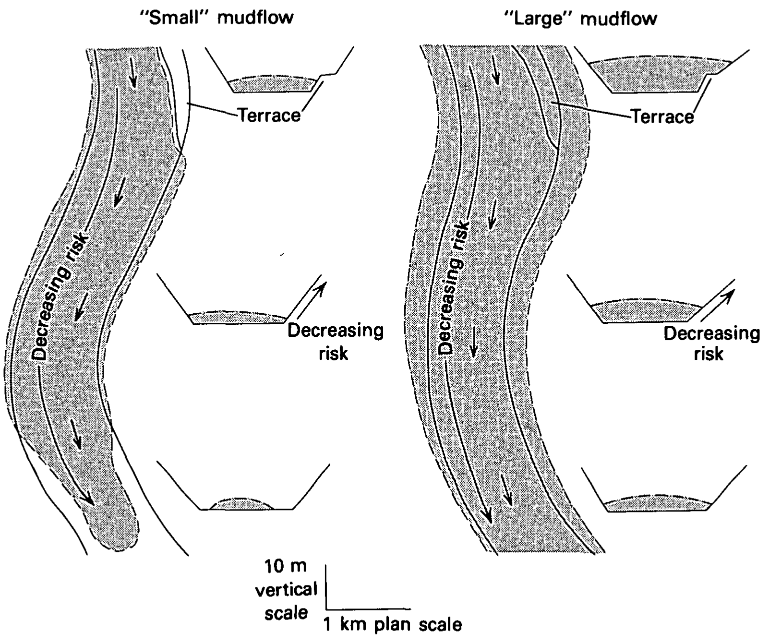


FIGURE 19.—Diagrammatic maps and cross sections of hypothetical mudflows, showing relations of potential risk to length and thickness (depth) in a valley, "Small" mudflows occur more frequently than "large" mudflows. The shaded portions show extent and maximum height reached by mudflows, but thicknesses that remain after mudflows come to rest may be substantially less. Short arrows point downvalley.

The character of recent eruptive activity suggests that there is little or no danger that the next eruption of Mount Hood will significantly affect the Portland metropolitan area. Future mudflows that reach the Columbia River will probably be of such small volume at that distance from the volcano that they will have virtually no effect on the discharge of the Columbia. Inasmuch as no appreciable volume of pumiceous tephra has been erupted at Mount Hood during the last 15,000 years, the probability that large-volume eruptions of this kind will occur in the near future seems to be exceedingly small. In the unlikely event that a large volume of tephra were erupted, the chance is small that a significant amount would

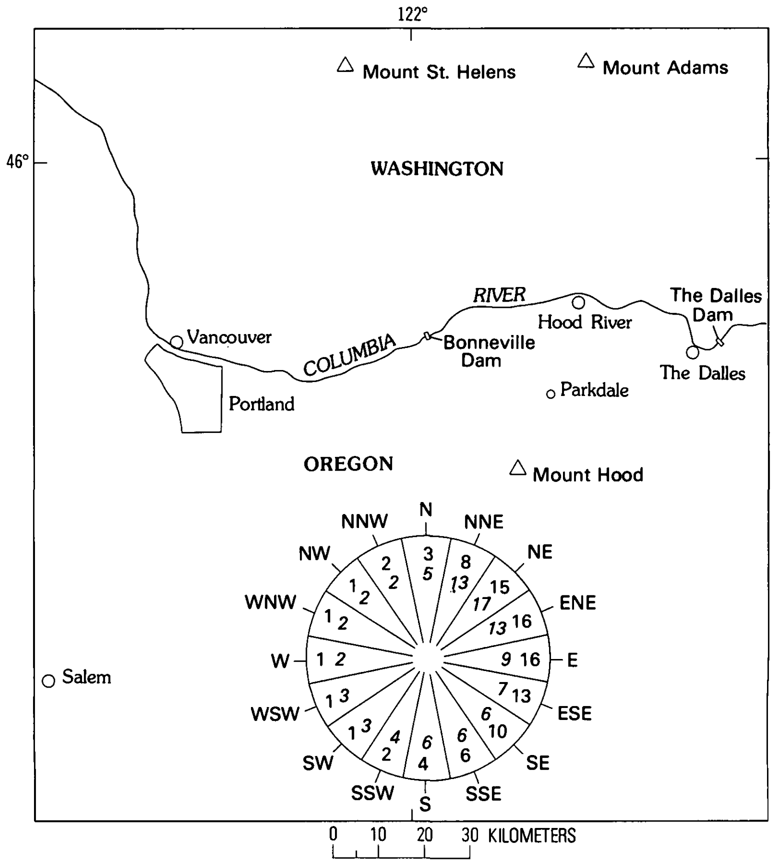


FIGURE 20.—Approximate percentage of time, annually, that the wind blows toward various sectors at Salem, Oreg. Percentages are rounded averages of frequencies determined at altitudes between about 4,000 and 16,000 m; percentages in italics are frequencies at an altitude of about 2,500 m. The height of Mount Hood is 3,424 m. (Compiled from Winds Aloft Summary of the Air Weather Service, U.S. Air Force, for years 1956–70, available from the National Climatic Center, Asheville, N. C.)

fall on the Portland metropolitan area. At altitudes of 4,000 to 16,000 m, which is a reasonable estimate of the heights to which ash could be erupted above the volcano, winds in this region blow toward the west-northwest only about 1 percent of the time annually, according to upper-level wind records at Salem, Oreg. (fig. 20).

Planning for the Next Eruption

Planning before an Eruption Occurs

CONTINGENCY plans could be made now by responsible local, State, and Federal agencies for actions to be taken in the event of an eruption of Mount Hood. The primary goals of such plans would be to anticipate hazardous events before they occur and to prepare responses to such events that would mitigate their impact on people and property. An important aspect of these plans would be the determination of lines of authority and areas of responsibility for local, State, and Federal agencies. After such plans are prepared, they could be updated as new information becomes available concerning the volcano, as uses of the land around Mount Hood change, and if comprehensive monitoring systems are permanently installed at the volcano in the future.

Predicting the Next Eruption

THE last known eruptions of Mount Hood occurred during the middle of the 19th century (Harris, 1976). Such recent eruptions, as well as the thermal activity that has continued to the present at and adjacent to the Crater Rock dome, suggest that molten rock is still present within or beneath Mount Hood, although its existence has not yet been proven. The volcano seemingly was dormant for at least 1,200 years between the Timberline and Old Maid eruptive periods, but only a little more than a century elapsed between the Old Maid period and the activity reported in the mid-1800's. Mount Hood almost surely will erupt again, and possibly in the very near future, but as yet we have no way to predict when the next eruption will occur.

Warning Signs of an Impending Eruption

VOLCANIC eruptions are often preceded by a variety of phenomena which, if detected and properly interpreted, can warn of an impending eruption. These include:

Increase in gas emission and temperatures at fumaroles, and changes in composition of gases.

Rapid melting of snow and unusually high stream discharge not due to weather conditions.

Local earthquakes.

Earthquakes related to an impending eruption are caused by movement of molten rock into or within a volcano. Such earthquakes initially may be too weak to be detected except by instruments. However, if earthquakes are felt, and if they progressively increase in number and strength over a period of hours or days, an impending eruption should be suspected. Some earthquakes might trigger avalanches of snow or rock from the volcano.

Volcanic eruptions often begin on a small scale and might not be detected if weather conditions were to cause poor visibility. However, andesitic and dacitic volcanoes also have been known to erupt violently with virtually no warning, and with little or no preliminary small-scale activity.

If an eruption began on a relatively small scale, it might first be recognized by one or more of the following:

Clouds of white or gray steam and "smoke" rising above the volcano.

A glow in the sky above the volcano at night.

Loud rumbling noises or sharp explosions.

Darkening, by tephra, of snow on the volcano's flanks.

Plumes of water vapor vapor ("steam") are often seen rising from the area of Crater Rock when atmospheric conditions are favorable; they sometimes are several hundred meters high. These originate in fumaroles on and adjacent to the Crater Rock dome and should be considered warning signs of a possible eruption only if they increase greatly in volume and persistence.

What to Do if There Are Signs of an Impending Eruption

IF signs of an impending eruption appear, the effects of volcanism might be minimized if people in threatened areas are warned in time. It is suggested that the following actions be taken if warning signs appear, or if an eruption begins without warning:

1. Notify local, State and Federal authorities (such as District Ranger, U.S. Forest Service, County Sheriff offices, State Police, State Division of Emergency Services).
2. Put into effect contingency plans for responding to various kinds of eruptions, including possible restrictions on access to and use of potentially hazardous areas and possible evacuation.
3. Establish a warning system by which residents of threatened areas could be informed of the likelihood of an eruption, the extent and nature of its possible effects, and the contingency plans of governmental agencies for various kinds of eruptions.
4. Establish a volcano watch, by which the volcano would be observed regularly during daylight hours from ground stations and intermittently from aircraft. Seismic and heat-flow conditions of the volcano could be monitored using seismometers and infrared imagery.

Other kinds of geophysical and geochemical monitoring that might be appropriate at Mount Hood and that were utilized at Mount Baker volcano in 1975–76 are described by Frank, Meier, and Swanson (1977).

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APPENDICES

APPENDIX A
TERMINOLOGY

In this section some technical terms and volcanic processes are explained that might be unfamiliar to readers who do not have a background in geology. The meaning of these terms and knowledge of these processes is necessary to understand the report.

A **volcanic dome** is a mass of solid rock that is formed when pasty lava pushes upward from a vent and is too stiff to flow sideways more than a few tens or hundreds of meters. Movement is chiefly upward in the center of the dome, which causes the sides to become very unstable. Because of this instability, the height of domes generally is limited to only a few hundred meters. Rock masses frequently fall and avalanche as the dome is formed, some triggered by the movement of the dome itself, others by explosions. Avalanches of hot rock debris may move down the volcano's flanks at high speed and reach distances of 10 km or more from their point of origin. Such avalanches of swiftly moving hot rock debris are called pyroclastic flows and form **pyroclastic-flow deposits**.

Pyroclastic flows generally consist of two parts. One is the basal mass of rock debris that moves along the ground, and the other is the turbulent **ash cloud** of fine material that is generated by the basal flow and rises hundreds or thousands of meters above it. When this material settles to the ground, often after being carried downwind from the pyroclastic flow, it forms an ash-cloud deposit. Such a deposit generally is of fine to coarse sand size and consists of particles of minerals and rock. Typically, near-surface winds carry the ash less than 10 km before it drops to the ground. However, because the ash originates in a moving pyroclastic flow, deposition of ash may occur in a relatively narrow band adjacent to the entire length of the pyroclastic flow if the wind direction is at right angles to the direction the pyroclastic flow is moving.

Many deposits formed by pyroclastic flows can be recognized by the presence of wood that has been wholly charred and by a reddish-gray zone as much as 2 m thick at their tops. The presence of charred wood can distinguish a pyroclastic-flow deposit from a glacial deposit or river deposits, but not from a mudflow that was carrying hot rock debris. When such mudflows come to rest, wood fragments in contact with hot boulders can become charred.

Many pyroclastic-flow deposits also contain intricately cracked blocks of rock that have the appearance of a three-dimensional jigsaw puzzle. This type of cracking is referred to as **prismatic jointing**; it results from contraction of the rock while it is cooling.

Since cooling progresses from the outside of the block toward its center, the cracks form at right angles to the surface and progress inward (Wise, 1966). When blocks like these are exposed to the weather, they tend to disintegrate along the joints. The presence of abundant prismatically jointed blocks in a deposit is believed to be evidence that the deposit originated during an eruption and that it was formed either by a hot pyroclastic flow or a hot mudflow. The inference that rock fragments were still hot when they came to rest can be tested by determining, using a magnetometer, the direction of **remanent magnetism** within the rock. The orientation of remanent magnetism in a rock is determined by iron-bearing magnetic minerals in that rock. As a once-molten rock cools through a critical temperature, which can be experimentally determined and is generally at least several hundred degrees Celsius, these minerals acquire a magnetic orientation that is parallel to the Earth's magnetic field. If a volcanic deposit came to rest while rock fragments in it were still above this critical temperature, the orientation of remanent magnetism of the fragments should be uniform and parallel. But if the fragments cooled before they were incorporated in a moving mass, or while the mass was still moving, their magnetic orientation would be random. At Mount Hood, all prismatically jointed blocks that were tested with a magnetometer showed magnetic evidence that they were still hot when the deposit in which they occur was formed.

Reddish-gray ("pink") tops on otherwise gray pyroclastic-flow deposits are believed to result form the deposition of finely divided hematite (iron oxide) by hot gases after a pyroclastic flow comes to rest and while it cools (Williams, 1960, p. 13).

A **mudflow** is a mass of water-saturated rock fragments, ranging in size from clay to large boulders, that moves downslope as a fluid. During movement, a mudflow resembles a flowing mass of wet concrete; after it comes to rest and dries out, it looks like bouldery concrete although lacking in cementation. Stones carried by volcanic mudflows can be hot or cold. Mudflows that carry hot rock debris can be generated by pyroclastic flows that melt snow and thus provide water to mix with the hot rock debris. Some relatively small mudflows occur when heavy precipitation saturates masses of loose rock debris lying on steep slopes and when a body of water impounded by a glacier on a volcano is suddenly released.

Pumice is a volcanic glass that is very porous (**vesicular**) because of a high gas content when it was erupted. Pumice contrasts with the rock of most domes and lava flows, which is relatively nonporous (**nonvesicular**). **Ash** and **lapilli** are size terms that refer to the diameter of fragments of pumice or other volcanic rock. Ash is restricted to particles less than 4 mm in diameter, and lapilli are fragments 4–32 mm in diameter; larger fragments are called **blocks**. Ash may consist of volcanic glass, mineral crystals, or fragments of dense rock (lithic ash). Lapilli and blocks generally consist either of pumice or dense rock.

Tephra is the term used in this report to describe ash, lapilli, and blocks that are erupted from a vent into the air above a volcano. The individual fragments may consist of pumice or dense rock or a mixture of the two, accompanied by variable amounts of mineral crystals. The term is used here in this restricted sense so as to differentiate the material erupted directly from a vent from the clouds of fine fragmental material generated by pyroclastic flows. Although tephra and ash-cloud deposits have some characteristics in common, they also have some significant differences with respect to potential hazards.

Other geologic terms used in the report are defined below:

Amphibole—a group of ferromagnesian rock-forming minerals; includes the minerals hornblende and cummingtonite.

Andesite—a fine-grained volcanic rock made up of feldspars and ferromagnesian minerals; typically has a SiO_2 content of 54 to about 62 percent (Wise, 1969, p. 973).

Augite—a ferromagnesian rock-forming mineral of the pyroxene group.

Basalt—a fine-grained volcanic rock made up of feldspars and ferromagnesian minerals; typically has a SiO_2 content of less than 54 percent.

Biotite—a ferromagnesian rock-forming mineral of the mica group.

Cirque—a glacially eroded basin shaped like half a bowl.

Colluvium—a deposit formed by earth material that has moved downslope primarily due to gravity.

Cummingtonite—a ferromagnesian rock-forming mineral of the amphibole group.

Dacite—a fine- to coarse-grained volcanic rock made up of feldspars and ferromagnesian minerals; dacites at Mount Hood typically have SiO_2 contents of about 62 to 66 percent (Wise, 1969, p. 973).

Feldspar—a large group of generally light-colored rock-forming minerals.

Ferromagnesian—an adjective applied to some rocks and generally dark-colored rock-forming minerals that contain iron and magnesium and that include the amphibole, pyroxene, and mica minerals groups and olivine.

Hornblende—a ferromagnesian rock-forming mineral of the amphibole group.

Hypersthene—a ferromagnesian rock-forming mineral of the pyroxene group.

Loess—a deposit of primarily silt-size (0.005–0.05 mm) material laid down by wind.

Moraine—rock debris deposited by a glacier; a lateral moraine is formed at the side of a glacier, and a terminal moraine at the downvalley end.

Olivine—a ferromagnesian rock-forming mineral especially common in basalt.

Pyroxene—a group of ferromagnesian rock-forming minerals that includes augite and hypersthene; distinguished from the amphibole group primarily by chemical composition.

Till—an unsorted, unstratified mixture of fine and coarse rock debris deposited by a glacier.

APPENDIX B

MEASURED SECTIONS

MEASURED SECTION 1

Location: In bluff overlooking Salmon River near center SE¼ sec. 25, T. 2 S., R. 6 E., along road to rock quarry, about 0.4 km southwest of U.S. Highway 26.

	Thickness in meters
7. Mudflow of pre-Polallie age: mixture of angular and subangular fragments of light-gray dacite or andesite mostly less than 0.5 cm in diameter in gray sand matrix, massive; oxidized yellowish brown in upper 1 m	1.4
6. Mudflow, as above: rock fragments as large as 2 cm in diameter; oxidized yellowish brown in upper 20–30 cm	1.4
5. Colluvium: angular fragments of basalt as large as 0.5 cm in diameter in matrix of reddish-brown clay; fragments have weathered rinds as much as 2 mm thick; lenses out to south; as much as	1.4
4. Pumiceous ash, yellow; contains cummingtonite, hornblende, and biotite; identified by D. R. Mullineaux (oral commun., 1976) as an ash erupted at Mount St. Helens between about 30,000 and 40,000 years ago	0.4

MEASURED SECTION 1—Continued

	Thickness in meters
3. Sand, very fine to coarse, and scattered granules; gray, oxidized yellowish brown in upper 40 cm; contains small fragments of charcoal in upper half	0.7
2. Sandy silt (loess?), brown; contains scattered rock granules and small fragments of carbonaceous matter near top	1.8
1. Till of Hayden Creek(?) age. Poorly sorted mixture of round and subround cobbles and boulders, some of which are faceted, in compact matrix of gray sand; more than	2

MEASURED SECTION 2

Location: Roadcut and bank of Sandy River at confluence with Zigzag River 0.5 km north of Zigzag, in SE¼SE¼ sec. 33, T. 2 S., R. 7 E.

10. Mudflow of Old Maid(?) age: poorly sorted mixture of angular and subangular rock fragments as much as 10 cm in diameter in compact sand matrix, light brownish gray	1
9. Mudflow: poorly sorted mixture of subangular and subround rock fragments as much as 10 cm in diameter in compact sand matrix; dark yellowish brown at top grades down to light olive brown; layer of forest litter 3 cm thick at top contains charred wood fragments less than 200 radiocarbon years old (sample W-3744)	1.2
8. Mudflow: poorly sorted mixture of subangular and subround rock fragments as much as 30 cm in diameter in mottled gray and yellowish-brown sand matrix; bed of sand 2–5 mm thick at top contains carbonaceous matter	0.9
7. Mudflow: poorly sorted mixture of subangular and subround rock fragments as large as 1 m in diameter in compact matrix of dark-grayish-brown sand; upper 20 cm in yellowish brown	1.75
6. Sand, fine, light-olive-brown to grayish-brown, locally reddish-yellow (middle portion not exposed); about	1.4
5. Sand, fine, brown; contains scattered lapilli of pumice that contains hypersthene and augite	0.35
4. Sand, medium to coarse, gray; contains scattered pebbles and small cobbles	0.6
3. Mudflow: poorly sorted mixture of subangular and subround rock fragments as much as 50 cm in diameter in gray sand matrix	1.5
2. Sand and pebble, cobble, and boulder gravel	1.5
1. Mudflow(?): poorly sorted mixture of subangular and subround rock fragments as much as 1 m in diameter in pinkish-gray sand matrix; contains zones in which matrix is absent; more than	5

MEASURED SECTION 3

Location: South bank of Sandy River in SE¼SW¼ sec. 33, T. 2 S., R. 7 E., about 1 km west-northwest of Zigzag

	Thickness in meters
5. Mudflow: poorly sorted mixture of rock fragments as large as 10 cm in diameter in gray sand matrix, lenticular; as much as	1
4. Mudflow: poorly sorted mixture of round to subangular rock fragments as much as 50 cm in diameter in gray sand matrix	1
3. Mudflow of Timberline age: poorly sorted mixture of subangular and subround rock fragments as much as 1.5 m in diameter in silty sand matrix, mottled yellowish brown and purplish gray; most rock fragments are coated with yellowish brown iron oxides; wood fragment about 20 cm above base had radiocarbon age of 1,780±200 years (sample W-3742)	5
2. Sand, medium to very coarse, and granule gravel; contains a few rock fragments as much as 30 cm in diameter; all material appears to be fresh rock débris from Mount Hood, mostly massive, but has local planar bedding and crossbedding; gray, oxidized light yellowish brown in upper 50-60 cm; uppermost 1-3 cm locally humidifed and contains particles of carbonized wood	2-5
1. Sand and pebble, cobble, and boulder gravel, gray; more than	6

MEASURED SECTION 4

Location: Drainage ditch on south side of parking lot at Mount Hood Meadows, SW¼SW¼ sec. 3, T. 3 S., R. 9 E.

	Thickness in meters
4. Ash-cloud deposit of Timberline age: fine to very fine lithic ash, pinkish-gray and light-yellowish-brown; has crude planar laminations; contains scattered lapilli of white pumice as much as 4 cm in diameter in lower 10 cm	0.4
3. Ash, lithic, gray; has faint planar laminations; uppermost beds contain vegetative matter	0.2
2. Ash(?), lithic, dark-yellowish-brown; contains much disseminated vegetative matter and, at top, fragments of carbonized wood; appears to represent a soil developed on ash, lenticular; as much as	0.2
1. Till of Fraser age; more than	0.3

APPENDIX C

CHEMICAL ANALYSES

Chemical analyses, in percent, of some dacitic rocks erupted at Mount Hood during the last 15,000 years

[Rapid rock analyses were performed in the laboratories of the U.S. Geological Survey by Z. A. Hamlin using the method described under "single solution" in U.S. Geological Survey Bulletin 1401 (Shapiro, 1975)]

	Blocks from pyroclastic-flow deposits of Polallie age			Block in Timberline pyroclastic flow	Crater Rock dome	Block in Old Maid pyroclastic flow	Young pumice (1859-65?)
	1	2	3	4	5	6	7
SiO_2	62.3	63.2	61.8	62.0	62.5	63.6	62.6
Al_2O_3	16.9	16.8	17.3	16.6	17.0	16.7	16.9
Fe_2O_3	2.2	1.8	1.8	2.1	1.4	1.3	1.7
FeO	3.0	3.4	3.6	2.8	3.4	3.0	3.1
MgO	2.6	2.5	2.6	2.8	2.4	2.1	2.3
CaO	5.5	5.3	5.5	5.3	5.1	4.7	5.2
Na_2O	4.3	4.3	4.1	4.2	4.8	4.6	4.2
K_2O	1.6	1.5	1.3	1.4	1.3	1.4	1.4
H_2O+	.7	.35	.82	.26	.22	.14	1.1
H_2O-	.15	.20	.43	.09	.01	.03	.45
TiO_2	.81	.81	.85	.78	.80	.77	.77
P_2O_5	.25	.26	.25	.17	.17	.16	.24
MnO	.08	.08	.08	.05	.06	.06	.08
CO_2	.06	.04	.02	.00	.01	.00	.04
Totals	100.45	100.54	100.45	98.55	99.17	98.56	100.08

LOCATIONS FROM WHICH SAMPLES WERE OBTAINED FOR CHEMICAL ANALYSIS

1. About 0.9 km southwest of Tilly Jane Guard Station at head of Polallie Creek valley, about 4 km northeast of the summit of the volcano. Prismatically jointed block of black dacite from pyroclastic-flow deposit about 40 m vertically below top of a succession of deposits of Polallie age.
2. About 0.75 km southwest of Tilly Jane Guard Station at top of north valley wall of Polallie Creek. Prismatically jointed block of light-gray dacite from pyroclastic-flow deposit at top of succession of deposits of Polallie age.
3. On north side of knife-edged ridge adjacent to trail along Newton Creek at about the 5,440-foot-contour line, 4.8 km southeast of the summit of Mount Hood. From deposits of the intermediate fill described on p. 15.
4. Surface of fan formed by pyroclastic-flow deposits of Timberline age on the south side of the volcano along Skyline Trail about 1 km northwest of Timberline Lodge. Prismatically jointed block of gray dacite.
5. Southeast base of dacite dome of Old Maid age in summit crater.
6. Surface of pyroclastic-flow deposit of Old Maid age in White River valley in NW¼NE¼SW¼ sec. 16, T. 3 S., R. 9 E. Prismatically jointed block of gray dacite.
7. At ground surface on terrace formed by pyroclastic-flow deposits of Old Maid age in White River valley, in NW¼ sec. 16, T. 3 S., R. 9 E. Pumice lapilli.

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[Italic page numbers indicate major references]

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