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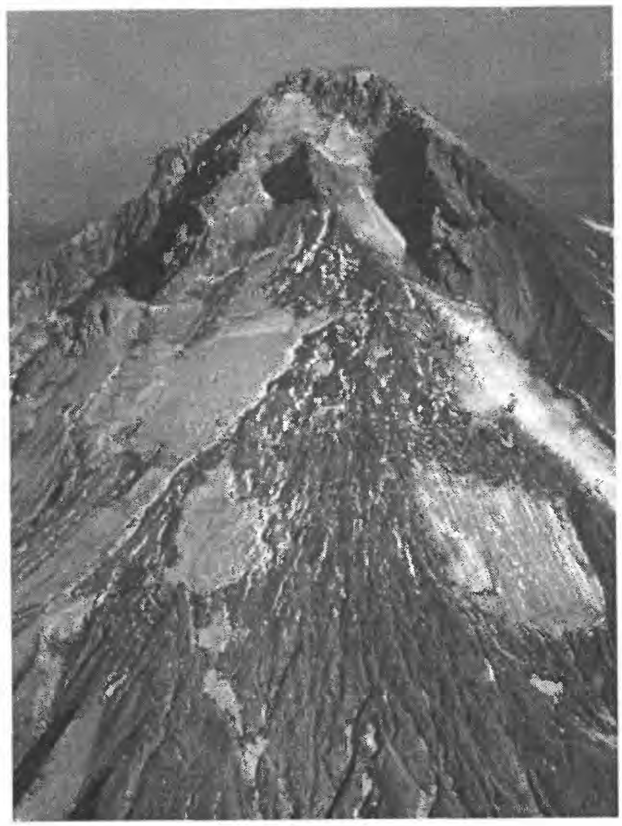
Geologic History of Mount Hood Volcano, Oregon–A Field-Trip Guidebook



by

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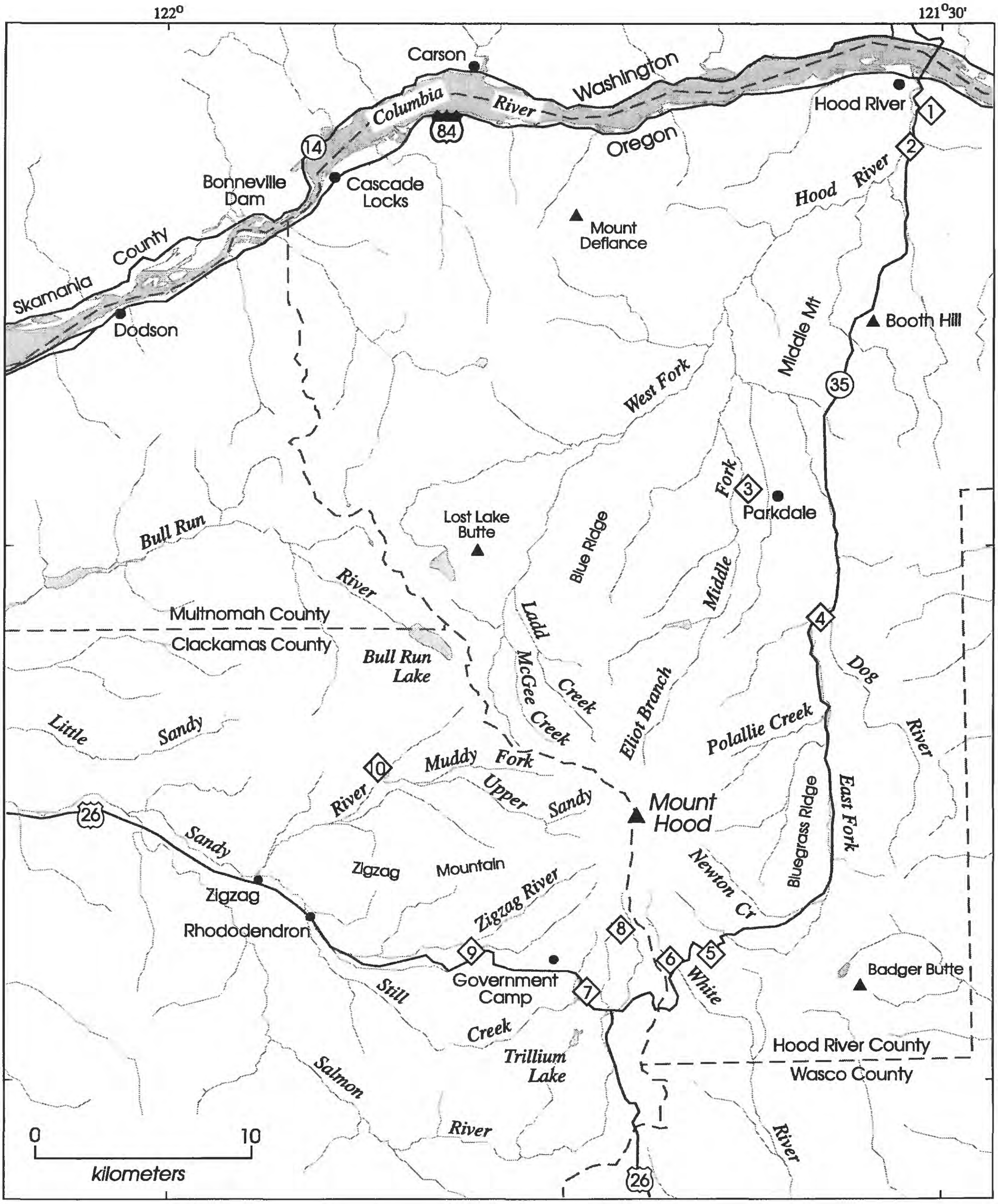


Frontispiece. Index map to geographic features and field-trip stops (diamonds).

GEOLOGIC HISTORY OF MOUNT HOOD VOLCANO, OREGON–A FIELD-TRIP GUIDEBOOK

by

W.E. Scott, C.A. Gardner, D.R. Sherrod, R.I. Tilling, M.A. Lanphere, R.M. Conrey

This guidebook was prepared for a field trip that was part of the April 1996 meeting of the Cordilleran Section of the Geological Society of America, which was held in Portland, Oregon. The trip provides participants with a broad understanding of the evolution of Mount Hood volcano from stops at several view points and at outcrops that sample the range of eruptive products and other deposits around the volcano. The trip begins in Portland, follows U.S. Interstate Highway 84 (I-84) east through the Columbia River gorge, ascends Hood River Valley southward to Mount Hood, and returns to Portland along the Sandy River valley (frontispiece). Most of the stops are on public land, but Stop 2 and parking for Stop 3 are on private land.

OVERVIEW OF MOUNT HOOD VOLCANO

Mount Hood is a chiefly andesitic volcano of Quaternary age that has been built by a succession of lava-flow and lava-dome eruptions (Wise, 1968, 1969; Crandell, 1980). Its volume of about 50 km^3 (Sherrod and Smith, 1990) is mid-sized among the major Cascade centers. The apparent lack of widespread pumiceous tephra deposits suggests that the volcano has not produced explosive plinian eruptions. From the perspective of its recent behavior, the greatest hazards posed by Mount Hood include (1) collapse of growing lava domes and generation of pyroclastic flows, which in turn melt snow and ice to form lahars that flow far down valleys; (2) the long-term adjustment of river channels to the large quantities of volcanogenic sediment dumped into valleys that head on the volcano; and (3) landslides of hydrothermally altered material from the steep upper slopes of the volcano that spawn debris avalanches and related lahars that sweep far downstream. The last class need not be associated with eruptive activity, but the triggering of the largest volume and farthest traveled events is likely heightened during periods of unrest as magma intrudes and deforms the volcano, accompanied by earthquakes and phreatic and magmatic explosions.

The Mount Hood edifice occupies a long-lived focus of andesitic volcanism that, on the basis of our initial K-Ar results, has been recurrently active for the past 1.5 m.y. (fig. 1). The cone of Mount Hood has been present for at least 0.5 m.y. By the conclusion of our work, we hope to have a well-constrained estimate of eruption rate throughout Quaternary time. The following discussion and figures summarize our current understanding of the stratigraphy and chronology of Mount Hood products. Many of our interpretations should be regarded as preliminary because numerous units remain undated and stratigraphic relations in many locations need further resolution.

ROCK AND DEPOSIT TERMINOLOGY

Nomenclature of volcanic rocks follows Le Bas and Streckeisen (1991). Boundaries are in weight percent silica: basalt <52 percent; basaltic andesite, 52 to <57 percent; andesite, 57 to <63 percent. Mount Hood lava has silica values as high as 64 percent, but for simplicity we will refer to them as andesite, not dacite. Potassium-argon ages obtained as part of our study are reported with one-sigma error.

Dome rocks are more vesicular than most lava flows. We use differences in vesicularity to interpret the genesis of volcaniclastic deposits. Pyroclastic-flow deposits at Mount Hood consist of slightly to moderately vesicular clasts, which likely originate by gravitational collapse or explosive disruption of lava domes. Pyroclastic-flow deposits of this type have also been called block-and-ash-flow and lithic pyroclastic-flow deposits. Pumice is rare at Mount Hood, and what little there is was deposited as fallout tephra.

Explanation of map units

	Alluvial and glacial deposits		Mount Hood volcano: clastic deposits	Mount Hood volcano: lava flows and domes		Lava flows and pyroclastic deposits of other vents in map area
		hol		of Old Maid eruptive period		
al	Alluvium	hoc	of Old Maid eruptive period			
gln	Till of neoglacial age	htc	of Timberline eruptive period			
		htd	Debris avalanche of Ladd Cr		bapk	Basaltic andesite of Parkdale
		hpl		of Polallie eruptive period		
		hpc	of Polallie eruptive period			
get	Till, Evans Creek advance					
		hcm	of McGee Creek			
		hs		undivided; of summit		
		hcc	of Clear Creek		bap	Basaltic andesite of The Pinnacle
		hct	of Top Spur			
		hctj	of Tilly Jane Creek		bas	Basaltic andesite of Stump Creek
		hcg	of Griswell Creek			
		hl		undivided; of main cone	hlcc	Basaltic andesite of Cloud Cap
		hlo		older units; N polarity	baN	Basaltic andesite; N polarity
		hlR		older; R polarity	sgv	Basalt to andesite of Sandy Glacier volcano
					baR	Basalt and basaltic andesite; R polarity
					Tert	Pre-Quaternary lava flows and sedimentary rocks

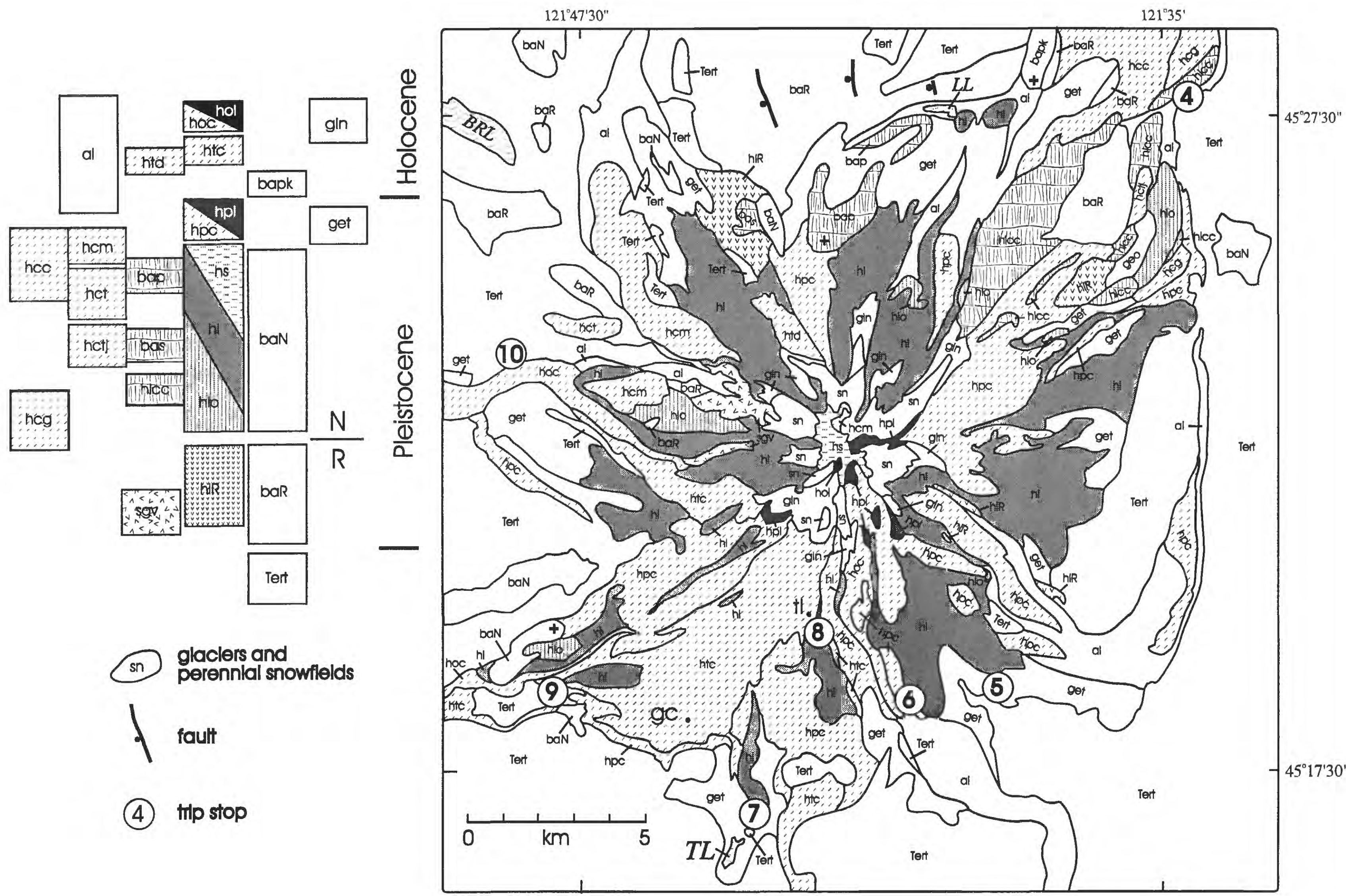


Figure 1. Generalized geologic map of Mount Hood. Sources include unpublished mapping by authors, Sherrod and Scott (1995), and Wise (1969). BRL, Bull Run Lake; LL, Laurance Lake; TL, Trillium Lake; tl, Timberline Lodge; gc, Government Camp.

RECORD BEFORE 0.5 MA

The reversely magnetized 1.3-Ma, basaltic to andesitic Sandy Glacier volcano underlies the west flank of Mount Hood (fig. 2A; **Stop 10**; Wise, 1969). Other andesite lava with reversed-polarity magnetization crops out low on the northwest (0.824 Ma) and southeast (1.471 Ma) flanks, and deep in canyon heads on the southeast flank (0.884 Ma). Normally polarized lava flows that have ages of 0.932 and 0.931 Ma crop out on the northwest and northeast flanks, respectively. Except for Sandy Glacier volcano, vent locations are unknown but must lie within a few kilometers of the present summit. These lavas are petrographically and chemically similar to younger Hood products (plots and tables in text and appendix). Most are lava flows, but the upper part of Sandy Glacier volcano is composed of a thick sequence of diamicts that were probably deposited chiefly by pyroclastic-flow (block and ash flow), lahar, and colluvial processes.

We have dated only one lava flow (0.599 Ma on southeast flank) that was emplaced between 0.5 and 0.8 Ma on Mount Hood itself. However, a vent on the east end of Zigzag Mountain produced the basaltic andesite of Devils Canyon about 0.7 Ma (Keith and others, 1985); some other basaltic andesites within 15 km southwest, northwest, and northeast of Hood may also date from this time period. Several ages in the range of 0.2–0.8 Ma were reported from one or more lava flows exposed in a small area (and limited stratigraphic range) in the Zigzag River valley (Keith and others, 1985). More precise dating by Lanphere of one of these flows and correlative flows downstream has produced fairly consistent ages that range from 0.213 to 0.235 Ma (with errors of order 10 ky). Therefore we have chosen to disregard the former ages.

500 to 200 KA

The time period from 500 to 200 ka is represented by several sequences of lava flows on the northeast, west, and southwest flanks (fig. 2B). Ages from units on the northeast flank are consistent with stratigraphic relations in the valleys of Eliot Branch and East Fork Hood River (see discussion at **Stop 4**). The extensive basaltic andesite of Cloud Cap was erupted about 424 ka from a concealed vent that lies no more than 5 km northeast of the present summit. The Cloud Cap lava overlies a Hood andesite flow that is exposed only in the vicinity of Wallalute Falls on Eliot Branch. The andesite of Wallalute Falls has an age of 492±15 ka. Another Hood andesite lava that flowed into an ancestral East Fork Hood River valley about 475 ka also underlies the basaltic andesite of Cloud Cap. The stratigraphic relation between the two pre-Cloud Cap andesite flows is unknown. Wise (1969) inferred that the Cloud Cap lava was relatively young and that it postdated the major cone-building of Mount Hood. Instead, we find that Cloud Cap lavas form a broad wedge on the northeast flank that has been buttressed by but never overtopped by Mount Hood lava. The margins and head of the wedge have been partly buried by diamicts of several ages, most recently by pyroclastic-flow and lahar deposits during the Polallie eruptive period (fig. 1), 20-13 ka, and by glacial deposits of Neoglacial age.

Several lava-flow sequences on the west flank of Mount Hood range in age from about 450 to 200 ka (fig. 2B), although stratigraphic relations among them are not demonstrable. Keith and others (1985) report several ages of 0.4-0.5 Ma obtained from a Hood andesite lava flow that overlies deposits of Sandy Glacier volcano; the weighted mean age is 0.45±0.02 Ma (Sherrod and Scott, 1995). A topographically and probably stratigraphically higher andesite flow that caps Yocum Ridge yielded an age of 303±12 ka. As mentioned previously, another lava-flow sequence that is exposed in the bottom of upper Zigzag Canyon and forms the north wall of lower Zigzag Canyon (**Mile 125.9**) is about 225 ka in age (individual ages range from 213 to 235 ka). An olivine-bearing andesite that is exposed deep in Coe Branch and Compass Creek valleys on the north flank was thought by Wise (1968, 1969) to be perhaps one of the oldest lavas on the volcano; however, although it is deeply buried, its age of 225±17 ka indicates that it is relatively young. An overlying sequence of lavas appears to us quite young because surface forms such as lobes and levees, although modified by glacial erosion, are reasonably well preserved. Such an interpretation is consistent with an age of 86±10 ka for one of the lower flows in the overlying sequence (fig. 2C).

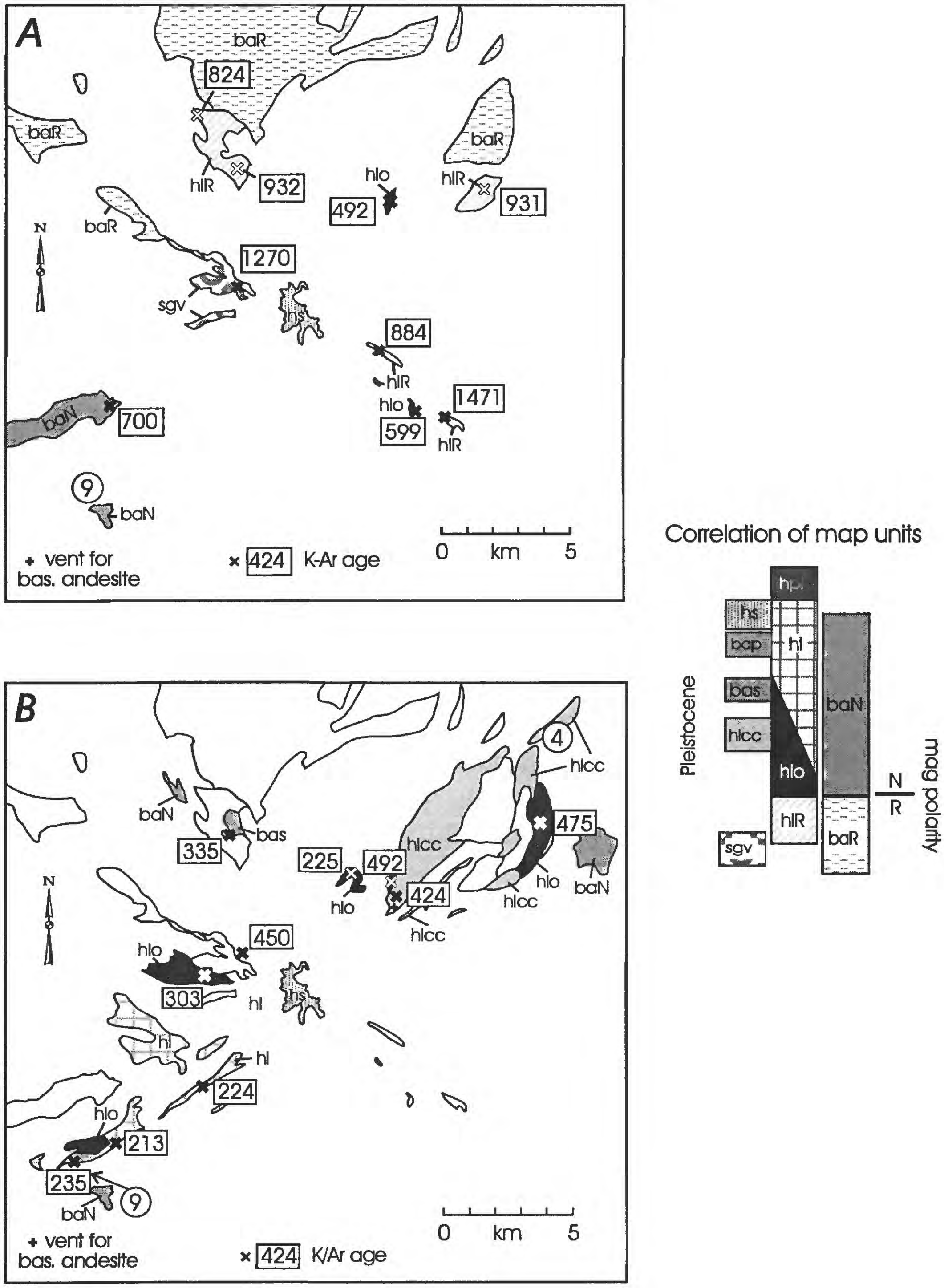


*Figure 2. Time-sequential maps showing lava flows and domes of Mount Hood and surrounding vents and radiometric ages. **A**, units older than 500 ka. **B**; units 500–200 ka. Unconsolidated deposits not shown. Outline of patterned units are carried to successively younger maps; unit hs, Mount Hood near-summit lava domes, flows, and breccia, is shown on all maps. Potassium-argon ages from Lanphere, Wise (1969), Keith and others (1985), and Sherrod and Scott (1995); see text for sources of ^{14}C ages. Circled numbers are road log stops. Figure 2C on next page.*

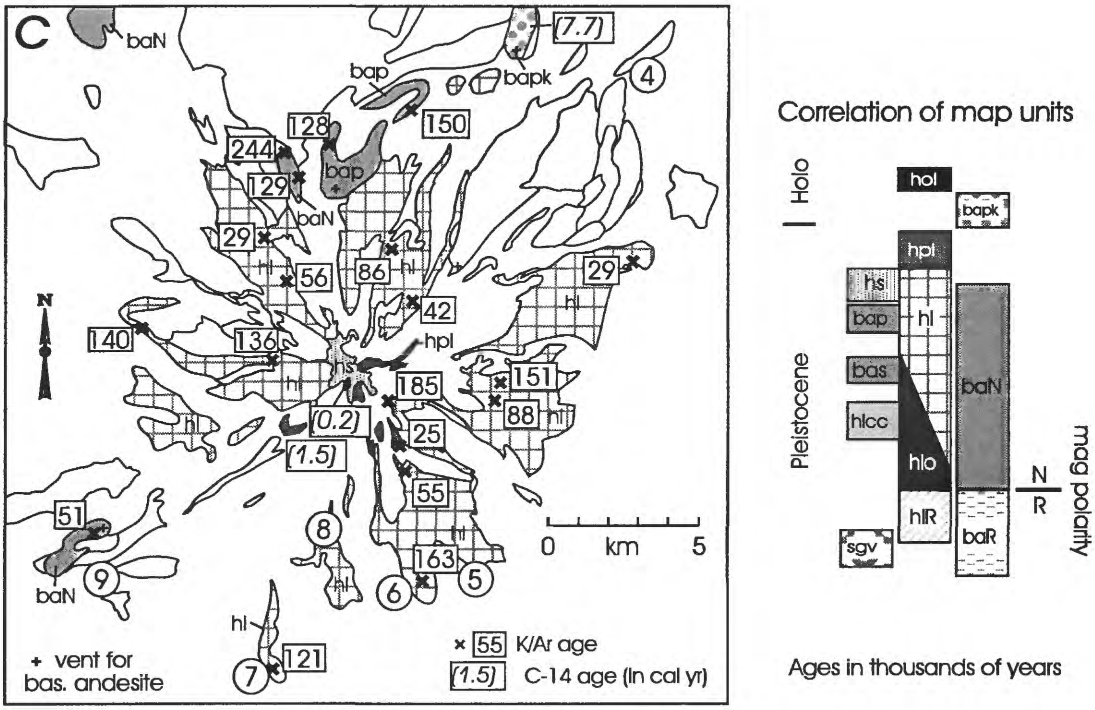


Figure 2, continued. C, Units younger than 200 ka. Other symbols explained on previous page. Age of 1.5 ka is for diamicts of Timberline eruptive period, and corresponds to a probable predecessor of Crater Rock dome.

200 to 50 KA

Lava flows younger than 200 ka have been mapped on most flanks of the volcano (fig. 2C), and we think that several additional sequences with ages pending will also date from this time period. A glacially eroded scoria cone, The Pinnacle, and its basaltic andesite lava flows were emplaced on the north flank about 128 ka (see discussion at **Stop 4**). A similar age of 150±20 ka was reported by Keith and others (1985) (age recalculated as 140±20 ka in Sherrod and Scott, 1995). Since Pinnacle time, the only other basaltic andesite eruptions that occurred in the Mount Hood region were the 7.7-ka basaltic andesite of Parkdale (**Mile 91.3**) and, possibly, Lost Lake Butte, a small shield whose lava apron edges into the northwest corner of the Mount Hood map area. **Stop 7** features a 121-ka, south-flank andesite flow. Several substantial lava-flow sequences yield ages younger than 100 ka. **Mile 93.3** describes the 29-ka andesite of Tamanawas Falls on the east flank. However, the relatively large errors in the <100-ka ages have prevented us from verifying the units' detailed succession of emplacement.

SINCE 50 KA

Most volcanic activity in the past 50 kyr has consisted of the growth and collapse of lava domes—which fed numerous pyroclastic flows—and the eruption of stubby lava flows on the summit and upper flanks (table 1). Probably also during this time period, somewhat more voluminous sequences of lava flows (Tamanawas Falls and Cathedral Ridge) were emplaced on the lower flanks. However, as the dominant activity was generation of pyroclastic flows, two fundamental questions we would like to answer at Mount Hood are: (1) were lava-dome processes unimportant in the earlier history of the volcano and (2) if so, then what caused the change to an eruptive pattern dominated by dome processes?

Substantial fans and fills of volcanic diamicts (primarily deposits of pyroclastic flows and lahars) occur on all flanks of Mount Hood. The late Holocene deposits primarily of the Timberline eruptive period form the extensive fan that gives the southwest flank its distinctive morphology (**Stops 6, 7, 8, and 10**). These deposits are related to dome extrusion at or near the site of Crater Rock, the youngest dome on the volcano. Several fan remnants of older eruptive periods are preserved downslope of thick, near-summit lava masses that we interpret as lava domes. The lava mass above Cooper Spur on the northeast flank and Steel Cliff (**Stop 7**) on the southeast flank are the most striking examples of these domes. Both probably date from the Polallie eruptive period, whose eruptions accompanied and immediately postdated the last major Pleistocene glaciation in the region, which we call the Evans Creek advance. The Evans Creek is not dated locally, but it probably culminated about 24.5 ka (Porter and others, 1983).

Table 1. Notable geologic events since 50 ka near Mount Hood; Hood eruptions in boldface.

Date or age	***Event***	***Deposits***
A.D.1859, 1865, 1907?	**Minor explosive eruptions**	Scattered pumice
late 19th century	Late neoglacial advance	Prominent, sharp-crested moraines
late 18th century	**Old Maid eruptive period**	Lava dome, pyroclastic-flow and lahar deposits, tephra
about 500 yr ago	Debris flows in Zigzag River	Debris-flow deposits
1 ka	Debris flows in upper Sandy River	Debris-flow deposits
1.5 ka	**Timberline eruptive period**	Lava dome, pyroclastic-flow and lahar deposits, tephra
7.7 ka	**Eruptions from vent near Parkdale;** also Mazama ashfall	Basaltic andesite of Parkdale lava flow; about 5 cm Mazama ash
11 to 20 ka	Waning phases of Evans Creek glaciation	Moraines
13 to 20 ka	**Polallie eruptive period**	Lava domes, pyroclastic-flow and lahar deposits, tephra
20-25 ka	Maximum of Evans Creek glaciation	Belts of moraines in most valleys
20-30 ka	**Dome eruptions**	Lava domes, pyroclastic-flow and lahar deposits
30(?) to 50(?) ka	**Hood lava-flow eruptions**	Andesite lava flows of Cathedral Ridge and Tamanawas Falls

A thick sequence of diamicts are preserved as fill remnants along the Muddy Fork of the Sandy River and form a large ridge on the lower northwest flank between Elk and McGee Creeks. The deposits in Muddy Fork lie about 350 m above the present channel. Crandell (1980) surmised that the fill was deposited in a valley that was partly occupied by a glacier, and that the entire canyon was never totally filled with diamicts. But the part of the fill that extends down McGee Creek clearly was deposited in a broad valley cut in Tertiary rocks. Subsequently, moraines of Evans Creek age were deposited within the new valley cut along the contact between the diamicts and the Tertiary and Hood-related Quaternary lavas that make up the east valley wall. Thus, the fill in both valleys may have been deposited in nearly ice-free conditions. If so, much of a once thick and extensive fill has been eroded from the Muddy Fork valley. Such poor preservation of diamicts suggests that similar deposits were formed repeatedly in Mount Hood's past but were largely eroded and therefore are poorly represented in the geologic record. If future eruptions were to send lava flows down the Muddy Fork and fill it to a depth of several hundred meters, subsequent incision would likely occur along the valley margins where the new flows were in contact with the old valley wall formed in diamicts. The diamicts would no doubt be preferentially eroded as canyon cutting progressed and would likely not be preserved. We have found a few localities where diamicts are preserved below lava flows that now form ridges, but such relations are uncommon. Perhaps lava-dome processes were active in the past, but the evidence of such events has a low probability of preservation, whereas intracanyon lava-flow sequences tend to be well preserved as major ridges on the lower flanks.

HISTORICAL RECORD

Native American legends abound with descriptions of the brothers Wy'east (Hood) and Pahto (Adams) battling for the fair La-wa-la-clough (St. Helens). Behaviors attributed to Wy'east (as paraphrased from Harris' (1988) summary of Native American lore) include hurtling of hot rocks from gaping holes, sending forth streams of liquid fire, loss of formerly high summits, and choking of valleys with rocks. These are fair descriptions of Mount Hood's reconstructed activity over the past two millennia.

The most recent eruptive period at Mount Hood, the Old Maid eruptive period (table 1), occurred at about the time that U.S. and European parties were exploring the Pacific Northwest coast in the late 18th century. The first of them to describe the mountain was British naval Lieutenant W.E. Broughton, the leader of a party sent up the Columbia River in October 1792 from Captain George Vancouver's expedition to bolster British claims to the northwest. He named the mountain for A.A. Hood, a famous British naval officer. Broughton reached as far upstream as the mouth of the Sandy River and noted a shallow bar extending across the Columbia, but his log reveals nothing about possible eruptive activity. Lewis and Clark visited the mouth of the Sandy River in November 1805 and April 1806, noted its similarity to the braided Platte River of the High Plains, and named it the Quicksand River. Their description is unlike the present gravel-bed river and suggests that the river was responding to an excessive sediment load imposed by volcaniclastic deposits emplaced during Old Maid eruptions. They also describe a large bar between two distributary channels that forces the Columbia into a narrow channel against the north side of the valley.

Early settlers reported eruptive activity in 1859 and 1865 (summarized in Harris, 1988). Witnesses refer to fire, smoke, flying rocks, and voluminous steaming, which may well describe modest explosive eruptions from the cooling conduit and dome (Crater Rock) active decades earlier during the Old Maid eruptive period. Crandell (1980) thought that a scattering of pumice on the south and east flanks may have been produced by the 1859 or 1865 event. We have found no other deposits that can be tied unequivocally to either of these 19th century events.

In 1907, a U.S. Geological Survey topographer described dense steaming around Crater Rock accompanied by nighttime glow. Mild fumarolic activity has continued throughout this century, mostly in areas around Crater Rock.

Earthquakes occur sporadically at Mount Hood, typically as short-lived swarms of small events (≤magnitude 3.5) that locate chiefly on the south flank and below the summit at depths of less than 11 km (fig. 3; following information from USGS and University of Washington Geophysics Program). One to several swarms per year have been recorded since the seismic system was upgraded in 1980. A typical swarm occurred in summer 1980; a magnitude-2.9 event was followed by seven aftershocks ranging in magnitude from 1.6 to 2.8. A swarm in

February 1990 had 30 earthquakes, all smaller than M-1.3. Later that year a magnitude-3.5 earthquake was followed by 12 aftershocks. Focal mechanism for the M-3.5 event shows dominantly dip slip with slight component of lateral slip (nodal planes N30E, 43SE, minor left-lateral; and N30W, 60SW, minor right-lateral). Recently, on the morning of April 7, 1996, events of magnitude 3.0 and 2.4 occurred at a depth of 7 km below the summit.

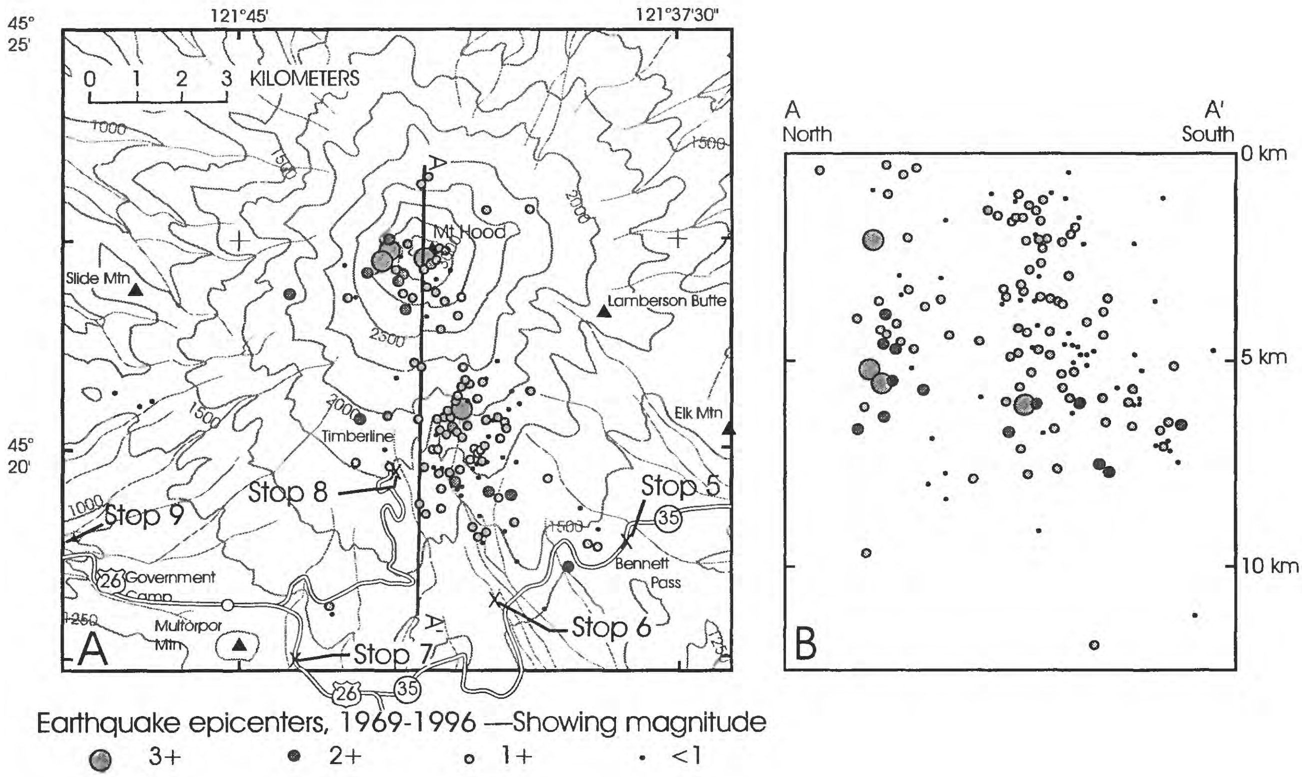


Figure 3. ***A****, Map showing earthquake epicenters in the Mount Hood area since 1969.* ***B****, Cross section through A-A' showing focal points projected onto plane of section. Earthquake data from U.S. Geological Survey and University of Washington Geophysics Program. Base map from U.S. Geological Survey, Mount Hood quadrangle, 1983. Contour interval, 250 m.*

FIELD GUIDE

Cumulative mileage is listed at left, and interval mileages are given in boldface at the end of each entry. Numerous mileage check points are available.

Mileage

0 Depart Red Lion Hotel (Lloyd Center) and head toward U.S. Interstate 84 (I-84) eastbound. Turn left (south) on NE 9th; turn left on Lloyd Blvd; right on NE 12th and cross over I-84; turn left onto Irving and left at NE 16th. **0.8**

0.8 Merge onto I-84 east. **4.0**

4.8 Mount Hood at 12:00. On the left is Rocky Butte, an early Pleistocene basaltic andesite volcano of the Boring Lava. Age is 1.30±0.14 Ma (K-Ar, whole rock; E.H. McKee, written commun., 1994); reversed-polarity thermoremanent magnetization (TRM). SiO_2 content, about 54 percent.

During peak flows of the latest Pleistocene Missoula floods, high velocities and turbulence induced by the submerged butte eroded huge scour pits on its upstream side; downstream, a gravel bars many kilometers long were deposited. I-84 curves around the south and east sides of butte in scour pits. **10.3**

15.1 Cross Sandy River at Troutdale (fig. 4). Sandy River drains the southwest and west flanks of Mount Hood, 90 km distant. Lahar deposits of Holocene age are exposed in the high bank on the west side of the river (now locally covered with riprap) and underlie much of the area between I-84 and the Columbia River. Sedimentation related to Holocene eruptions at Mount Hood has constructed a broad fan at the mouth of the Sandy, pushing Columbia River to the north side of its valley.

Broughton Bluff, the bluff east of Sandy River, is a lava flow from Chamberlain Hill, an eroded cinder cone or small shield located a short distance east. Age is 1.53±0.39 Ma (K-Ar, whole rock; Conrey and others, 1996b); reversed-polarity TRM. SiO_2 content, about 54 percent. Chamberlain Hill lava overlies sandstone and conglomerate of the the upper Miocene to lower Pleistocene Troutdale Formation.

Enter Columbia River Gorge National Scenic Area. **6.1**

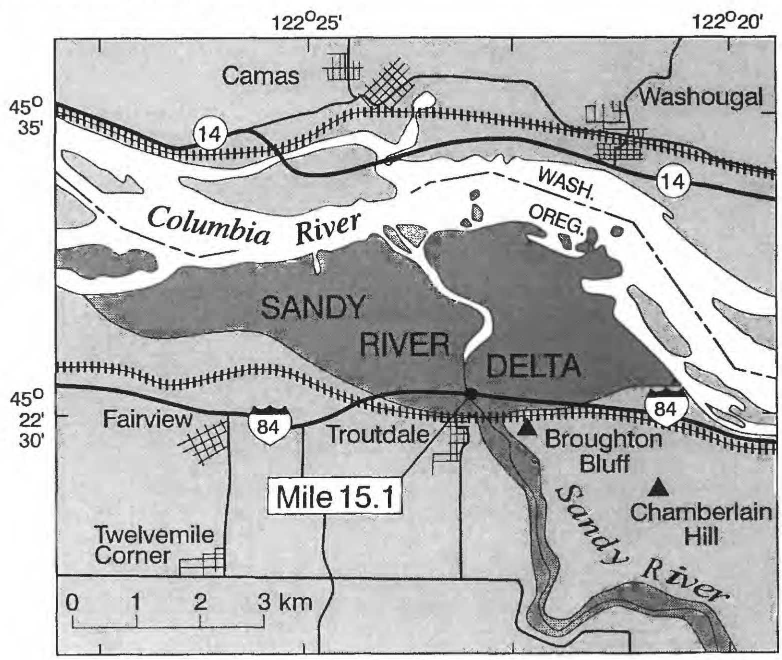


*Figure 4. Sandy River delta at mouth of Sandy River (**mile 15.1**). Shown in dark shading is generalized extent of debris-flow deposits emplaced during Timberline and Old Maid eruptive periods at Mount Hood ~1,500 and ~200 yr ago, respectively. Mount Hood lies 90 km east-southeast from the delta. Base map from U.S. Geological Survey, Vancouver quadrangle, 1979.*

21.2 Ahead on left, Rooster Rock is a slide block of Priest Rapids flow, a part of the Columbia River Basalt Group; the slide headwall forms the Crown Point cliffs, on right (Waters, 1973). **7.8**

29.0 Ahead on right, 183-m-high Multnomah Falls is one of the most visited tourist attractions in Oregon. **4.0**

33.0 Westernmost of several bouldery debris-flow deposits near Dodson that were emplaced during early February 1996 storm (fig. 5). I-84 was closed for many days, and the Union Pacific tracks were severely damaged. **0.9**

33.9 Easternmost debris-flow deposit near Dodson. **0.4**

34.3 Beacon Rock, on Washington side of river, is early Pleistocene volcanic neck. **3.4**

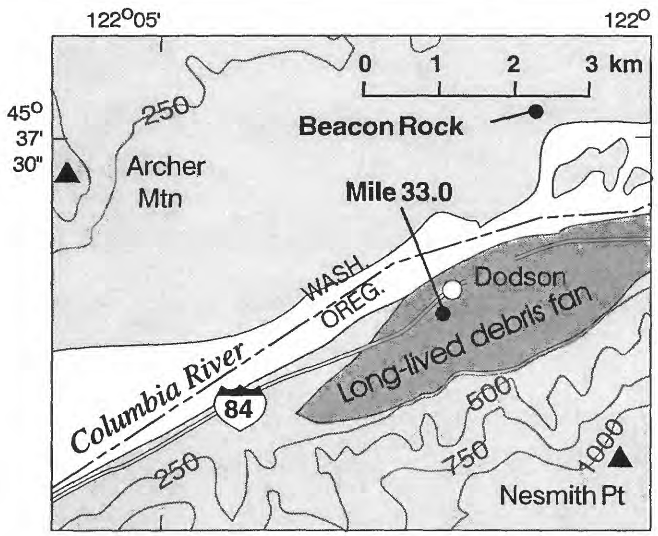


*Figure 5. Columbia River gorge near Dodson (**mile 33.0**). Geomorphic form of debris fan indicates a lengthy history of slope failure along this reach of Columbia's south shore. Debris flows in February 1996 that were generated by landslides along canyon walls near Nesmith Point deposited a new layer of boulders and sand on part of the fan. Also on map is Beacon Rock, a volcanic neck on the Washington side of Columbia River (**mile 34.3**). Base from U.S. Geological Survey, Vancouver quadrangle, 1979. Contour interval 250 m. interval 250 m.*

Beacon Rock

Beacon Rock is a basaltic andesite volcanic neck or plug (SiO_2 about 54 percent), as first suggested by Ira Williams (1916). Chemically it is similar to lava erupted from Chamberlain Hill (~30 km west at confluence of Sandy and Columbia Rivers). Lava flows of similar composition are exposed in the Beacon Rock picnic grounds (P.E. Hammond, oral commun., 1994), establishing the base of the Beacon Rock volcano (150 m elev.) and extent of downcutting since Beacon Rock time—130 m or more. An attempt by Rick Conrey to obtain an age from Beacon Rock failed when no radiogenic gas was obtained, probably owing to relatively young age of the unit and high concentration of atmospheric argon in the sample.

Uplift along the axis of the Columbia River gorge began well before Beacon Rock time. Pliocene lava flows cap the south wall of the Columbia River gorge, but the base of the Pliocene sequence, which now lies at about 750 m elevation across the axis of the gorge, includes pillowed lava and abundant palagonite (Williams, 1916), almost certainly an indication that the lava was encountering the floodplain of the Columbia River when emplaced ~3 Ma (ages in Conrey and others, 1996a, b). The amount of uplift since that time, on the order of 500 m, can be reckoned by considering that the Portland reach of the river was within or nearly in tidewater influence, owing to the proximity of the marine strandline at the present Oregon coast. The buildup of Pliocene lava forced the Columbia River northward, where it eroded a new channel near where the Columbia River Basalt Group laps out against older volcanic and sedimentary strata (Tolan and Beeson, 1984).

Increased understanding of Beacon Rock lava and its age may better constrain the uplift history by virtue of a bracketing youngest age and may provide additional insight into the history of downcutting by the Columbia River.

37.7 Bonneville Navigation Lock and Dam was completed in 1938, a second powerhouse began operation in 1982, and a new larger lock was opened in 1993 (fig. 6). The pool behind the dam is at an altitude of about 21 m above sea level and drowns the natural rapids known as the "Cascades of the Columbia," from which the Cascade Range takes its name. Roadcuts expose lahar deposits of the lower Miocene Eagle Creek Formation, which underlies the Columbia River Basalt Group (CRBG). Great cliffs of CRBG and Eagle Creek Formation high on the north side of the valley mark the head of the huge Bonneville landslide, a complex landslide that covers about 35 km^2 (Wise, 1961; Minor, 1984). According to Waters (1973), the main failure plane is the south-dipping contact at the base of the relatively permeable Eagle Creek Formation, which lies on a thick impermeable clay saprolite developed in the underlying Oligocene Ohanapecosh Formation. Movement 500 to 600 years ago temporarily dammed the Columbia to an altitude of about 75 m, giving rise to the Native American legend of the "Bridge of the Gods." The river breached the dam and created a flood that rose at least 30 m above typical low-water level at the Sandy River confluence near Troutdale (O'Connor and Waitt, 1995; O'Connor and others, 1996). **5.0**

42.7 Town of Cascade Locks. **2.6**

45.3 On left, quarry in diorite at Government Cove. **2.6**

47.9 Across the Columbia, Wind Mountain is a ~6-Ma quartz diorite intrusion (Korosec, 1987). Another of the great gorge landslides wraps around Wind Mountain and forms a narrow reach of the Columbia upstream. **2.7**

50.6 Rounding Shellrock Mountain, the southern, across-Columbia continuation of Wind Mountain. Age from Shellrock Mountain is 5.7±0.6 Ma (K-Ar, whole rock; Korosec, 1987). **6.4**

57.0 Mitchell Point. **1.8**

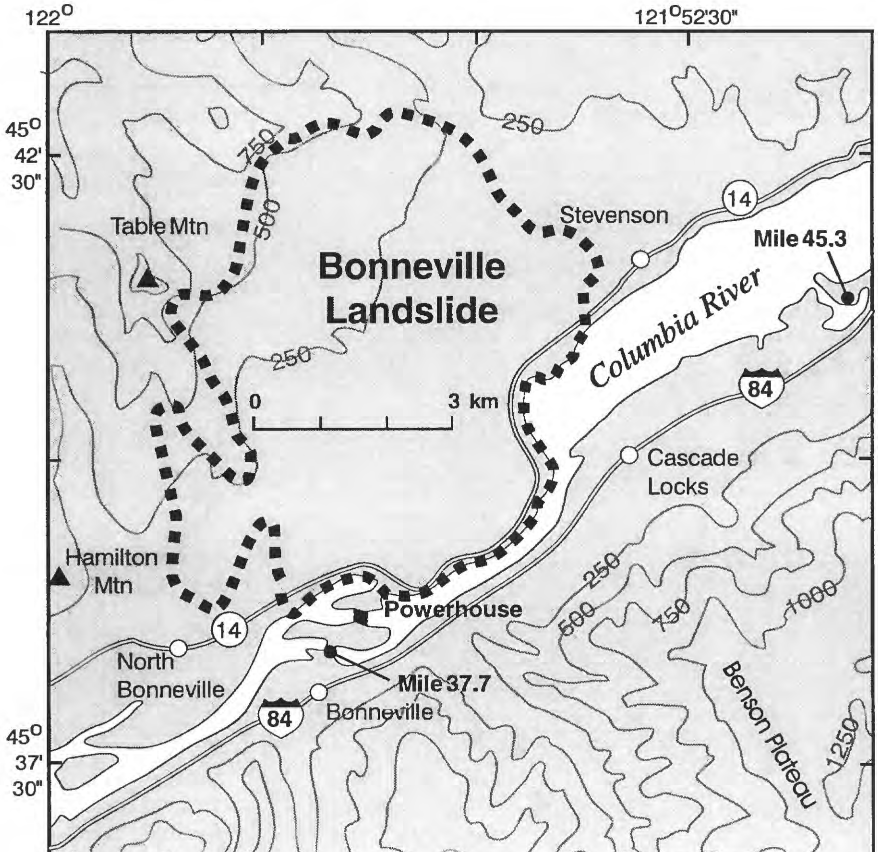


*Figure 6. Bonneville landslide, Columbia River gorge (**mile 37.7**). The landslide has temporarily dammed the Columbia in the past, giving rise to Native American legend of the Bridge of the Gods. Base map from U.S. Geological Survey, Hood River quadrangle, 1982. Contour interval 250 m.*

58.8 Roadcuts expose pillow lavas of Pliocene age. These exposures are part of a pillow-palagonite sequence that ascends westward along the base of the capping Pliocene lava flows in the Columbia River gorge. The pillows commonly are aligned, as is typical of foreset palagonite complexes built into water. A K-Ar age of 3.53±0.08 Ma (weighted mean of two ages) was obtained from the base of this sequence at Perham Creek, about 5.5 km southwest (Anderson, 1987; Conrey and others, 1996a). **3.8**

62.6 Cross Hood River, which drains the east and north flanks of Mount Hood, and immediately exit I-84 to southbound Oregon State Highway 35 (OR 35). **0.7**

63.3 Stop sign at OR 35 and U.S. 30; continue straight (south) on OR 35; roadcuts ahead on left are in CRBG (Frenchman Springs Member of Wanapum Basalt). **0.4**

63.7 Turn left onto scenic tour route and follow signs to Panorama Point. **1.5**

65.2 Turn right into Panorama Point County Park; continue to parking lot at top of hill. Restrooms are available here. **0.4**

Stop 1. Panorama Point overlook of Cascade Range, Mount Hood, and Hood River Valley

On a clear day, the view of Mount Hood is excellent (fig. 7). Below and east of the summit lies Cooper Spur, a remnant of the broad fan of pyroclastic-flow and lahar deposits of the Polallie eruptive period that originated from near-summit lava domes. Ridges radiating outward from the lower flanks are underlain chiefly by andesite and some basaltic andesite lava flows. The steep rugged north face contrasts markedly with the smooth fan-aproned south face that will be visible from later stops. The contrast results from Holocene eruptive activity, primarily lava-dome growth and collapse, that has been restricted to the south face.

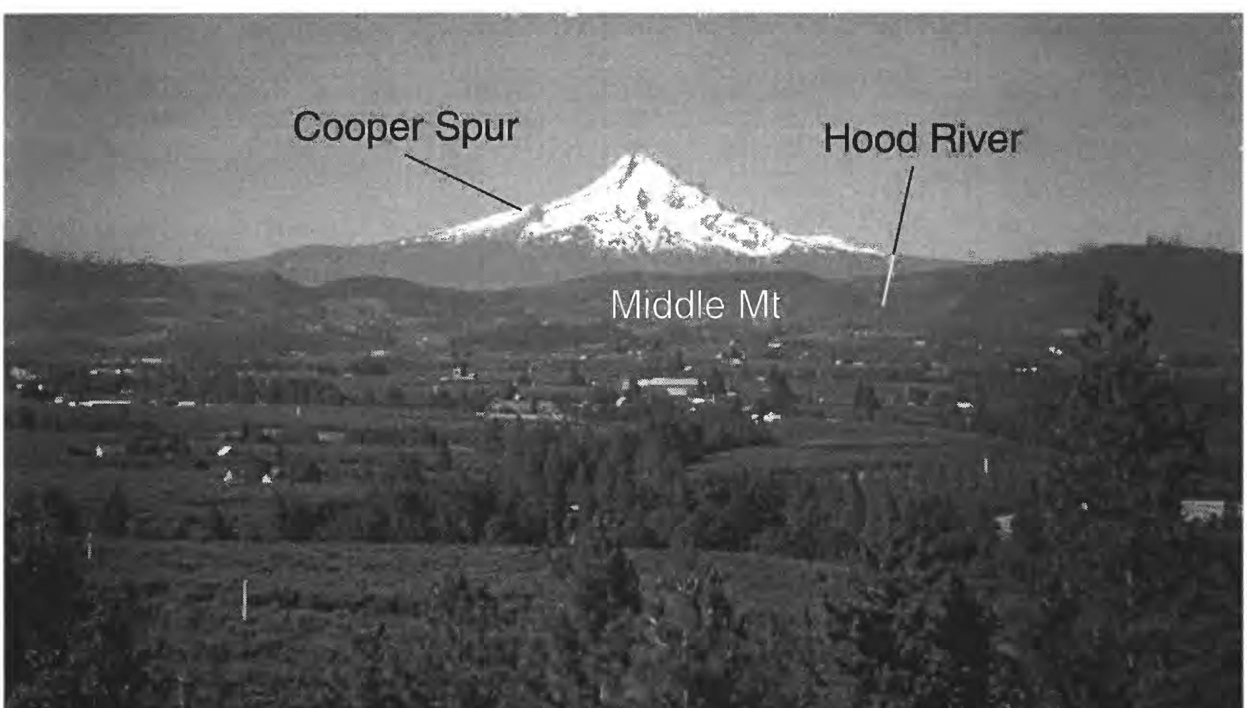


Figure 7. Photograph of Hood River Valley and Mount Hood from Panorama Point County Park.

The Hood River Valley is an incompletely understood structural depression extending north into Washington and southward toward Mount Hood. The valley's east margin is a series of anastomosing normal-slip faults that displace the Columbia River Basalt Group by about 550 m in the area of Panorama Point. Panorama Point itself is a promontory of the Wanapum Basalt Formation, but the hills to the east in the Hood River escarpment are underlain by the Grande Ronde Basalt, a stratigraphically lower formation (also in CRBG) displaced upward by the faults.

The valley extends north a few kilometers into Washington, although an early Pleistocene shield volcano, Underwood Mountain, fills much of it there. A lava from Underwood Mountain has a K-Ar age of 0.85±0.02 Ma (K-Ar, whole rock; Hammond and Korosec, 1983).

The west side of the valley slopes gently upward toward the Cascade Range summit. Pliocene and Pleistocene lava flows blanket the CRBG on most of the visible upland surfaces. The valley floor is mantled by middle Pleistocene alluvial deposits of the Hood River, including at least one lahar deposit derived from Mount Hood (**Stop 2**). The lahar probably originated from a large debris avalanche on the upper flanks of either the present or an ancestral cone. Missoula flood deposits form a late Pleistocene capping of sand and silt as thick as 30 m in some parts of Hood River Valley.

Mount Hood lies 40 km south-southwest of Panorama Point. Much closer (14 km) and nearly in line with it is Middle Mountain, which is underlain by lava of the CRBG. The field trip route passes through the gap east of Middle Mountain, whereas the Hood River wraps around its west side. Cinder cones of latest Pliocene or early Pleistocene age dot the surface between here and there: Van Horn Butte, Lenz Butte, and several cones at Booth Hill. Associated lava flows are exposed locally. A lava from Booth Hill (**Mile 71.3**) has a K-Ar age of 2.07±0.60 Ma (whole-rock; Conrey and others, 1996a). Behind Middle Mountain but beyond this view is the Upper Hood River Valley. The geomorphic and structural setting of the two valleys is similar, but structural relief is more than 600 m in the Upper Hood River Valley.

Middle Mountain is enigmatic in its structural setting. Faults in the area are mapped as steep to vertical normal faults. But Middle Mountain may have been part of a pre-Pliocene northeast-trending fold system. These folds, many of which have reverse faults on one or both limbs, are better preserved to the east on the Columbia Plain. Pliocene or Quaternary extensional faults have been superimposed on an older faulted and folded middle Miocene terrane (Swanson and other, 1981; Korosec, 1987).

65.6 Turn right back onto tour route. **0.5**

66.1 Turn right onto Whiskey Creek Drive. As road descends, roadcuts on the right expose (poorly) deposits of the Hood River lahar overlying a clayey reddish-brown soil developed in colluvium derived from CRBG. **0.6**

66.7 Turn left onto OR 35; cross under Mount Hood Scenic Railroad overpass; pull onto wide gravel shoulder immediately on right. The land along the tracks is owned by Mount Hood Scenic Railroad of Hood River, which operates tourist and freight trains and also maintenance vehicles on the tracks. There is little room for both people and trains, so check with the railroad before visiting this site. **4.6**

Stop 2. Hood River lahar

Cuts along railroad grade below OR 35 expose deposits of a lahar from Mount Hood that swept through the inner Hood River valley, crossed the Columbia River valley, and flowed at least 4 km **up** the White Salmon River valley on the Washington side (Vallance, in press). The White Salmon drains Mount Adams volcano, but the presence of hornblende-phyric andesite clasts indicates that Mount Hood, rather than Mount Adams, is the source of this deposit. The lahar reached an altitude here at Stop 2 of at least 120 m (400 feet). At the mouth of the White Salmon valley, the deposits are found as high as 105 m (350 feet) altitude, which suggests the lahar filled the Columbia valley, at least temporarily, more than 100 m (330 feet) deep. The massive deposits are locally as thick as 40 m and contain wood fragments that have radiocarbon ages >38 ka. Along this cut, the lahar deposit has a thickness of about 20 m (no more than half is exposed in any single cut). It lies on alluvium of Hood River that contains well-rounded boulders of basalt and andesite of Tertiary and Quaternary age. The lahar deposit is overlain by poorly exposed sandy Missoula-flood deposits. Features of lahar deposits and other clastic deposits are compared in table 2.

The Hood River lahar contains clasts of basalt and andesite, some of which are from sources other than Mount Hood. By the time it had reached this site 45 km downstream from the volcano, the lahar had incorported material from other deposits along the valley, including large rounded boulders from the underlying alluvium. A substantial fraction of fresh, subangular to subrounded, dense to vesicular, pyroxene and pyroxene-hornblende andesite clasts in the deposit are thought to originate from Mount Hood on the basis of mineralogy, fresh appearance, and chemistry (appendix 1, No. 10). Intraclasts as large as several meters in diameter are composed of volcanic diamict. From paleomagnetic evidence, Vallance (in press) showed that some of these intraclasts are composed of pyroclastic-flow deposits.

The matrix of the lahar deposit is slightly cohesive, yellowish- to brownish-gray, muddy sand that contains about 7–9 percent clay-size fraction of plagioclase, smectite, and, locally, kaolinite (Vallance, in press). The presence of altered andesite fragments and smectite indicates that this lahar contains abundant hydrothermally altered rock. Such lahars are thought to originate as avalanches of weakened, altered, water-rich masses from the upper flanks of volcanoes (K. Scott and others, 1995). The substantial clay fraction in cohesive lahars retards settling of coarse particles and decreases the miscibility with streamflow, which prevent deposition of sediment and dilution of the lahar. The result is a flow that can travel long distances as a high-concentration debris flow and not transform into lower concentration flows that are prone to more rapid attenuation downstream.

Table 2. Characteristics used to distinguish diamicts of various origins at Mount Hood; most useful are in bold.

Feature / Origin	Debris avalanche	Lahar	Pyroclastic flow	Till
Surface morphology	**hummocky, closed depressions**	flat or gently crowned; veneer	flat; veneer	**steep-sided to rounded ridges;** hummocky
Lithology	mono- and heterolithic	mono- and heterolithic	**monolithic**	chiefly heterolithic
Clast shape and character	mostly angular; some clasts hydrothermally altered	angular to rounded	angular to subrounded; **prismatic jointing common**	angular to subrounded; **faceted and striated clasts; pentagonal shapes common**
Wood fragments	uncharred	uncharred and charred	**charred**	none found; should be uncharred
Matrix	may be clayey	**clayey (cohesive)** to sandy (noncohesive)	sandy	**silty and locally compact**
Pink top to deposit	no	rare	**some**	no
Thermoremanent magnetization	no	generally no, but can be if emplaced hot	**yes**	no
Fluid-escape pipes	no	rare	**some**	no

Deposits of the Hood River lahar are found near present river level and reached some unknown altitude above the exposures along Whiskey Creek that we just passed. If the lahar flowed down a valley of similar size to the current one, the minimum cross-sectional area of the flow would have been about 23,000 m^2. An empirical relationship developed by R.M. Iverson (W. Scott and others, 1995) that relates cross-sectional area to volume for lahars generated by debris avalanches suggests that the volume was at least 0.3 km^3. For comparison, the 1980 debris avalanche at Mount St. Helens had a volume of 2.3 km^3 (Voight and others, 1981). The 500-yr-old Electron Mudflow and 5,000-yr-old Osceola Mudflow at Mount Rainier had estimated volumes of about 0.26 and 3 km^3, respectively (K. Scott and others, 1995).

71.3 Odell junction; basalt of late Pliocene or early Pleistocene age (2.07±0.60 Ma, Conrey and others, 1996a) cropping out on left was probably erupted from Booth Hill cinder cone 3.5 km to south. Continue on OR 35. Middle Mountain, the hills ahead west of the highway, is formed of CRBG and separates Hood River Valley from Upper Hood River Valley. **4.3**

75.6 Enter Upper Hood River Valley. The valley is underlain by pyroclastic and epiclastic sediment derived from Mount Hood and its predecessors. Thickness is at least 50 m (as indicated by well logs). **2.4**

78.0 Turn right at junction by Mount Hood Store onto Cooper Spur Road and head toward Parkdale. **0.9**

78.9 Cross East Fork Hood River, which drains the east flank of Mount Hood. Early February 1996 floods nearly equaled December 1964 flood of record; note shredded trees and brush and fresh gravel deposits. Climb grade that exposes a sequence of Mount Hood lahar deposits of unknown age (but probably older than 100 ka on basis of degree of soil formation). **0.9**

79.8 Junction; turn right on Baseline Road toward Parkdale. **0.6**

80.4 Intersection at west edge of Parkdale with highway to Dee; continue straight ahead on Baseline. **0.7**

81.1 Turn right on Old Parkdale Road. **0.2**

81.3 Turn left on Red Hill Road. Blocky basaltic andesite of Parkdale lava flow ahead in valley of Middle Fork Hood River. Age is 6,890^{14}C yr B.P. (Harris, 1973); calibrated age is 7.7 ka. Vent for 9-km-long basaltic andesite and andesite (55–58 percent SiO_2) flow is 11.5 km north-northeast of summit of Mount Hood. **0.6**

81.9 Turn right into driveway to small hydroelectric plant of Middle Fork Irrigation District. Park and walk short distance back east to roadcut on south side of Red Hill Road. **0.6**

Stop 3. Lahar deposits of Polallie eruptive period

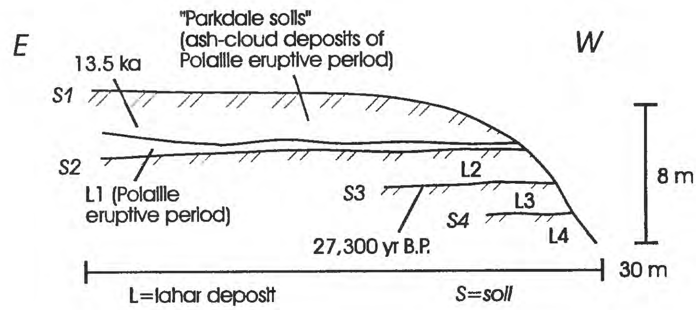
Roadcut exposes a sequence of four lahar deposits separated by buried soils below a thick mantle of massive to locally bedded silt and sand (fig. 8). The mantling fine-grained deposit was interpreted by Crandell (1980) as ash-cloud deposits related to dome-collapse pyroclastic flows of the Polallie eruptive period. Granule-size, roughly spherical aggregates of ash-size particles in the deposit are probably accretionary lapilli. At this (?) roadcut, Harris (1973) obtained a radiocarbon age of 12,270±190 yr B.P. (calibrated age about 13.5 ka) on charcoal from a zone 1.7-2.1 m below the top of the mantling deposit (which he referred to as Parkdale soils).

The upper lahar deposit (L1), best exposed at the east end of the outcrop, directly underlies the ash-cloud deposit. There is no evidence of an intervening period of weathering. It contains abundant pebbles, cobbles, and small boulders, many of which have the vesicular, coarsely and abundantly porphyritic texture of typical dome lava. The matrix is friable, gray, and sandy and contains little clay in contrast to the cohesive lahar deposit at the last stop. We infer that this lahar originated when a dome-collapse pyroclastic flow swept across snow and ice on the volcano, produced copious meltwater, and generated hot slurries of pyroclastic debris and water. The slurries could have formed either by admixing of meltwater into the pyroclastic flow or by meltwater entraining previously deposited pyroclastic debris. Either origin inhibits production or incorporation of much clay. The lack of clay in these noncohesive lahars allows transformation from debris flow to hyperconcentrated stream flow as coarse material is deposited and streamflow is incorporated into the flow. Such flows attenuate rapidly and transform to muddy, bedload-transporting floods as sediment concentration decreases downstream.

Like the upper lahar deposit, the lowest lahar deposit (L4), best exposed on the west end of the outcrop, also has a large component of dome lava. We infer that it had a similar origin. The base of unit L4 is clast rich; the upper part contains few coarse clasts and was probably deposited by hyperconcentrated flow. These features demonstrate the textural variability common in noncohesive lahars.

The middle two units (L2 and L3) are also noncohesive lahar deposits, but they are composed mostly of dense Mount Hood andesite clasts and contain little vesicular dome lava. They also contain clasts of basaltic andesite from vents on the flanks of Mount Hood and from pre-Mount Hood vents. The origin of these middle units is problematic. They may reflect eruptive events that produced lahars by meltwater entraining loose heterolithic material, or they may have formed by some noneruptive process.

*Figure 8. Sketch of outcrop along south side of Red Hill Road (**Stop 3**) west of Parkdale showing lahar deposits, buried soils, and location of radiocarbon samples discussed in text.*



Buried soils separate each of the lower three lahar deposits, evidence of time breaks on the order of perhaps several thousand years between them. The soils are formed in the lahar deposits and in finer-grained deposits that overlie them. The fine-grained material is of uncertain origin but could be loess, ash-cloud deposits, hyperconcentrated-flow deposits, or alluvium. Charcoal fragments collected from the upper part of the soil (S3) that underlies lahar deposit L2 yielded an age of 27,300±2,940 ^{14}C yr B.P. (Beta-84993). This age and the buried soils suggest episodic emplacement of lahar deposits at this site between about 30 and 13 ka. At least two and perhaps all four lahar deposits represent episodic eruptive activity at Mount Hood. Similar evidence for episodic lahar deposition during this time period has also been found in the Sandy River valley west of Mount Hood by J.W. Vallance (oral commun., 1992).

Crandell (1980) presented convincing stratigraphic and geomorphic evidence that the Polallie eruptive period occurred late in the last glaciation, probably as multiple episodes over a period of a few thousand years. Paleomagnetic results show widely differing magnetic-field directions for Polallie deposits in different geomorphic positions and in various sectors around the volcano, also consistent with this model (fig. 9). From the evidence at this exposure and others around the volcano, we infer that lava-dome eruptions occurred both during and before the maximum of the Evans Creek advance. An issue in our mapping is deciding whether to extend the beginning of the Polallie period back in time to include these older units or to maintain Crandell's more restricted time limits and to make a separate category for the older deposits.

Return east on Red Hill Road

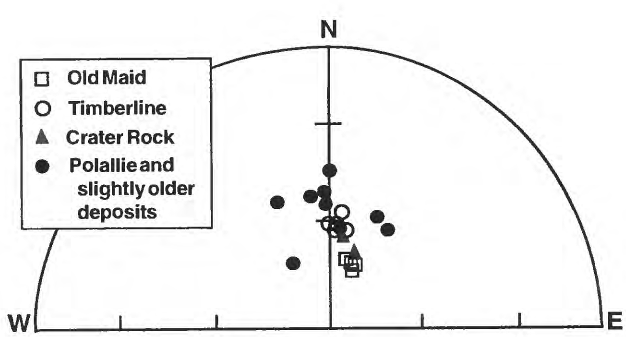


Figure 9. Paleomagnetic directions for pyroclastic-flow deposits and lava domes from Old Maid (~200 yr B.P.), Timberline (~1,500 yr B.P.), Polallie (~13–20 ka), and a slightly older eruptive period. Mean direction for Old Maid is D=18.5°, I=70° down; for Timberline, D=5°, I=62° down.

82.5 Turn right onto Old Parkdale Road; left onto Baseline and continue east through Parkdale. **1.6**

84.1 Intersection of Baseline and Cooper Spur Road; great view of Mount Hood to right, with the lava dome and diamict fan of Cooper Spur on the northeast side of the volcano. The summit is 17 km to the south and 2900 m above us. Continue east on Baseline. **2.3**

86.4 Cross East Fork Hood River at junction with OR 35; turn right (south). Roadcut near junction is Frenchman Springs Member of Wanapum Basalt (part of CRBG). **2.5**

88.9 Cross East Fork Hood River. **0.3**

89.2 Park on wide gravel shoulder on right—appropriately enough, just past "ROCKS" sign. **1.6**

Stop 4: Basaltic andesite of Cloud Cap and discussion of Quaternary mafic lavas near Mount Hood
Caution: Watch out for rockfalls!

Cliff and roadcuts expose two sequences of intracanyon lava flows and a clastic unit plastered against them (fig. 10). The upper sequence (two or more flows here) forms part of the normal-polarity, plagioclase,-orthopyroxene-, and olivine-bearing basaltic andesite to andesite lava flows of Cloud Cap (appendix 1, no. 26). The lower sequence (one flow here) is thought to come from vents high on the east rim of the canyon (basaltic andesite of Dog River; appendix 1, nos., 28, and 29) rather than from Cloud Cap. The clastic unit is composed of lahar deposits of Polallie age and glaciofluvial deposits of Evans Creek age.

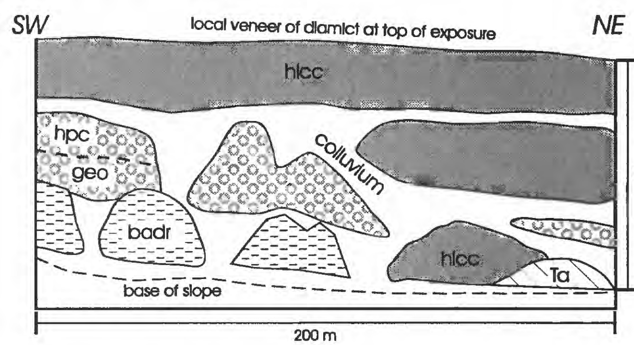


*Figure 10. Sketch of cliff and roadcut exposures at **Stop 4**. Symbols are: hpc, lahar deposits of Polallie eruptive period; geo, outwash of Evans Creek advance; hlcc, Cloud Cap lava; badr, Dog River lava; Ta, Tertiary andesite.*

Parts of both lava-flow sequences show evidence of emplacement against paleovalley walls in the form of fanned arrays of small columns and quenched glassy lava. Flowing from the southwest and entering the paleovalley occupied by the basaltic andesite of Dog River, the Cloud Cap lavas displaced the East Fork of the Hood River eastward to its present position. Subsequent incision cut a canyon close to present stream level by onset of the late Pleistocene Evans Creek glaciation. Bouldery outwash gravel of Evans Creek age forms the lower part of the clastic unit that is plastered against the cliff here; the upper part consists of lahar deposits of Polallie age. Upstream along the East Fork, these units underlie a terrace that is as much as 50 m above the present channel.

The Cloud Cap sequence is the largest of several, relatively small-volume outpourings of basaltic andesite and andesite lava from vents peripheral to or low on the flanks of Mount Hood (fig. 11). These lava flows are temporally and spatially related to the main andesitic cone-building lavas that form Mount Hood. Numerous (>10) lava flows of Cloud Cap exposed in the east canyon wall of Elliot Branch have a combined thickness exceeding 100 m. A sample from near the middle of the Cloud Cap sequence has an age of 424±19 ka. This age is younger than ages of 0.49 to 0.65 Ma obtained by Keith and others (1985) from a sample near the top of the sequence. The Cloud Cap sequence overlies Hood andesite lavas that have K-Ar ages of 492±15 ka and 475±14 ka (fig. 11), which is consistent with our age. Paleomagnetic results indicate that the entire sequence was emplaced in a few centuries or less (fig. 12).

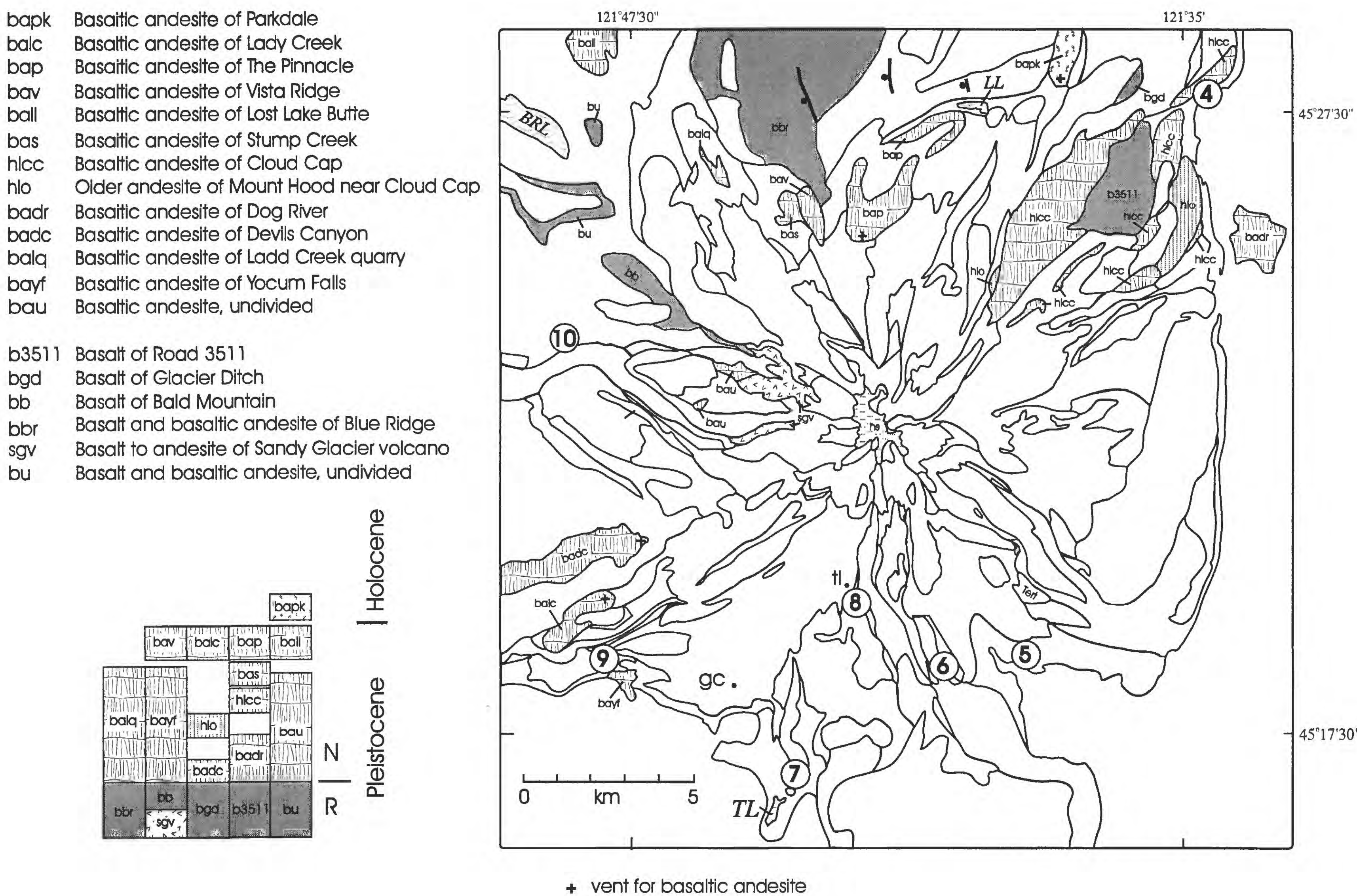


Figure 11. Map showing basalt and basaltic andesite lavas (<1.5 Ma) near Mount Hood. BRL, Bull Run Lake; LL, Laurance Lake; TL, Trillium Lake; gc, Government Camp; tl, Timberline Lodge. Adapted from Sherrod and Scott (1995).

Cloud Cap lava ranges from basaltic andesite to andesite, 55.1 to 58.6 percent SiO_2. The less-silicic flows have plagioclase and olivine phenocrysts, whereas the more-silicic flows have plagioclase and orthopyroxene phenocrysts with rare olivine.

The lower sequence is chemically and petrographically similar to the normal-polarity basaltic andesite of Dog River (Sherrod and Scott, 1995). The Dog River lava has higher Sr, Zr, and K_2O contents than does Cloud Cap lava, although many other elements are similar (fig. 13). We have so far been unable to obtain a reliable paleomagnetic direction from this flow.

Basalt was erupted during late Pliocene and early Pleistocene time from scattered vents in the Mount Hood region (Sherrod and Scott, 1995; Conrey and others, 1996a), but none since the last major magnetic reversal at 0.78 Ma (Brunhes Normal-Polarity Chron; age from Shackleton and others, 1990; Baksi and others, 1992).

The basaltic andesite lavas erupted during the past 780 ky show broad similarities on silica-variation plots and it is difficult to differentiate map units on the basis of any single element (fig. 13). However, used together the variation plots show that individual analyses from most map units form clusters. This method of differentiating units fails in thick sequences for which there are few analyses and where lavas from several sources are grouped into one unit (for example, basaltic andesite of Blue Ridge).

Still unclear is the petrochemical relation between basaltic andesite lavas that border Mount Hood and Hood's andesitic lavas. Wise (1969) argued against Hood andesite being derived from basaltic andesite of Cloud Cap on the basis of moderate K_2O values of the andesite: if the andesite lavas were derived from a basaltic andesite parent, then they should have higher K_2O values. On the basis of a preliminary inspection of our chemical data (fig. 14), we can't discount a genetic link between basaltic andesite and andesite, though we cannot evaluate this assertion until petrochemical modeling is completed.

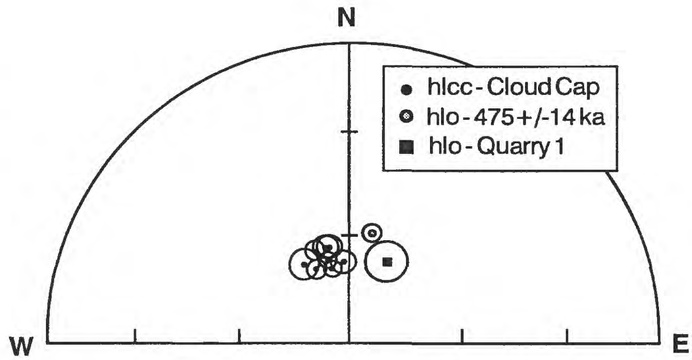


Figure 12. Paleomagnetic directions of Cloud Cap lavas (hlcc) and proximal older Hood andesites (hlo on Figure 11). A sample from near the middle of the Cloud Cap sequence has an age of 424±19 ka. Cloud Cap lavas overlie the older andesites, one of which has an age of 475±14 ka. The similarity of Cloud Cap directions indicates that the entire sequence was probably emplaced within a few centuries or less.

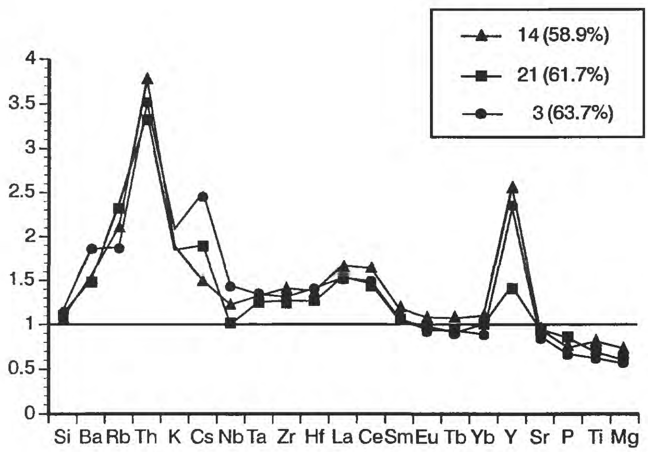


Figure 14. Hood andesites normalized to a Cloud Cap basaltic andesite (55.2 percent; analysis 24). Sample 14 is from a lava flow in the upper Mount Hood Meadows area; sample 21 is the lava flow of Wallalute Falls; and sample 3 is from a pyroclastic-flow deposit of Old Maid age in the Sandy River drainage. Silica contents in parentheses; complete analyses in appendix 1.

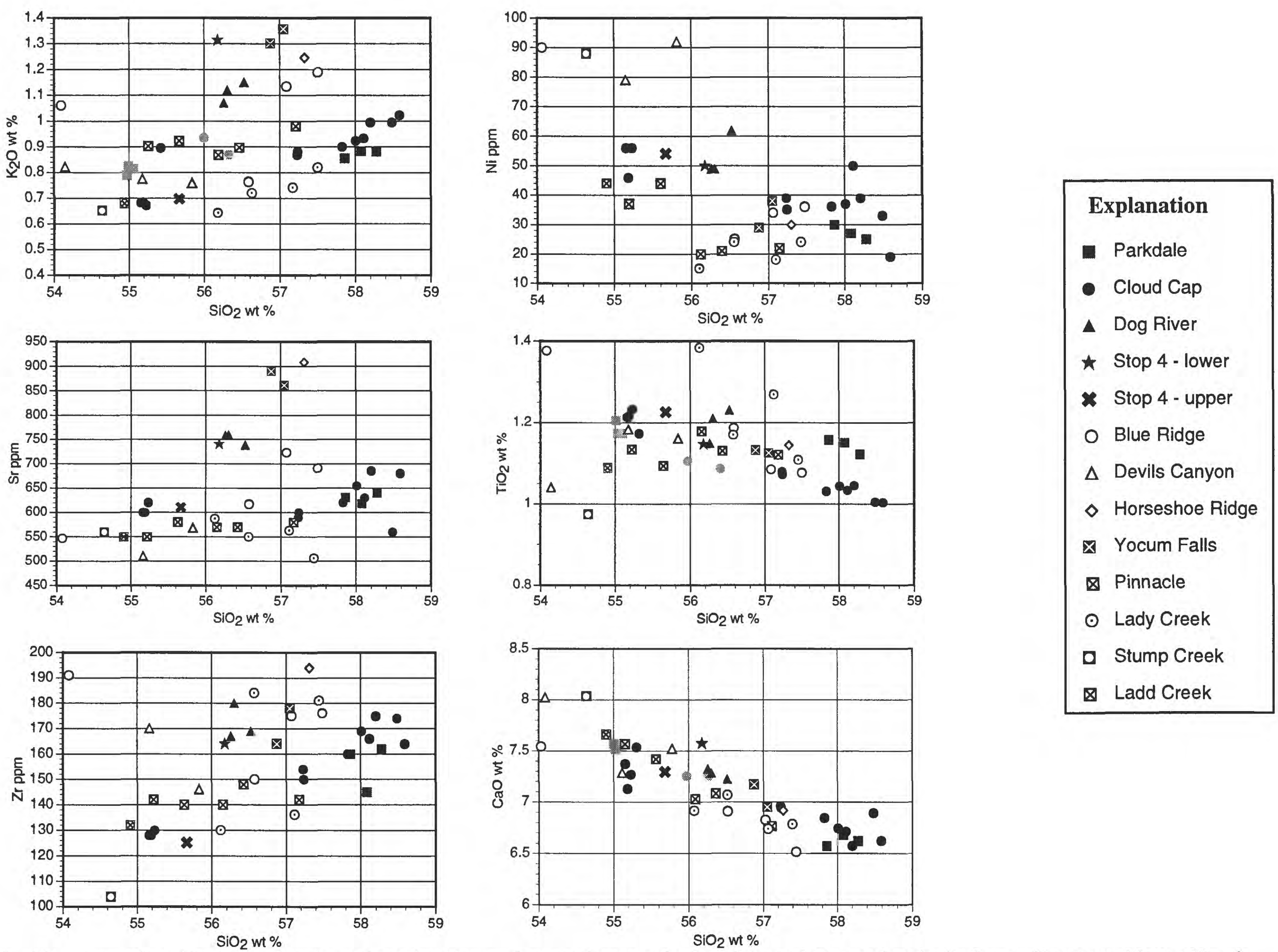


Figure 13. Silica-variation diagrams showing selected major and trace elements for basaltic andesite and andesite lava adjacent to Mount Hood. Screened Parkdale and Cloud Cap data points are from Wise (1969). Differences in Parkdale analyses may reflect interlaboratory differences rather than a real compositional gap.

90.8 Roadcut in upper Miocene andesite lava flow (Wise, 1969) with K-Ar age of 8.18±0.06 Ma (Keith and others, 1985). The andesite is overlain by outwash of Evans Creek age and lahar deposits of Polallie age that form a terrace about 50 m above the East Fork. The top of the ridge west (right) of the highway is formed of an andesite flow from Mount Hood that has a K-Ar age of 475 ka. Intracanyon lava flows from Mount Hood and Cloud Cap have forced the East Fork eastward so that the river is cutting a narrow canyon into these Tertiary rocks. **2.0**

Rhododendron and Dalles Formations

Mount Hood is not the first large andesitic volcano in this part of the Cascade Range. Older, extensive volcaniclastic-rich strata are exposed on the west and east sides of the volcano—the Rhododendron and Dalles Formations, respectively. These formations were thought to form a broad volcaniclastic apron, and they were presumed to be similar in age (for example, Wise, 1969). They are not in contact, but both overlie the Columbia River Basalt Group.

We now know that the Dalles Formation is younger than the Rhododendron Formation. Rhododendron time began about 14 Ma and had ended by 11 Ma. The Rhododendron Formation is capped in many places by a lava known as the andesite of Last Chance Mountain (**Stop 10**), which has K-Ar ages ranging from 9.5 to 11 Ma (Priest and others, 1982; Keith and others, 1985). In contrast, the Dalles Formation was emplaced from 8 to 6.5 Ma, on the basis of an age from a Dalles clast and from several ages on andesite lava flows and domes in the proximal facies of the unit (P.E. Hammond, in Fiebelkorn and others, 1983; Keith and others, 1985; Sherrod and Scott, 1995; Gray and others, 1996). The ~8-Ma andesite described at mile 90.8 is one of these lava flows.

The Rhododendron and Dalles Formations are similar chemically and are also similar to Mount Hood andesite (Gannett, 1982). Indeed, except for characteristically higher Sr in the Quaternary rocks, these three groups of intermediate-composition strata cannot be distinguished from each other chemically, despite their emplacement during three discrete periods over the past 14 million years.

92.8 Junction with Cooper Spur Road; continue on OR 35 over Polallie Creek. Polallie Creek originates on the broad fan of pyroclastic-flow and lahar deposits of Polallie age that forms Cooper Spur on the northeast flank of Mount Hood. Correlative deposits exposed in roadcuts just ahead form a terraced fill in lower Polallie Creek that is younger than moraines of Evans Creek age. Glaciers of the Evans Creek advance terminated about 2 km upstream from the East Fork. **0.5**

1980 debris flow and flood on Polallie Creek

Intense rainfall on Christmas Day, 1980, triggered a landslide in Polallie deposits at the steep head of the creek. The landslide transformed into a debris flow (Gallino and Pierson, 1985). The debris flow entrained material from the valley bottom and entered the East Fork Hood River, carrying a volume 20 times greater than the initial landslide. One person was killed when the debris flow burst from Polallie Creek canyon and overran the truck in which he slept at the former Polallie Creek Campground. The debris flow came to rest at the mouth of Polallie Creek and temporarily dammed the East Fork. About 12 minutes later the dam was breached and a flood surged down the East Fork, destroying about 5 miles of highway–a total of $13 million in damage.

93.3 The canyon of the East Fork narrows greatly through the next 0.5 mile; upper Miocene lava flows, breccia, and diamicts are exposed in river and roadcuts. The ridge west of the river is capped by the andesite of Tamanawas Falls, a Hood lava that has a K-Ar age of 29±11 ka and is overlain by moraines of the Evans Creek advance. This constricted reach of the East Fork canyon no doubt reflects the youthfulness of the lava flow. Polallie Creek follows the north margin of the flow. Cold Spring Creek, which drains a large sector on the lower east flank of Mount Hood, enters the East Fork at the south margin of the lava flow. **1.2**

94.5 Sherwood Campground; canyon widens. Roadcuts for next 0.3 mile expose interbedded lahar, alluvial, and lake deposits that underlie a terrace whose tread (east of highway) is formed in lahar deposits of the Polallie eruptive period and lies from 25 to 30 m above the East Fork. Several mechanisms existed for damming the East Fork in the constricted reach between Polallie and Cold Spring Creeks and ponding water up to the level of the lake sediments in these exposures: the andesite lava flow of Tamanawas Falls; an outwash fan of Evans Creek age from Polallie or Cold Spring Creek; or a fan of lahar deposits emanating from Polallie or Cold Spring Creek during the Polallie eruptive period of Crandell (1980). Polallie-like lahar deposits interbedded with the lake beds suggest a connection with the Polallie eruptive period, but as demonstrated at stop 2, Polallie-like clasts are present in deposits as old as ~30 ka. We're still searching for sufficient organic material in the lake beds to date them directly. **1.5**

96.0 Junction with Forest Road 44; continue on OR 35. The highway is traversing an apron of alluvial and debris-flow deposits derived from the east valley wall. The steep basins along this part of the valley produced copious runoff during the February 1996 floods. Bluegrass Ridge forms the west valley wall and consists of much the same upper Miocene and Pliocene rocks as does the east valley wall. **2.5**

98.5 Cross East Fork at Robinhood Campground; CRBG exposed in rock quarry on east side of East Fork just upriver from bridge. The highway traverses a broad valley floor underlain by lahar and alluvial deposits of Polallie age. Beginning just upstream, the Polallie deposits are buried by a gradually thickening sequence of upper Holocene outwash and debris-flow deposits from Newton and Clark Creeks. **1.0**

99.5 Cross Newton Creek. **1.4**

100.9 Cross Clark Creek. **0.9**

101.8 Hood River Meadows entrance (lower entrance) to Mount Hood Meadows Ski Area. Roadcuts ahead expose till of Evans Creek age on andesite lava flow of Sahalie Falls, which is part of a sequence that underlies Mount Hood Meadows Ski Area. The youngest flow in the sequence has a K-Ar age of 55±14 ka. Samples of the andesite of Sahalie Falls contained very little radiogenic Ar (0.1 percent) and gave a meaningless age of 5±18 ka. **1.3**

103.1 Bennett Pass forms the drainage divide between the Hood River and White River basins; Hood River drains north to the Columbia River and White River flows east to the Deschutes River. Cross highway and park on wide paved shoulder (Bennett Pass Snow Park) on left. **Drivers, please make this maneuver safely; be alert to oncoming traffic. 0.2**

Stop 5. Bennett Pass glacial deposits

The roadcuts at the pass expose three diamicts that mantle a ridge of Miocene volcanic rocks. The ridge projects 2 km northwest before being buried by lava flows from Mount Hood. Crandell (1980) interpreted the roadcut as three tills separated by buried soils, the upper till forming a lateral moraine of Fraser (Evans Creek) age.

The diamicts display the characteristics that we use to distinguish till from similar-looking colluvial deposits and volcanic diamicts such as pyroclastic-flow and lahar deposits (table 2). Striated and glacially shaped clasts are common in the units, especially the lower two. The matrix contains more silt than do typical noncohesive lahar deposits and is locally quite compacted. Bedding is absent or crude, unlike typical sequences of volcanic diamicts. The middle unit does have a couple of poorly bedded, slightly graded diamicts that may be flow till (essentially debris-flow emplacement of superglacial drift), unsurprising in a moraine depositional environment.

The lower till is composed dominantly of dense andesite clasts, many of which contain rounded light-colored fine-grained inclusions.. We can't identify a specific source, but similar lava flows lie upslope from here in and near Mount Hood Meadows Ski Area. One flow has a K-Ar age of 163±14 ka; others lie below a lava whose K-Ar age is 55±14 ka.

About one half of the clasts in the upper unit are highly porphyritic and vesicular, similar to clasts found in Polallie deposits derived from collapse of lava domes (**Stop 3**). The terminal moraines of Evans Creek age east of here contain a high proportion of similar clasts, many of them incipiently prismatically jointed, suggesting that dome growth and collapse was occurring during the Evans Creek advance and shedding debris onto ice, which was then transported to moraines as superglacial drift.

The soils that separate the units are quite different in degree of development. The lower soil is as much as 1 m thick, although it has been beveled by erosion, and has an incipient argillic (textural) B horizon. Overall it displays a greater degree of development than does the surface soil formed in the 15,000 yr since the end of the Evans Creek advance. The upper buried soil is thinner than the lower, is less intensely oxidized, and has no argillic horizon. Locally some of the oxidized material has preserved bedding. The upper buried soil probably represents a limited time of soil formation and the two upper units may both date from the last glaciation. Small pumice lapilli, one example of the rare pumiceous products of Mount Hood, are scattered throughout the upper part of the upper buried soil.

The age of the lower till is unknown but is probably either roughly 75 ka or 150 ka, considering the degree of development of the lower buried soil and our estimates of the timing of pre-Evans Creek glaciations.

103.3 Descend south side of Bennett Pass; outcrops of Tertiary volcanic rocks locally overlain by till. View below of White River valley. **1.5**

104.8 Roadcut in talus (and small in-place outcrop) of Hood andesite lava flow that lies against paleovalley wall in highly fractured and altered Tertiary andesite. **0.4**

105.2 Cross White River; view to canyons in upper White River valley. Outburst floods from White River Glacier have taken out numerous, lesser versions of the highway bridge. The aggrading valley floor downstream displays several surfaces formed during this century that can be differentiated by the size (age) of trees growing on them. The sediment sources for the aggradation are White River Glacier and the canyons that are being cut into diamicts of Polallie and Old Maid age downstream from White River Glacier. **0.1**

105.3 Turn right into White River Snow Park; outhouse available, but it is closed in summer. Park and hike about 500 m up to stream cuts in terrace southwest of White River. **0.2**

Stop 6. Pyroclastic-flow deposit of Old Maid eruptive period along White River

This stop provides a close-up inspection of a pyroclastic-flow deposit produced by collapse of a growing lava dome at the site of present Crater Rock during the Old Maid eruptive period. Having occurred 200 years ago, the Old Maid is the youngest major eruptive period at Mount Hood (Crandell, 1980; Cameron and Pringle, 1987). Crandell (1980) studied this exposure soon after a 1964 flood greatly eroded the terrace scarp. A lower lahar deposit (now buried in colluvium shed from the scarp) that extended below river level is overlain by a pyroclastic-flow deposit 5–20 m thick. Farther upstream, several lahar deposits overlie the pyroclastic-flow deposit. The pyroclastic-flow deposit contains clasts of dense to vesicular, highly porphyritic, silicic andesite—62.8 percent SiO_2 in a block here (appendix 1, No. 1) and as much as 64.0 percent in deposits upstream—in a gray to pinkish-gray, friable, granular sandy matrix. Many clasts are prismatically jointed, indicative of rapid cooling of hot blocks after the deposit was emplaced. Other evidence of hot emplacement includes abundant charcoal fragments (which have yielded a ^{14}C age of 260±150 yr B.P.), pinkish color indicative of high-temperature oxidation, and vertical fluid-escape pipes. In addition, uniform thermoremanent magnetic field direction was determined from numerous clasts and matches that of other pyroclastic-flow deposits of Old Maid age and at least part of Crater Rock, a lava dome of Old Maid age (fig. 9).

105.4 Turn right back onto OR 35. **1.8**

107.2 Barlow Pass; good views to south side of Mount Hood from right shoulder as we descend pass. Crater Rock and debris fan of mostly Timberline age lie in breached crater below summit ridge; a lava dome of Polallie age and a remnant of a debris fan derived from it are visible on the right crater rim. **1.1**

108.3 Roadcuts in Polallie diamicts. **0.6**

108.9 Highway descends onto surface underlain by diamicts of Timberline eruptive period that came down Salmon River. **0.4**

109.3 Exit right onto U.S. Highway 26 (U.S. 26) west toward Portland. **1.0**

110.3 Intersection with road to Trillium Lake. The dam at the south end of the lake provides a good view of the upper south flank, Crater Rock, and the debris fan of Timberline age. For those who choose, drive 1.7 mi south of U.S. 26 on Forest Road 2656, bear right on Road 2612 just south of Trillium Lake Campground, park in lot by dam and walk out on dam. (Mileage in guidebook does not include this side trip.) **0.5**

110.8 Park on right shoulder along roadcut in Mount Hood andesite lava flow. Ahead on southwest slope of Mount Hood, the prominent cliff is Mississippi Head, a thick, stubby lava flow of Polallie age. The flow overlies a thick sequence of pyroclastic-flow, lahar, and debris-avalanche deposits. It is buried by till of neoglacial age (last few centuries) and by deposits of Old Maid and Timberline age; its vent location is unknown. **1.0**

Stop 7. Mount Hood andesite lava flow along U.S. Highway 26

CAUTION: Be careful of traffic and falling rocks.

This stop provides an opportunity to see and sample a middle-of-the pack andesite lava flow from Mount Hood. Lava flows and clastic deposits from Mount Hood contain from 57–64 percent SiO_2 (fig. 15); this flow has 61.1 percent (table 3). This flow has normal-polarity magnetization and a K-Ar age of 121±13 ka (fig. 2C). The lava flow, overlain locally by till of the Evans Creek advance, is one of a sequence that can be traced up to an altitude of about 1800 m (6000 feet), above which they are buried by diamicts of Polallie and Timberline age.

The mineral assemblage of this flow is dominated by plagioclase and orthopyroxene with minor clinopyroxene. Similar to most lavas from Mount Hood, this one contains abundant, mostly round, inclusions. Two types are seen here: a common fine-grained type with a mineral assemblage similar to that of the host rock (plagioclase > orthopyroxene and

Table 3. Geochemical analyses of Hood lava flow and inclusions at Stop 7. Oxides reported in weight percent, normalized volatile free. Trace elements in parts per million.

	Lava flow 92T-58	Inclusion, fine-grained 92T-58A	Inclusion, coarse-grained 92T-58B
SiO_2	61.1	56.9	56.1
Al_2O_3	17.3	18.2	18.8
$FeTO_3$	6.07	7.33	7.18
MgO	3.23	3.95	3.98
CaO	5.77	7.13	7.89
Na_2O	4.15	4.14	3.49
K_2O	1.23	0.91	1.04
TiO_2	0.84	1.07	1.24
P_2O_5	0.21	0.24	0.17
MnO	0.10	0.11	0.10
Rb	22	14	18
Sr	530	590	560
Zr	158	142	132
Y	16	15	17
Ba	345	275	255
Ce	33	<30	<30
La	<30	<30	<30
Cu	33	54	285
Ni	34	44	17
Zn	63	71	60
Cr	40	41	46
La	15.2	13.0	11.2
Ce	31.1	27.1	23.1
Nd	16.0	14.4	12.8
Sm	3.80	3.76	3.66
Eu	1.110	1.184	1.140
Tb	0.482	0.514	0.519
Yb	1.29	1.36	1.49
Lu	0.202	0.193	0.209
$^{87}Sr/^{86}Sr$	0.70336	0.70336	0.70335
$^{143}Ns/^{144}Nd$	0.51293	0.51291	0.51294

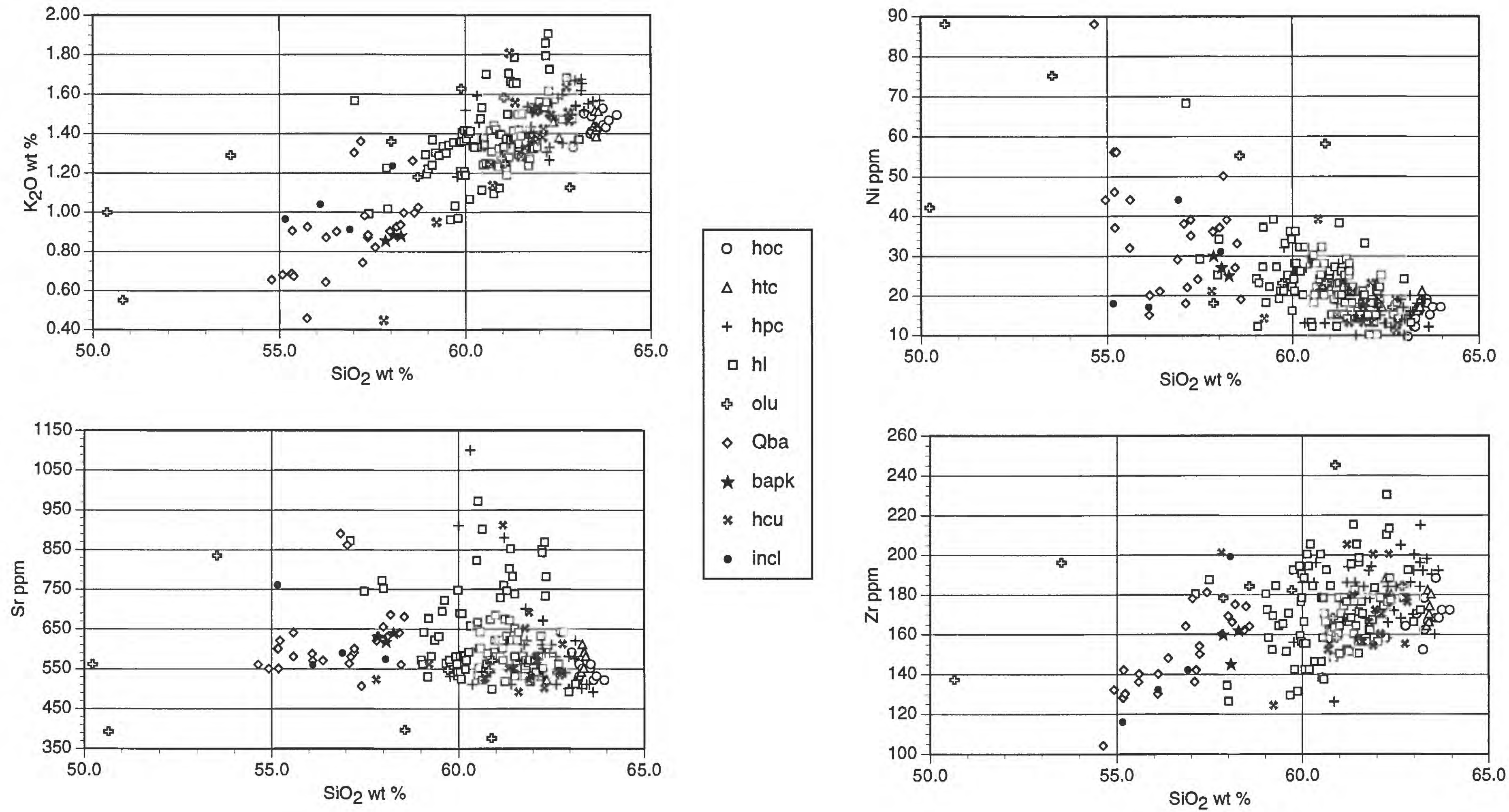


Figure 15. Silica-variation diagram of lavas from or adjacent to Mount Hood. Symbol designations are the same as for map units except: olu - older lavas undivided; Qba - Quaternary basaltic andesite (see Stop 4); hcu - Hood clastics undivided (>Polallie age); and inclu - inclusions. The group olu includes reversed-polarity basalt lavas (undated) on the NE flank and reversed-polarity andesite lavas (dated and undated) on the N and SE flanks of Mount Hood (see figs. 1 and 13).

minor clinopyroxene), and a less-common coarse-grained type. The coarse-grained inclusions are dominated by plagioclase with lesser amounts of orthopyroxene, but they also contain numerous large phenocrysts that have been completely replaced by iron-titanium oxides. Most inclusions have lower silica contents than their hosts (table 3) and chemically resemble basaltic andesites. However, mineralogically the inclusions are more similar to their andesitic hosts in that they lack olivine, the dominant phenocryst of basaltic andesites. Therefore, the inclusions appear to be glass-poor crystal cumulates (cognate inclusions) from the host lava.

Lava flows and clastic deposits from Mount Hood show a relatively narrow range of chemical composition, mineralogy, and isotopic values (fig 15 and appendix 1). All are phenocryst rich (between 35 and 45 percent); mineralogy is dominated by plagioclase with subordinate amounts of hypersthene and iron-titanium oxides, ± hornblende, ± augite, ± olivine. There is a general trend toward slightly more silicic products during the last two eruptive periods, but otherwise it is difficult to discern any mineralogical or compositional trend with time. Strontium isotopic values ($^{87}Sr/^{86}Sr$) for Hood rocks range from 0.70328 to 0.70336 and $^{143}Nd/^{144}Nd$ from 0.51288 to 0.51293 (J. Arth, oral commun., 1994); the analyses plot in the same field as the mantle array, mid-ocean ridge basalt and the Columbia River Basalt Group on Nd vs Sr isotopic plots (for example, Faure, 1986, p. 222). The high Nd and low Sr isotopic values suggest little contamination of Hood magmas by more evolved crustal sources.

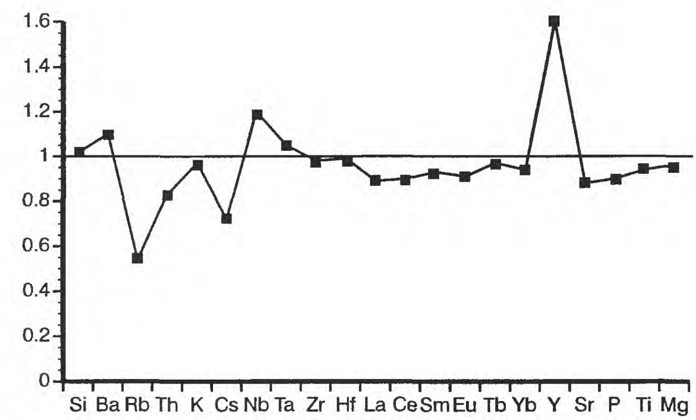


Figure 16. Clast from a pyroclastic-flow deposit of Old Maid age (63.7 percent SiO_2; analysis 3) normalized to a clast from a diamict of Polallie age (62.5 percent SiO_2; analysis 7).

From trace-element data, White (1980) deduced that the Polallie, Timberline, and Old Maid deposits are unrelated to one another through crystal fractionation processes, a conclusion supported by our data. Incompatible-element (for example, K, Sr, Ba, Rb) values are higher in the lower silica Polallie deposits than in the higher silica Timberline and Old Maid deposits (fig. 16). Major-, trace-, and rare-earth-element, mineralogic, and isotopic data all point to a common origin and petrologic evolution of the Hood andesites, but it is unclear if any one sequence is directly related to another. A fundamental question is, how did this volcano produce such geochemically similar lavas of differing eruptive volumes and repose periods throughout its (at least) 0.5-m.y. life?

111.8 Turn right onto road to Timberline Lodge; roadcuts ahead on left expose diamicts of Polallie eruptive period. **0.6**

112.4 Road climbs west margin of andesite flow seen at Stop 7. **0.5**

112.9 Roadcuts ahead in diamicts of Polallie age that overlie andesite flow. **1.7**

114.6 Roadcuts in andesite flow. **1.0**

115.6 Shallow borrow pit in diamicts of Timberline eruptive period that spilled down small tributary of West Fork Salmon River. The tributary is incised into diamicts of Polallie age and andesite flow. **0.4**

116.0 First of several good exposures of diamicts of Polallie age that locally are seen overlying andesite lava flow. **1.1**

117.1 Turn right onto paved pull out on west wall of Salmon River valley, across from outcrop of andesite lava flow. **0.3**

Stop 8. Overlook of the upper south flank of Mount Hood

This stop provides an overlook of the pyroclastic fan on the upper south flank and several landmarks above the fan (fig. 17). Illumination Rock, a remnant of a thick andesite lava flow, lies on a sequence of volcanic diamicts. Crater Rock, a lava dome of Old Maid age, also marks the apparent site of dome extrusion during the Timberline eruptive period. Ground temperatures near 85°C and fumarole temperatures as high as 92°C (slightly above boiling point of water at 3,100 m altitude) were measured in summer 1987 in the area of warm ground, hydrothermal alteration, and sulfur deposition that wraps around the east, north, and west sides of the dome (Cameron, 1988; Swanson and others, 1989). The crater wall is composed of massive to brecciated andesite with little stratigraphic continuity. The rocks show variable amounts of hydrothermal alteration; breccia displays the most intense alteration. Much of the wall may be composed of remnants of lava domes and related breccia and near-vent lava flows. On the east crater rim, Steel Cliff is the eroded margin of a lava dome of broadly Polallie age that contributed pyroclastic-flow and lahar deposits to the fan surface that lies above the White River Glacier and slopes toward Mount Hood Meadows. The dome of Steel Cliff lies on a glacially eroded andesite flow of uncertain correlation to lava flows on the lower south and southeast flanks.

We consider the andesite flow at this stop to be part of the same sequence as the 121-ka flow at stop 7. The flow is exposed at several sites along Salmon River upstream from here, the highest about 100 m higher than the stop. Above that point volcanic diamicts of the Polallie, Timberline, and Old Maid eruptive periods, which form the broad fan below the breached summit crater, completely bury older lava flows up to the crater walls. Drill holes for geothermal exploration on the debris fan southwest and west of here penetrated 30-70 m of diamicts before penetrating andesite lava flows. Diamicts of Polallie age underlie most of the rolling terrain between Salmon and White Rivers. Timberline deposits form the relatively smoother, reddish-gray, boulder-studded central and western parts of the fan. Many of the boulders are prismatically jointed and some are as large as 10 m. A terrace underlain by Timberline deposits is visible on the west side of the Salmon, directly below the stop, where Timberline flows were being funneled into valleys cut into Polallie deposits and older lava flows. Deposits of Timberline age (other than ashfall deposits) are much less voluminous in the upper White River valley than in any valley of Sandy River or its tributaries on Mount Hood. This difference suggests that the terrain during Timberline time was not like that of the present, in which Crater Rock lies at the head of the upper White River valley. Rather, at least a partial topographic barrier must have existed between the vent and the head of White River. Perhaps the surface underlain by Polallie deposits extended to the east crater rim through what is now the trough occupied by White River Glacier. Upslope from this stop, deposits of Old Maid age are confined to channels cut into Timberline or Polallie deposits, but a thick (≥60 m) sequence of diamicts of Old Maid age forms a terraced fill in the White River valley.

A renewal of dome growth in the Crater Rock area would, at least initially, probably follow the pattern of events during the Old Maid eruptive period. Incision of the margins of the debris fan by White River Glacier and Zigzag Glacier, which lies mostly out of view below and left of Crater Rock, would funnel dome-collapse avalanches into those drainages rather than directly onto the Timberline fan. Persistent dome growth and collapse would have to fill the heads of these marginal valleys with debris before widespread deposition could begin on the central part of the fan, conditions that were evidently not met during the Old Maid eruptive period. Regardless, other processes at growing lava domes, such as explosions that generate pyroclastic surges and hurl ballistic projectiles out for several kilometers, would endanger areas in the central part of the debris fan.

Another process common at volcanoes like Mount Hood are debris avalanches of altered and fractured rock from the upper flanks, which pose potential hazards during both dormant and eruptive periods. Early in the Timberline eruptive period, a mass of tens to perhaps 100 million m^3 avalanched down the southwest flank and formed a cohesive lahar that traveled down the Zigzag and lower Sandy Rivers to the Columbia. Its deposits are exposed in the banks of Sandy River at the I-84 bridge (mile 15.1).

117.4 Wy'East day lodge; restrooms available. Follow signs to U.S. 26. **5.3**

122.7 Turn right onto U.S. 26, westbound. **2.3**

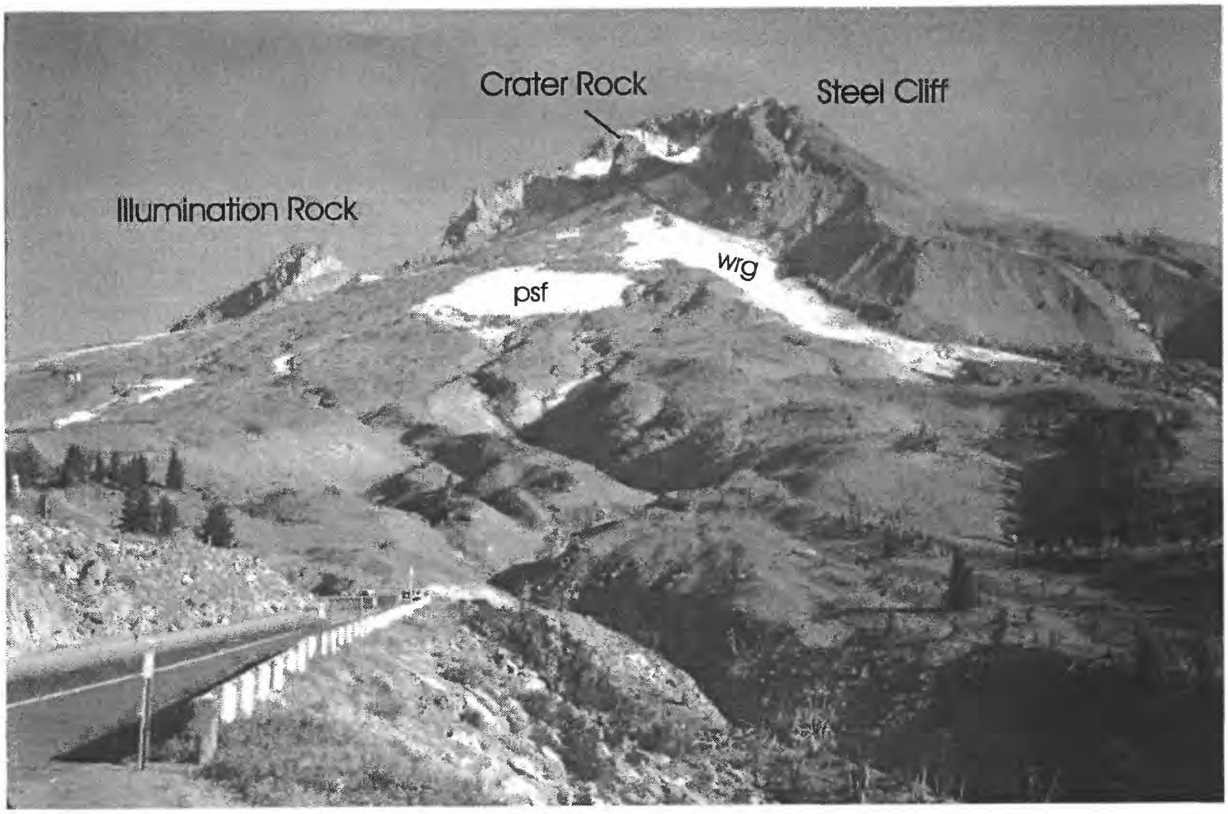


*Figure 17. Photograph of upper south flank of Mount Hood from **Stop 8** showing prominent summit features and broad fan of pyroclastic-flow and lahar deposits. psf, Palmer Glacier (snowfield); wrg, White River Glacier. Surface from psf to center left is chiefly Timberline age and surface extending to right of terminus of wrg is underlain by deposits of Old Maid age. Gullies and rolling surface in center to lower right is underlain by deposits of Polallie age, as is surface that extends to right center below Steel Cliff. Andesite lava flow is exposed in roadcut and slope below road.*

125.0 Diamicts of Polallie eruptive period exposed in roadcuts (Crandell, 1980). As highway turns to north at head of Camp Creek valley, underlying basaltic andesite lava flow of Yocum Falls is exposed (appendix 1, No. 30). Wise (1969) mapped this as a Mount Hood lava, but we think it was erupted from a vent (not exposed) near Mirror Lake on the north side of Tom Dick and Harry Mountain, south of the highway. A sample from the roadcut and one collected from about 60 m higher on the south valley wall are similar in composition and are unlike any Hood andesite analyses, owing chiefly to their higher Sr content (fig. 13). **0.5**

125.5 Roadcuts on both sides of highway expose quartz diorite of the ~8.5-Ma Laurel Hill pluton (Bikerman, 1970; Keith and others, 1985). **0.4**

125.9 On right are valleys of Little Zigzag and Zigzag Rivers. Mount Hood andesite flows are exposed in both valleys. The flow that forms the long cliff along the north side of Zigzag River yielded K-Ar ages of 235±13 and 213±9 ka (fig. 2B). **1.1**

127.0 Runaway truck ramp. **0.2**

127.2 Basalt dikes in quartz diorite of Laurel Hill pluton. One dike yielded a K-Ar age of 5.1±1.0 Ma (Bikerman, 1970). **1.2**

128.4 Turn right onto Forest Road 2639 toward Mount Hood Kiwanis Camp; road ahead crosses surfaces underlain by lahar deposits of Timberline and Old Maid age on south side of Zigzag River. **1.5**

129.9 Road on south bank of Zigzag River. Terrace scarp visible through trees on north bank exposes a lahar deposit of Old Maid age. For convenience and safety on this narrow road, proceed to the end of the road, then retrace route a short distance to the next stop. **0.9**

Was there eruptive activity between the Timberline and Old Maid periods?

The lahar of Old Maid age exposed on the north bank of Zigzag River overlies debris-flow and fluvial deposits (now mostly covered by colluvium) that bury tree stumps in growth position. One of the stumps has an age of 550±130 ^{14}C yr B.P. (Cameron and Pringle, 1986). Cameron and Pringle (1986) defined the Zigzag eruptive period on the basis of these deposits and others in the upper Sandy River valley. But no evidence indicates that these deposits along Zigzag River resulted from eruptions. The clasts are derived chiefly from the thick sequence of Polallie deposits that form the walls and head of upper Zigzag Canyon. An age of 455±135 ^{14}C yr B.P. from a deposit of a hot lahar in the upper Sandy was reported by Cameron and Pringle (1986); the deposit was considered correlative to the deposits along Zigzag River and therefore evidence for establishing a new eruptive period. We redated charcoal from the deposit in the upper Sandy and obtained an age of 110±50 ^{14}C yr B.P. (J.W. Vallance, written commun., 1991); further we can not differentiate the deposit stratigraphically from deposits of Old Maid age. Therefore, we don't find support for an eruptive period between the Timberline and Old Maid. We think that this 550-B.P. debris-flow deposit along the Zigzag was of noneruptive origin.

130.8 Mount Hood andesite lava flow at end of road. Turn around and head back down road Forest Road 2639. **0.4**

131.2 Turn right onto shoulder at small borrow pit across from camp. **2.0**

Stop 9. Pyroclastic-flow and lahar deposits of Timberline eruptive period along Little Zigzag River

This small borrow pit and nearby roadcuts expose diamicts that underlie a terrace along the north side of Little Zigzag River. The deposits were emplaced during the 1.5-ka Timberline eruptive period. The Zigzag River flows parallel to the Little Zigzag, just beyond a low divide to the north. The quarry exposes a lahar deposit on top and one to four underlying diamicts, depending on how recently colluvium has been removed from the base of the quarry wall. The lahar deposit is 1-2 m thick, has a yellowish color owing to a substantial component of hydrothermally altered material, and is slightly cohesive. The lahar deposit directly overlies a pyroclastic-flow deposit, which is about 2-2.5 m thick and is gray with a pinkish-gray top. It contains charcoal (1,440±155 ^{14}C yr B.P.; Cameron and Pringle, 1986) and some prismatically jointed andesite clasts (62 percent SiO_2) in a friable sandy matrix. Many clasts were deposited hot as indicated by paleomagnetic data obtained from this unit in roadcuts to west. The magnetic field direction obtained from this deposit is similar to that of other deposits of Timberline age (fig. 9). The pyroclastic-flow deposit here, about 12 km from the crater, is the farthest traveled of any age we've found around Mount Hood.

The pyroclastic-flow deposit lies on a 20- to 30-cm-thick normally graded unit that has a pebbly basal layer and a silty-sand top. Its origin is uncertain: it may represent a pyroclastic surge (Swanson and others, 1989) or fluvial reworking.

A pebbly gray diamict lies below the normally graded unit. It contains partly charred wood (1,830±50 ^{14}C yr B.P.; Swanson and others, 1989) and lacks pinkish oxidation, which suggest deposition at a temperature lower than that of the upper pyroclastic-flow deposit. Paleomagnetic data show no coherent orientation of clasts, indicating that deposition occurred below the lower blocking temperature limit of the andesite clasts (about 350°C). This lower unit may be a lahar deposit.

After calibration of the radiocarbon ages to calendar ages, the ages are still more than 500 yr different. Even at a 1-sigma uncertainty, the minimum range of the older and the maximum range of the younger are more than 200 yr apart. But we don't think that the deposits are necessarily that far apart in age. The great variation in age of wood in an old-growth forest (some species live more than 500 yr) provides for a potentially wide range in age of charcoal fragments incorporated into deposits. Paleomagnetic data from deposits of Timberline age suggest an elapsed time of less than two centuries and there is little stratigraphic or weathering evidence here or elsewhere of lengthy repose periods during deposition of Timberline deposits. The best evidence of a short hiatus is found in a few locations on the east flank of the volcano where a thin layer of peaty sediment is interbedded in ash-cloud deposits. We surmise that the peat represents a time interval of a few decades or, at most, a century.

133.2 Turn right onto U.S. 26. The highway crosses a fill of sandy lahar deposits of Timberline age. **2.6**

135.8 Cross Zigzag River; lahar deposits of Old Maid age are restricted to a narrow zone within the surface of mostly Timberline deposits. The two are not separated by a conspicuous scarp as they are upstream. **1.5**

137.3 Rhododendron. **0.5**

137.8 Cross Zigzag River at west end of Rhododendron. **1.6**

139.4 Enter Zigzag; turn right onto Lolo Pass Road. **0.2**

139.6 Cross Zigzag River. November 1995 and early February 1996 floods greatly eroded banks upstream, deposited much gravel in the reach above the bridge and scoured the bridge abutments. Surface ahead is underlain by thin Old Maid lahar deposits on Timberline deposits. **0.7**

140.3 Cross Sandy River; road turns east and follows north bank of the Sandy. **3.2**

143.5 Junction with Forest Road 1825; stay on Lolo Pass Road. Road climbs off surface of Old Maid Flat, which is underlain by lahar deposits of Old Maid age. The young sandy lahar deposits support a relatively open (by northwest standards) forest that contains numerous lodgepole pine, an uncharacteristic species at this altitude on the west slope of the Cascades. The sandy lahar deposits drain rapidly and have low moisture retention, so the tree assemblage must be suited to dry conditions during summer (in an area that has mean annual precipitation of about 2.5 m). Roadcut ahead exposes ~11-Ma lava flow in the middle Miocene Rhododendron Formation, a thick accumulation of volcaniclastic and epiclastic strata and interbedded lava flows. **1.3**

144.8 Turn into small gravel turnout on left side of road; walk back down road to Mount Hood viewpoint under power lines. **Caution: Watch out for traffic along this narrow road. 5.4**

Stop 10. Upper Sandy overlook

This overlook provides a good view of the west side of Mount Hood (fig. 18) and the upper Sandy River valley with its broad flat fill of lahar deposits of Old Maid age. Deposits of Polallie and Timberline age are probably present at depth. Geothermal drilling about 5 km upvalley penetrated 30–80 m of lahar deposits (Priest and others, 1982).

The upper Sandy is flanked by Last Chance Mountain on the north and Zigzag Mountain on the south. Lower slopes of Last Chance Mountain are underlain by Rhododendron Formation, whereas the upper one-third is capped by ~11-Ma andesite of Last Chance Mountain (Wise, 1969; Priest and others, 1982).

This view of Mount Hood shows the contrast between the smooth southwest slopes formed in fragmental deposits of late- and postglacial age and the rugged, steep slopes on the west and north flanks. The headwalls of Sandy and Reid Glaciers expose fractured and hydrothermally altered rock, and both areas have been sources of small rock avalanches during this century. Both areas are also potential sources of avalanches of tens to a couple hundred million cubic meters in volume that could generate cohesive lahars capable of traveling far down the Sandy valley and, for the larger ones, entering the Columbia. Such avalanches could occur passively from the gradual weakening of the edifice by erosion and hydrothermal alteration, but, for larger events, triggering by strong regional earthquakes or by earthquakes and deformation related to lava intrusion is more likely.

The rugged valley step below the Sandy Glacier (terminus about 1,900 m altitude) exposes lava flows and pyroclastic deposits of the Sandy Glacier volcano (SGV; Wise, 1969), which we have traced up to an altitude of about 2,150 m. The lower part of SGV consists of basalt and basaltic andesite lava flows and tuffs; the upper part includes andesite lava flows and diamicts that, although slightly altered, are similar to Hood diamicts of Holocene age (fig. 19). The flows and diamicts dip eastward and are cut by numerous dikes. A lava flow with reversed-polarity magnetization near the terminus of Sandy Glacier has K-Ar ages of 3.2±0.3 Ma (Wise, 1969) and 1.14 to 1.35±0.05 Ma (Keith and others, 1985; weighted mean age, 1.27±0.02 Ma, Sherrod and Scott, 1995). Like Keith and others (1985), we consider the younger age more compatible with regional relationships. We have found andesite lava flows with reversed polarity in several drainages on Mount Hood, the highest just 100 m lower than the highest deposits of Sandy Glacier volcano. Three reversed-polarity lava flows in northwest and east sectors have ages ranging from 0.82 to 1.47 Ma, which shows that an andesitic focus has existed near the present vent of Mount Hood for most of the Quaternary Period.

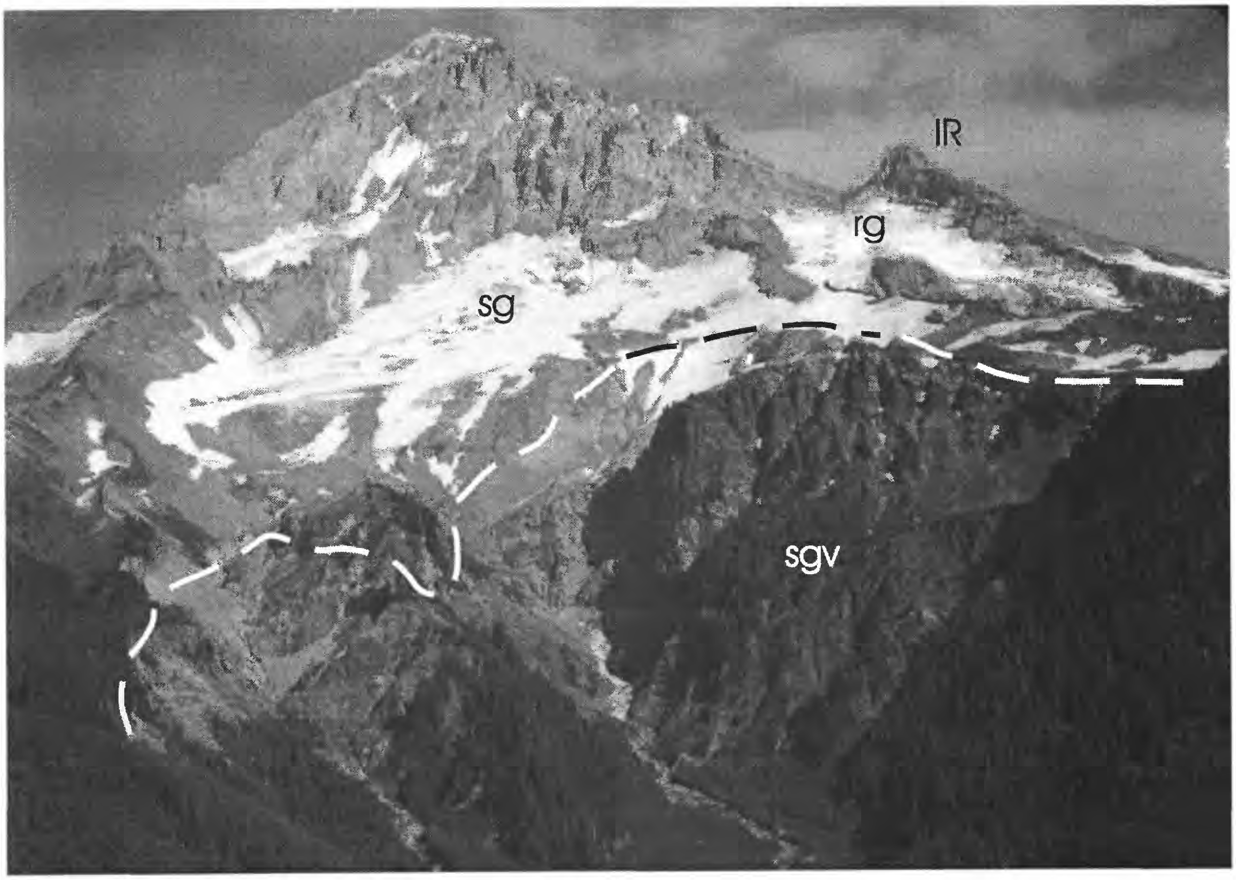


Figure 18. Photograph of headwaters of Muddy Fork of Sandy River showing contact between lava flows of west flank of Mount Hood and lava flows and diamicts of Sandy Glacier volcano (sgv). sg, Sandy Glacier; rg, Reid Glacier; IR, Illumination Rock.

Return west on Lolo Pass Road.

150.2 Junction with U.S. 26 in Zigzag; turn right. The highway ahead traverses lahar deposits of Timberline age, at least one of which was spawned by a large debris avalanche on the southwest flank. Lahars of Old Maid age are confined to the channel and low terraces along the Sandy River. Boulders as large as several meters in diameter that were carried by the Timberline lahars now lie scattered on the surface; many have been used in landscaping or left in heaps by construction projects. **3.0**

153.2 Mount Hood RV Resort. U.S. Forest Service information center. Surface ahead is underlain by lahar deposits of probable Polallie age; the large lahar of Timberline age flowed both north (following the Sandy River) and south (following the Salmon River) of this broad surface. **0.8**

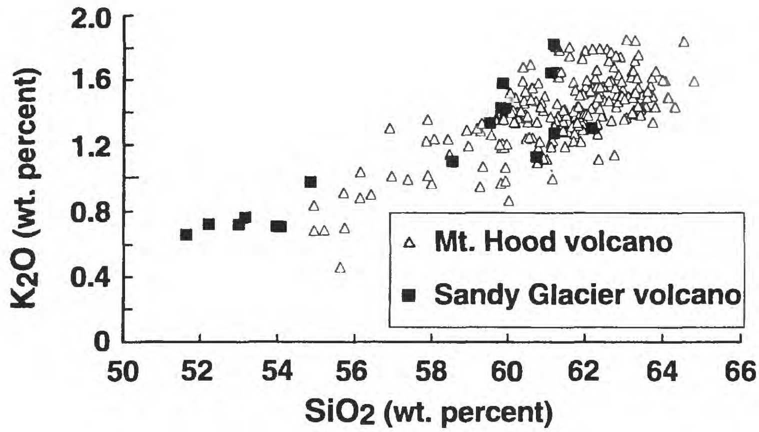


Figure 19. Silica-variation diagram showing analyses of Sandy Glacier volcano (early Pleistocene) and Mount Hood volcano (middle Pleistocene to Holocene). For Sandy Glacier volcano, basalt and basaltic andesite analyses are from lower part of sequence (characterized by lava flows), and the compositionally discrete andesite analyses are from upper part of sequence (chiefly diamicts).

154.0 Roadcuts in till of Hayden Creek age (Crandell, 1980) that probably forms a terminal moraine, marking the farthest downvalley evidence of glaciation in the Sandy River valley. Age of the till is uncertain, but on the basis of degree of soil development, we think it is probably about 150 ka. A stratigraphic sequence (now mostly overgrown) described by Crandell (1980) on a road to a rock quarry a short distance south of the highway exposes two lahar deposits of pre-Polallie age that overlie a sequence of colluvium, loess, and buried soils that in turn overlie Hayden Creek till. The colluvium contains a bed of a pumiceous tephra identified as Mount St. Helens set C, which is older than 30 ka (Mullineaux, 1986) and has a thermoluminescence age of 50 ka (Berger, 1991). We think the lahar deposits may be similar in age to the older deposits (L2-L4) seen at stop 3 in the Upper Hood River Valley and therefore older than the Polallie eruptive period (<20 ka) as defined by Crandell (1980). **0.6**

154.6 Cross Salmon River, which drains a small sector on the south flank of Mount Hood. Road ahead traverses terrace underlain by lahar deposits of broadly Polallie age. Noah's Ark ahead on left. **1.8**

156.4 Hummocky topography formed in landslide deposits from the south valley wall. **3.1**

159.5 Old cohesive lahar deposits in roadcut on left across from Cherryville Drive; they contain abundant clasts of vesicular to dense fresh gray andesite from Mount Hood. The deposits underlie a terrace that is about 75 m above the Sandy River and about 50 m higher than the terrace on the north side of the highway, which is underlain by lahar deposits of broadly Polallie age. The higher terrace and its cohesive lahar deposits are probably older than 100 ka. For next few miles, roadcuts expose lahar and alluvial deposits that form surfaces lying 150–200 m above the Sandy; they bear well-developed red clayey soils. Age of deposits and surfaces is unknown but could be as much as 500 ka or older. Downstream from here, the Sandy River enters a narrow canyon that drains west and then north toward the Columbia River. The terraces rise higher above the river downstream as they define gentler gradients than does the present channel. **5.6**

Springwater, Gresham, and Estacada Formations of Trimble (1963)

Trimble (1963), in his study of the geology of the Portland area, defined several map units that contain lahar (mudflow) deposits along the Sandy River west and downstream from these exposures along U.S. 26: from oldest to youngest they are the Springwater, Gresham, and Estacada Formations. The Gresham and Estacada form terraces in the Sandy River canyon that lie about 90–120 m and 60–90 m, respectively, above present river level; the Springwater underlies the broad surface into which the Sandy River canyon is cut and lies more than 60 m above the Gresham surface. The Hood lahar deposits across from Cherryville Drive (mile 159.5) underlie a terrace that is probably correlative with terraces underlain by Gresham Formation farther downstream; the terrace north of the highway that is underlain by lahar deposits of broadly Polallie age is probably correlative with downstream terraces underlain by the Estacada Formation (J.W. Vallance, oral commun., 1992)

165.1 Shorty's Corner. Road ahead is on Springwater Formation; note thick, red, clayey soils in roadcuts between here and Sandy. Trimble (1963) notes that the red soil is as thick as 6 m, and total depth of weathering is on the order of 20 m. **7.3**

172.4 Boring exit (OR 212); continue on U.S. 26. **1.5**

173.9 Hill '902' (spot elevation on topographic quadrangle) on north side of highway is Boring Lava (Trimble, 1963). **3.9**

177.8 Traffic light; U.S. 26 veers to left. Stay straight ahead on Burnside, toward I-84. **0.7**

178.5 Turn right onto 242nd Drive, headed toward I-84. **3.0**

181.5 Junction with I-84; head west toward Portland. **7.2**

188.7 Junction with I-205; stay on I-84. Continue 5.5 miles west to the Holliday/Lloyd Center exit; turn right on 12th to Red Lion Hotel.

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Appendix 1. Selected geochemical analyses of Mount Hood rocks and deposits

Sample no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Location	White River	Crater Rk	Sandy R.	L. ZigZag River	Salmon River	Miss. Head	Compass Creek	Cooper Spur	Lamberson Butte	RR lahar	Top Spur	Muddy Fk.	Coe Branch	upper Meadows	Cooper Spur Rd	Zigzag	Tmb. Rd
unit	hoc	hol	hoc	htc	htc	hlp	hpc	hpc	hpc		hct	hcm	hl	hl	hl	hl	hl
Field no.	G891004-3	S911003-6	G891005-2	MTH8	S900708-2	S910918-2	920806-1	940901-4	940823-1	921006-3A	S910816-1	920626-4	930810-6	S890920-3	931029-6	92T-62	RIT-92
SiO2	62.8	63.2	63.7	62.2	63.4	61.2	62.5	62.5	63.5	59.2	61.2	61.8	57.9	58.9	59.2	59.5	59.9
Al2O3	17.4	17.0	16.7	17.1	16.9	17.4	17.2	17.1	16.7	18.5	17.5	17.3	18.0	18.1	18.1	18.2	17.6
FeTO3	5.29	5.37	5.29	5.79	5.26	6.16	5.58	5.42	5.33	6.37	5.67	5.79	6.66	6.75	6.94	6.25	6.24
MgO	2.45	2.45	2.45	2.59	2.41	2.72	2.54	2.51	2.44	3.15	2.52	2.74	4.34	3.22	3.27	3.23	3.38
CaO	5.45	5.23	5.22	5.42	5.26	5.80	5.45	5.51	5.21	6.55	5.83	5.59	7.13	6.49	5.73	6.43	6.34
Na2O	4.31	4.31	4.22	4.27	4.28	4.17	4.19	4.25	4.23	4.07	4.21	4.26	3.92	4.00	4.06	3.87	4.11
K2O	1.33	1.40	1.43	1.46	1.42	1.35	1.47	1.58	1.56	0.95	1.81	1.37	1.01	1.29	1.28	1.34	1.20
TiO2	0.77	0.77	0.75	0.82	0.76	0.89	0.80	0.80	0.75	0.88	0.90	0.85	0.82	0.99	1.02	0.86	0.87
P2O5	0.18	0.19	0.18	0.25	0.18	0.24	0.20	0.23	0.22	0.16	0.23	0.21	0.18	0.20	0.24	0.21	0.20
MnO	0.09	0.09	0.09	0.10	0.09	0.10	0.09	0.09	0.09	0.11	0.09	0.10	0.10	0.11	0.11	0.10	0.10
XRF data																	
Nb	10	<10	13	<10	13	13	10	<10	<10	<10	<10	<10	<10	11	10	<10	<10
Rb	25	21	21	26	25	24	27	24	25	14	25	22	19	21	20	15	20
Sr	640	520	520	530	590	610	590	610	510	560	910	650	750	570	620	720	580
Zr	164	152	168	188	170	186	172	184	190	124	205	166	126	180	164	170	166
Y	22	14	21	18	24	24	13	<10	19	11	<10	<10	<10	23	20	15	15
Ba	350	330	390	355	390	350	350	390	360	220	440	360	275	325	340	310	330
Ce	36	35	37	39	31	40	46	55	<30	<30	61	38	32	32	45	44	52
Cu	13	20	19	36	24	24	32	27	24	16	32	19	26	51	34	57	47
Ni	18	12	15	23	17	18	13	13	19	14	15	14	34	24	22	19	28
Zn	61	46	54	89	53	60	49	52	46	49	63	50	41	64	64	53	56
Cr			<20					<20	<20				41		31	24	40
INAA data																	
Hf	3.72	3.86	4.12		3.86	4.09	4.17					4.29	2.92	4.02			3.58
Ta	0.661	1.53	0.716		0.708	0.759	0.685					0.711	0.39	0.705			0.62
Th	2.54	3.15	2.88		2.8	3.16	3.45					3.37	2.44	3.09			2.49
Rb	18.4	24	16.7		19.4	21.1	30.8					14.7	12	18.8			19
La	15.4	17.6	17.6		17	19	19.7					19.5	15.1	19.2			16.1
Ce	31.7	34.3	36.9		36.3	41.2	41					42.8	30.2	40.5			31.8
Nd	16.3	16	18.9		17.7	20.5	21.4					22.5	17	21.4			16
Sm	3.5	3.63	4.17		3.62	4.54	4.47					4.78	3.55	4.62			3.71
Eu	1.09	1.01	1.13		1.1	1.27	1.24					13	1	1.3			1.09
Tb	0.43	4.555	0.49		0.466	0.511	0.507					0.545	0.43	0.567			0.49
Yb	1.31	1.3	1.33		1.39	1.43	1.42					1.5	1.3	1.65			1.3
Lu	0.185	0.184	0.21		0.201	0.198	0.215					0.222	0.18	0.251			0.19
Latitude	45 21 26	45 22 09	45 23 23	45 18 52	45 18 23	45 21 28	45 23 58	45 23 13	45 21 55	45 40 52	45 24 24	45 23 56	45 24 55	45 20 48	45 25 41	45 19 04	45 18 29
Longitude (deg min sec)	121 44 30	121 41 56	121 48 11	121 48 12	121 41 32	121 43 26	121 40 42	121 39 53	121 39 27	121 30 27	121 47 03	121 45 27	121 40 26	121 40 42	121 35 05	121 48 37	121 42 20
analyst	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Sample no.	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Location	Hwy 26	Yocum ridge	Cathedral ridge	Wallalute Falls	Illumin. Rock	Cathedral quarry	Cooper Spur rd	Pinnacle	hwy 35 upper	S. Lady Creek	hwy 35 lower	Dog River	Yocum Falls	Wallalute Falls	Parkdale
unit	hl	hl	hl	hl	hl	hl	hlcc	bap	hlcc	balc	badr	badr	bayf	hlcc	bapk
Field no.	92T-58	950921-2	920701-2	930812-1	S911018-3	920709-qu	930715-1	92T-12	RCMTH-13	951031-2	RCMTH-12	S90-H4	RIT-32	930812-2	92T-55
SiO_2	61.1	61.1	61.5	61.7	62.6	54.9	55.2	55.6	55.7	56.1	56.2	56.3	56.9	57.8	58.3
Al_2O_3	17.3	17.3	17.6	17.5	17.2	18.4	18.6	18.3	17.9	18.7	17.7	18.2	17.9	17.9	17.9
$FeTO_3$	6.07	5.95	6.05	5.80	5.58	8.52	8.24	8.01	7.97	8.48	7.47	7.65	7.28	7.08	7.10
MgO	3.23	3.10	2.68	2.63	2.49	4.53	4.38	4.64	4.37	3.15	4.36	4.03	3.82	3.76	3.36
CaO	5.77	5.99	5.72	5.80	5.53	7.66	7.13	7.42	7.29	6.91	7.57	7.28	7.17	6.84	6.62
Na_2O	4.15	4.11	4.12	4.20	4.09	3.84	4.17	3.70	4.49	4.16	3.88	3.85	4.09	4.25	4.34
K_2O	1.23	1.28	1.28	1.27	1.47	0.68	0.68	0.92	0.70	0.64	1.07	1.12	1.30	0.90	0.88
TiO_2	0.84	0.85	0.83	0.84	0.80	1.09	1.22	1.09	1.23	1.38	1.15	1.21	1.13	1.03	1.12
P_2O_5	0.21	0.20	0.20	0.23	0.19	0.23	0.27	0.21	0.24	0.29	0.26	0.27	0.30	0.28	0.28
MnO	0.10	0.09	0.11	0.09	0.09	0.14	0.12	0.13	0.12	0.12	0.12	0.12	0.11	0.11	0.10
XRF data															
Nb	<10	10.5	<10	<10	12	<10	<10	<10	9.6	11.2	11.3	<10	<10	<10	10
Rb	22	19	13	22	28	11	<10	14	8	5	17	18	18	12	12
Sr	530	516	550	570	560	550	600	580	610	587	740	760	890	620	640
Zr	158	151	156	162	178	132	128	140	125	130	164	180	164	160	162
Y	16	16	<10	13	25	18	<10	21	17	18	19	22	16	12	17
Ba	345	280	280	315	370	192	210	205	210	176	300	330	330	290	295
Ce	33		<30	52	<30	38	<30	<30	27		36		36	38	<30
Cu	33		33	36	30	42	34	36	88		80	53	50	28	42
Ni	34	38	18	15	15	44	46	44	54	15	50	49	29	36	25
Zn	63	67	54	52	50	81	62	71	94	100	79	63	72	54	78
Cr	40	49		28			61	72	81	19	66	43	49	50	43
INAA data															
Hf	3.72			3.68	4.08		2.92							3.53	3.48
Ta	0.66			0.67	0.711		0.534							0.635	0.66
Th	2.38			2.77	3.38		0.82							1.48	1.2
Rb	19			21	22.3		8.9							13	12
La	15.2			17.7	19.7		11.5							16.2	14
Ce	31.1			36	39.1		24.7							32.7	30.1
Nd	16			18	19.9		15							18	16
Sm	3.75			4.08	4.12		3.9							4.31	4
Eu	1.11			1.17	1.16		1.2							1.29	1.31
Tb	0.48			0.48	0.503		0.528							0.564	0.51
Yb	1.3			1.5	1.46		1.5							1.6	1.4
Lu	0.2			0.18	0.216		0.19							0.23	0.2
Latitude	45 17 24	45 22 33	45 24 36	45 22 34	45 22 03	45 26 28	45 27 23	45 26 18	45 27 52	45 19 04	45 27 50	45 25 53	45 18 23	45 24 52	45 21 36
Longitude (deg min sec)	121 44 06	121 43 02	121 44 10	121 40 34	121 42 41	121 45 36	121 35 55	121 42 37	121 34 35	121 49 40	121 34 36	121 33 45	121 47 26	121 39 11	121 43 6
analyst	1	1,2	1	1	1	1	1	1	2	1,2	2	1	1	1	1

Notes: Major elements reported in weight percent and normalized water-free; trace elements in parts per million. Analyses by U.S. Geological Survey (1) and Washington State University (2). Where both referenced, major-element analyses by U.S.G.S., trace-element analyses by W.S.U. All major elements by wave-length dispersive X-ray fluorescence (XRF); trace elements by energy-dispersive XRF and instrumental neutron activation analyses (INAA) (U.S.G.S.), and by wave-length dispersive XRF (W.S.U.).