State of the Arc 2003
Timberline Lodge
August 16-23, 2003

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

by

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

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This field trip provides the participants of the State of the Arc Conference (SOTA, Timberline Lodge, 16-20 August 2003) with a broad understanding of the evolution of Mount Hood volcano – mostly from a field context - from stops at several viewpoints and at outcrops that sample the range of eruptive products and other deposits around the volcano. Our current efforts are focused on preparing a 1:24,000-scale geologic map of the volcano, obtaining chemical analyses and petrographic descriptions of eruptive products, and developing a detailed geologic history of the volcano through radiocarbon and K/Ar dating and secular-variation paleomagnetic studies.

The trip begins with a hike from Timberline Lodge to an overlook above the upper White River valley. The trip continues by vehicle on U.S. 26 and Oregon 35 around the south and east flanks of the volcano, into the Upper Hood River Valley, and up to Cloud Cap Inn on the north flank. Most of the stops are on public land, but Stop 6 is on private land.

OVERVIEW OF MOUNT HOOD VOLCANO

Mount Hood is a chiefly andesitic volcano of Quaternary age built by a succession of lava-flow and lava-dome eruptions (Wise, 1968, 1969; Crandell, 1980; Scott and others, 1997). Its volume of about 50 km^3 (Sherrod and Smith, 1990) is mid-sized among the major Cascade volcanic 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 unstable lava domes and generation of pyroclastic flows, which in turn melt snow and ice to form lahars that flow far down valley; (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 down valley. The debris-avalanche and lahar hazards need not necessarily 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 K-Ar geochronology, has been recurrently active for the past 1.5 m.y. (fig. 1). Much of the upper cone of Mount Hood is composed of lavas younger than 200 ka. With additional geochronological data we should be able to make a well-constrained estimate of Mount Hood's 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 some map units remain undated and stratigraphic relations in many locations need further resolution.

Explanation of map units

	Alluvial and glacial deposits		Mount Hood volcano:			Lava flows and pyroclastic deposits of other vents in map area
			clastic deposits	lava flows and domes		
		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

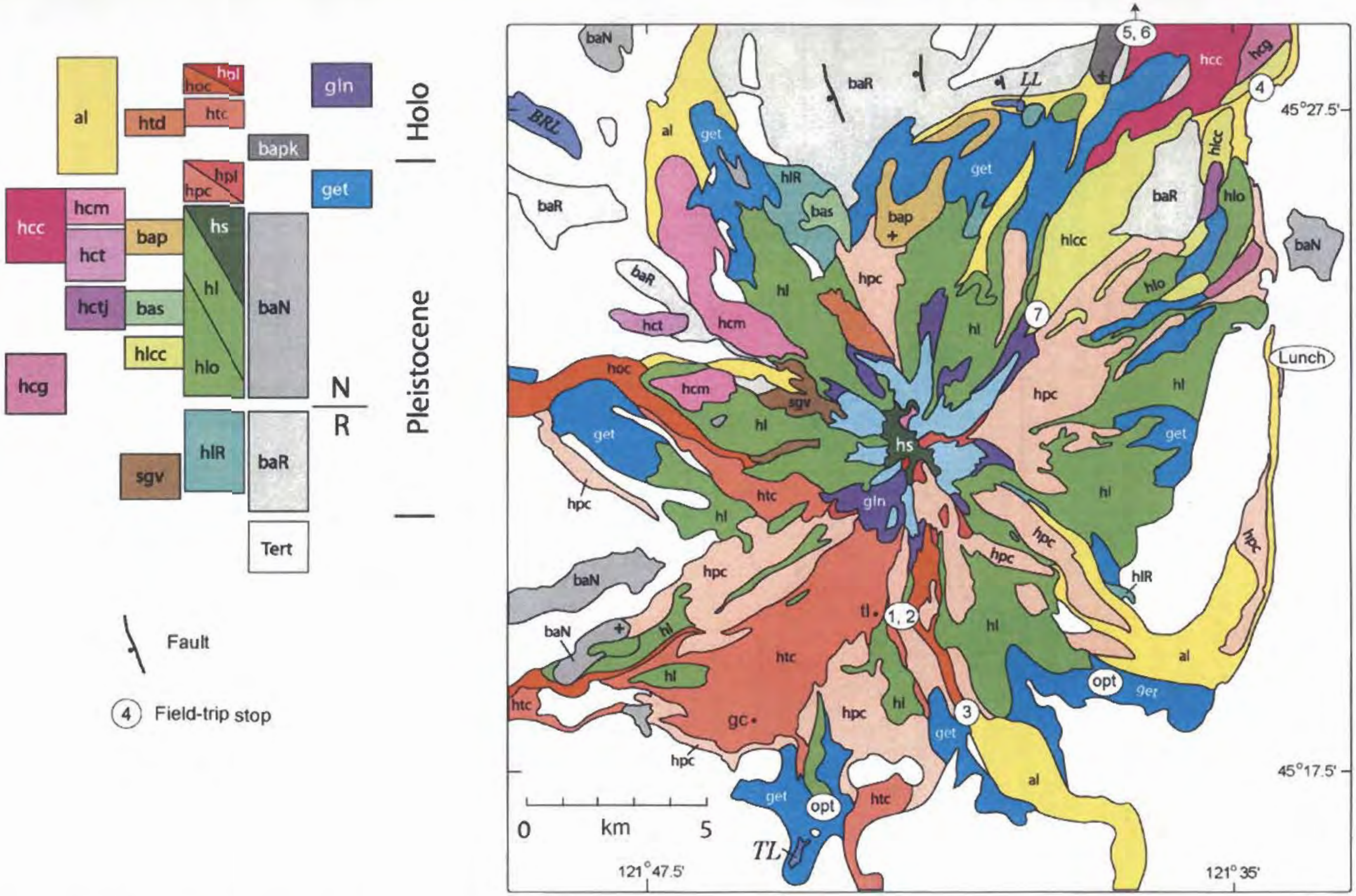


Figure 1. Generalized geologic map of Mount Hood. Sources include unpublished mapping by authors, Sherrod and Scott (1995), Wise (1969), BRL, Bull Run Lake; LL, Laurance Lake; tl, Timberline Lodge; gc, Government Camp.

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 these rocks also as andesite, not dacite. K/Ar ages are reported with one-sigma error.

Dome rocks are more vesicular than most lava flows. Pyroclastic-flow deposits at Mount Hood typically consist of slightly to moderately vesicular clasts, which likely originate by gravitational collapse or explosive disruption of still-hot 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. Lahar, or volcanic debris flow, debris avalanche, and glacial processes also produce deposits of massive, nonsorted sediment. Table 1 summarizes the characteristics by which we distinguish among them. We use the non-genetic term, diamict, to refer to such deposits of unknown origin or to sequences that include a variety of deposits.

Table 1. Characteristics used to distinguish diamicts of various origins at Mount Hood; most useful are in bold.

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

Record before 300 ka

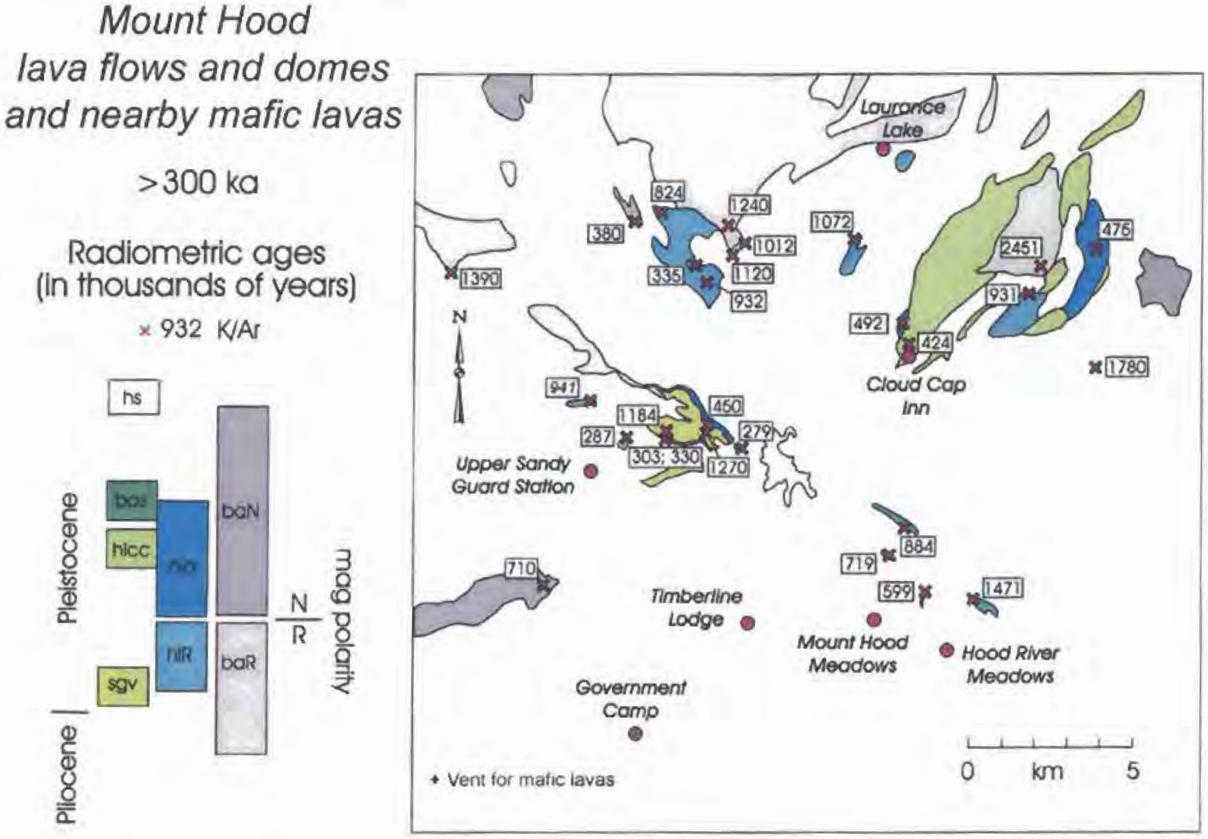


Figure 2. Map showing lava flows and domes of Mount Hood and surrounding vents and radiometric ages. For this and the next two figures, K-Ar ages from Lanphere, Keith and others (1985), and Sherrod and Scott (1995); see text for sources of ^{14}C ages.

The reversely magnetized 1.2-Ma, basaltic to andesitic Sandy Glacier volcano underlies the west flank of Mount Hood (fig. 2,3; Wise, 1969). Other andesite lava flows with reversed-polarity magnetization crop out on ridges north of the volcano and in deep canyons on the southeast flank (see fig. 17). Normally polarized lava flows that have ages of about 930 ka crop out on the northwest and northeast (mile 43.7) flanks. The outcrop patterns of these lavas suggest that their vents 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.

Andesite lava flows older than 300 ka erupted during the Brunhes Normal Polarity Chron have a distribution similar to that of the older lavas—isolated distal ridges and deep canyons. A major exception is ~300-to-500-ka lavas high on the west flank below Sandy Glacier. We suspect that lack of preservation and burial by younger deposits is the explanation for the lack of extensive exposure of lavas older than 300 ka rather than a reduced rate of lava production.

Figure 3. Headwaters of Muddy Fork of Sandy River showing Sandy Glacier volcano underlying west flank of Mount Hood. sg, Sandy Glacier; rg, Reid Glacier; aval, rock avalanche of altered material, probably 20th century.

Several basaltic-andesite volcanoes of Quaternary age grew prior to 300 ka in the north and west sectors. The most extensive one, the 424-ka basaltic andesite of Cloud Cap, will be seen at Stops 4 and 7. Wise (1969) inferred that the Cloud Cap lava was relatively young and that it postdated the major cone-building of Mount Hood. The three Hood lavas that demonstrably underlie basaltic andesite of Cloud Cap range from 475 to 931 ka. We find that Cloud Cap lavas form a broad wedge on the northeast flank that has been abutted 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.

300 to 150 ka

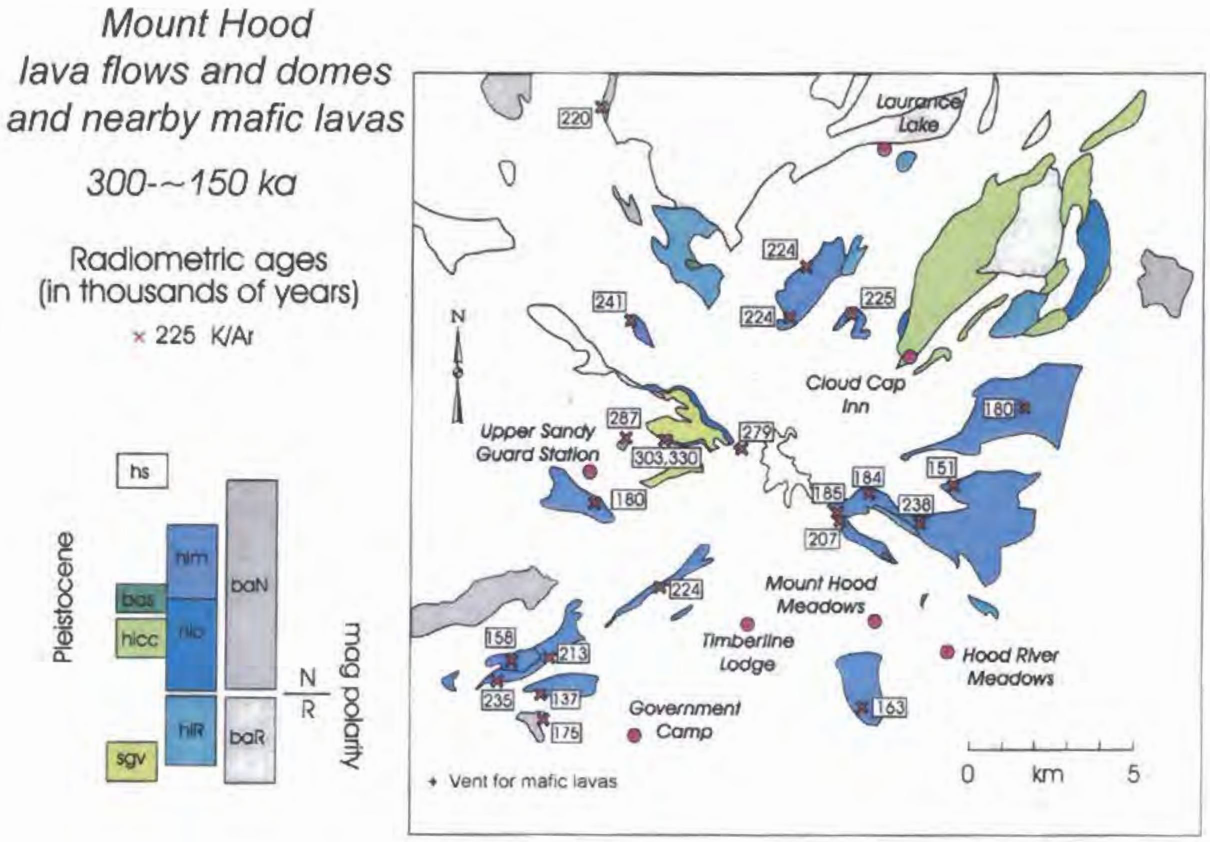


Figure 4. Map showing lava flows and domes of Mount Hood and surrounding vents and radiometric ages.

The time period from 300 to 150 ka is represented by sequences of lava flows on all flanks (fig. 4). Most are exposed as intracanyon flows or broad flow aprons in areas below treeline. But flows dated about 200 to 300 ka are found high on the cone on the southeast (fig. 17) and west (fig. 3) flanks. The closest the trip gets to a lava flow in this age range is a distant view of the 163-ka flow along the east side of White River across from Stop 3. A lava-flow sequence exposed in the bottom of upper Zigzag Canyon west of Timberline Lodge that forms the north wall of lower Zigzag Canyon is about 225 ka in age (individual ages range from 213 to 235 ka).

One of the few olivine-bearing andesites erupted from Mount Hood is exposed deep in Coe Branch and Compass Creek valleys on the north flank. Wise (1968, 1969) thought it to be perhaps one of the oldest lavas on the volcano, but, although it is deeply buried, its age of 225 ±17 ka makes it middle aged. The thick overlying sequence of lavas has an age of 86±10 ka (fig. 5).

Three dated mafic lava flows of this time period lie in the area of Figure 4. One is the basaltic andesite of Yocum Falls (175 ± 12 ka), which is exposed beneath diamicts of Polallie age in roadcuts along U.S. 26 west of Government Camp. Its vent, which hasn't been located, must be on the north side of Tom Dick and Harry Mountain near Mirror Lake. Another unit is along the West Fork of

Hood River low on Blue Ridge, northwest of Mount Hood. Conrey and others (1996) report a K/Ar age of 220 ± 90 ka. A small isolated body of barely andesite (57.3 wt % SiO_2) on Yocum Ridge is 287 ± 19 ka. Like the vent for the basaltic andesite of Cloud Cap, its vent must also be within 5 km of the summit of Mount Hood.

< 150 ka

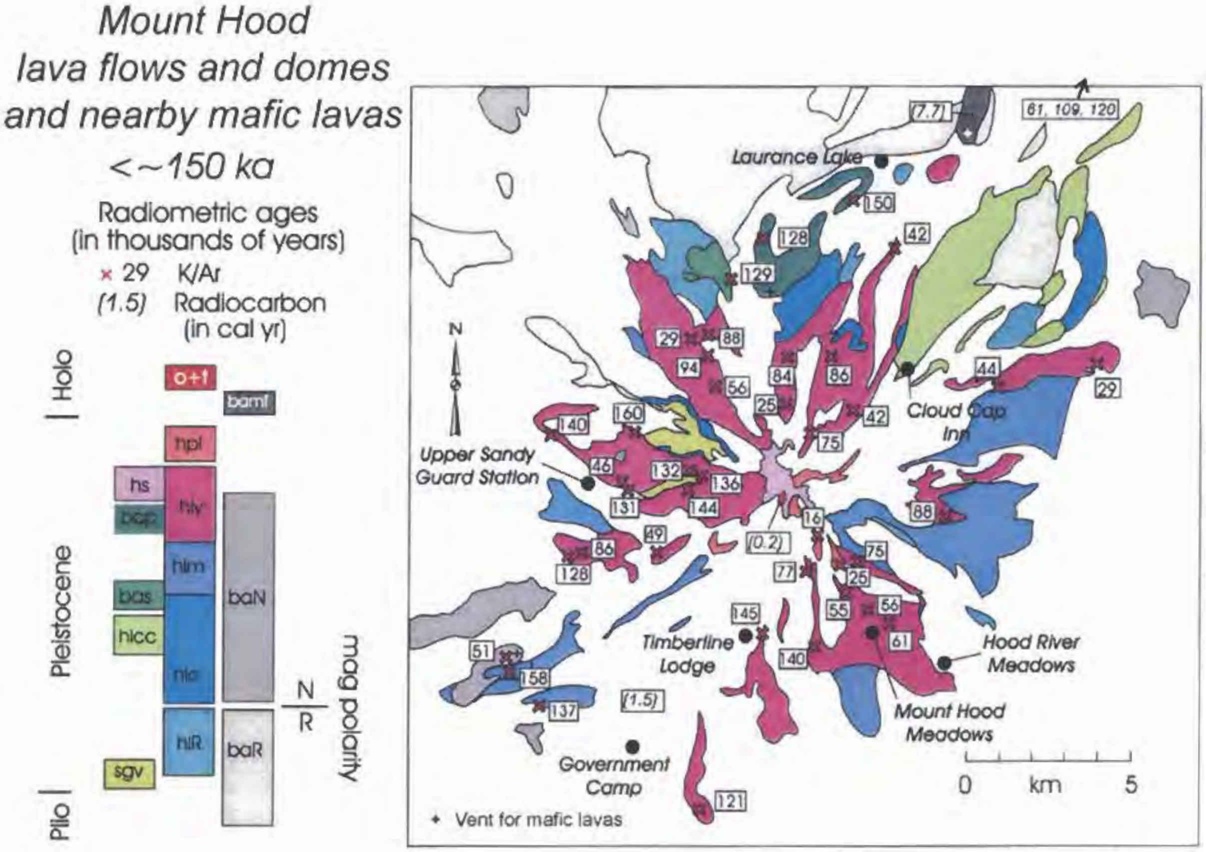


Figure 5. Map showing lava flows and domes of Mount Hood and surrounding vents and radiometric ages.

Lava flows younger than 150 ka have been mapped on all flanks of the volcano and form most of the upper part of the cone (fig. 5). Units of this age form the prominent ridges that head near the summit, such as Yocum Ridge and the ridge of Illumination Rock on the west flank (~130 to 160 ka), Cathedral Ridge-McNeil Point (29 to 56 ka) to the northwest, Snow Dome-Langille Crags-Barrett Spur (25 to 86 ka) to the north, and a broad complex of flows around Mount Hood Meadows (~50 to 60 ka) to the southeast. All of these flow sequences were overridden by glaciers of Evans Creek age and many are partly buried by moraines. *En route* to **Stop 3**, we'll drive past large outcrops of a 121-ka, south-flank andesite flow along U.S. 26 (mile 5.9). Mile 20.9 describes the andesite of Tamanawas Falls on the east flank (29 ± 11 ka and 44 ± 9 ka), which entered the East Fork Hood River valley and pushed the river eastward, resulting in erosion of a narrow canyon.

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 The Pinnacle, the only other mafic eruptions that occurred in the Mount Hood region were the 7.7-ka basaltic andesite of Parkdale (**Stop 6**), eruptions of barely andesite from a vent in lower Zigzag Canyon at 51 ± 14 ka, and, possibly, Lost Lake Butte, a small shield volcano whose lava apron edges into the northwest corner of the map area.

Lava domes since 30 ka

Most volcanic activity since the ~30-to-50-ka eruptions that emplaced extensive lava flows in several sectors 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 2; figs. 1, 5). However, because generation of pyroclastic flows and lahars related to dome growth are potentially the most hazardous types of activity, 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 of the Timberline eruptive period form the extensive fan near Timberline Lodge that gives the southwest flank its distinctive morphology **(Stops 1 and 2)**. 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 Eliot Glacier on the northeast flank (**Stops 5 and 7**) and Steel Cliff (**Stops 1, 2, and 3**) on the southeast flank are the most striking examples of these domes. Both 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 20 to 25 ka (Porter and others, 1983). Other deposits of Polallie age on the north, west, and southwest flanks (fig. 1) cannot be tied closely to conspicuous near-summit lava domes, although much of the variably hydrothermally altered summit mass (unit hs in fig. 1) is probably composed of lava domes, many of which could be sources for these diamicts.

crater rock [illegible] dome

Table 2. 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 to 10 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, Barrett Spur, Snow Dome-Langille Crags, and Tamanawas Falls

A thick sequence of probably pre-Polallie 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 (fig 1, unit hcm). 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 doubtless be eroded preferentially 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 apt 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 2), 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 later 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 but transient load imposed by volcaniclastic deposits emplaced during Old Maid eruptions. They also described a large bar between two distributary channels that forced 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 still-hot conduit and dome (Crater Rock), which was 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 mappable 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 (days) 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. 6). One to several swarms per year have been recorded since the seismic system was upgraded in 1980.

A typical swarm consists of tens of events including a few of magnitude 2 to 3. Some swarms consist of main shock-aftershock sequences; in others the largest event occurs within the swarm. The largest event since 1980 was a M4.5 event on June 29, 2002, which was accompanied by more than 100 smaller earthquakes. Recent work using relocation techniques (Jones and Malone, 2002a and b) show that events occur in four distinct clusters: 1) a small cluster just south of the summit, 2) a tight cluster 9 km south-southwest of the summit, 3) a N-S linear feature about 5 km south of the summit and 4) a linear NW-SE feature a few kilometers farther south of 3. Events show a distinct increase in depth with increasing distance from the summit. Mechanisms, relative locations, and swarm characteristics indicate that the earthquakes are more likely related to volcanic processes than regional tectonic stresses.

Earthquake epicenters, 01/01/1993 - 07/23/03

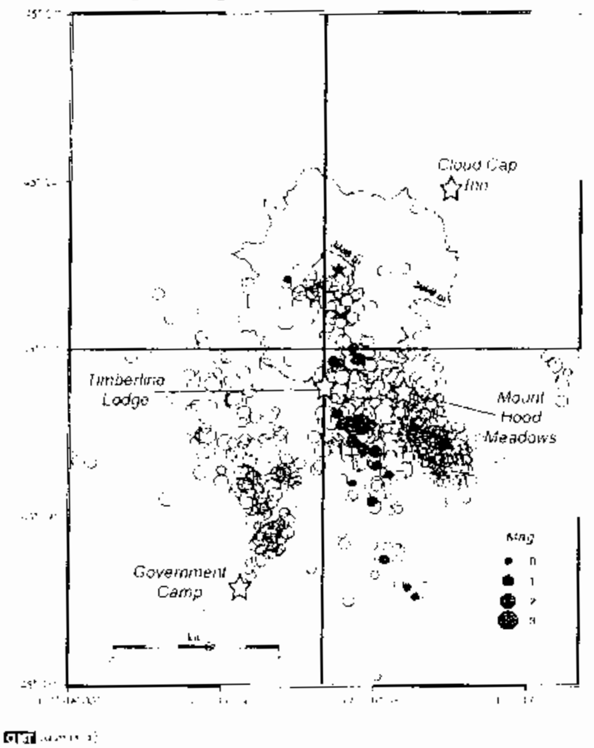
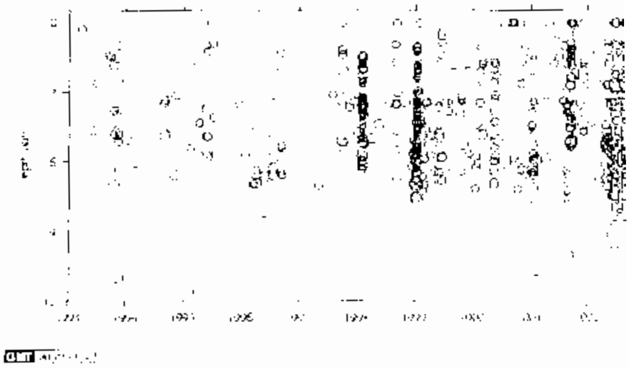


*Figure 6. **A**, Map showing earthquake epicenters in the Mount Hood area for the past decade. **B** Time depth plots of events shown in A.*

Mt. Hood Seismicity, 1993 - Present



FIELD GUIDE

The field trip starts from Timberline Lodge. We will walk to the first two stops and then get into vehicles for the rest of the field trip. The road-log portion of the field trip starts from the Timberline parking lot, just opposite the entrance to the day lodge.

Walk north from Timberline Lodge to the Timberline Trail and head east. The first stream crossing is one of the tributaries of the headwaters of the Salmon River. Stop 1 is bout 100 m north of the stream crossing.

Stop 1. Mount Hood andesite lava flow underlying latest Quaternary deposits of pyroclastic flows and lahars

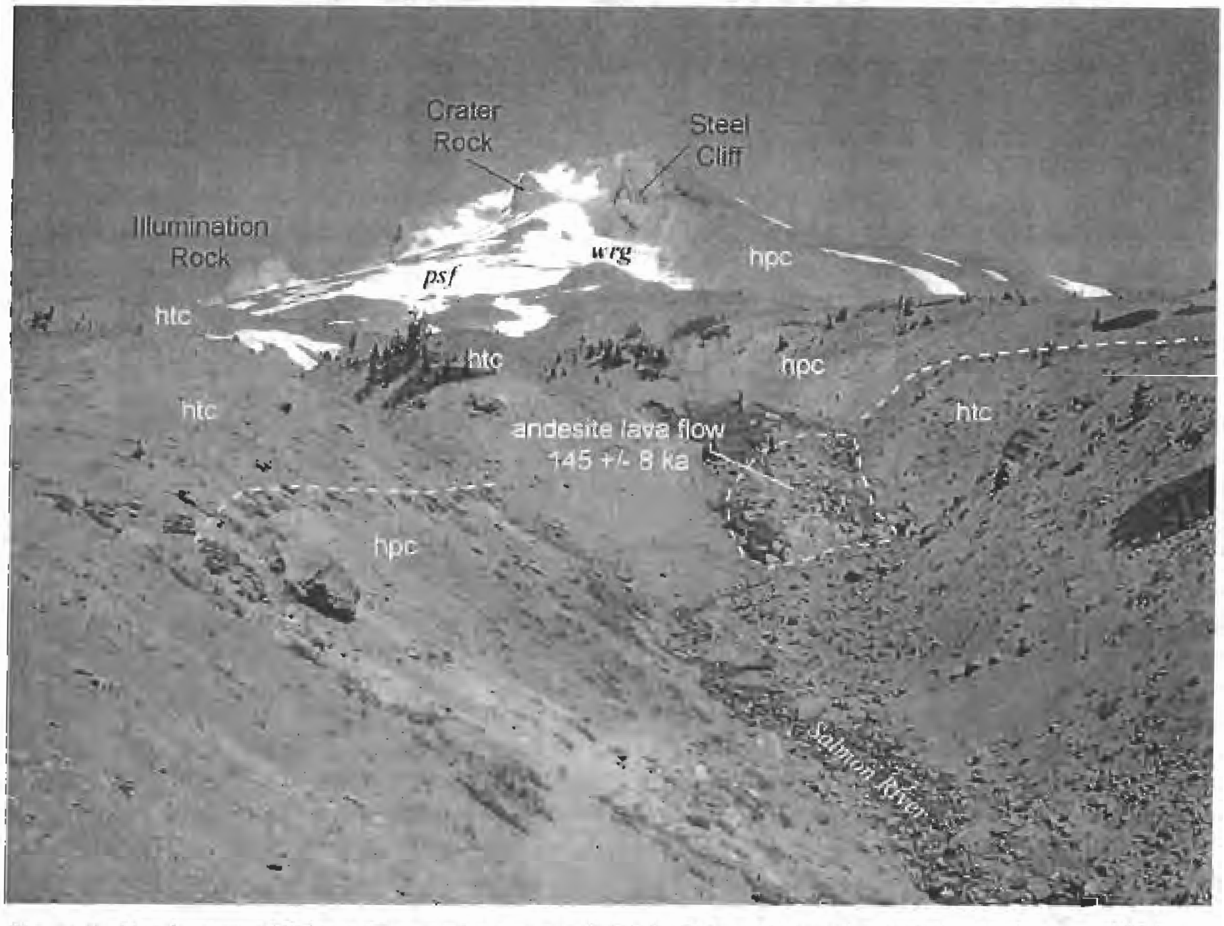


Figure 7. Headwaters of Salmon River and upper south flank of Mount Hood showing contact between 145 ka ± 8 lava flow and younger diamicts of Polallie age, hpc, and Timberline age, htc. psf, Palmer snowfield; wrg, White River Glacier.

The Salmon River, which heads as a meltwater stream from Palmer snowfield, has cut this shallow canyon through the south-flank volcaniclastic fan of latest Quaternary age to expose an underlying lava flow at altitude 1850 m (6100 ft) (fig 7). This is the highest exposure of a lava flow on the fan, which extends upslope to the base of Crater Rock at about 3050 m (10,000 ft). Crater Rock (63.4 wt. % SiO_2) is the youngest lava dome on the volcano and was the vent for the last major eruption of Mount Hood (Old Maid eruptive period), which occurred about 200 yr ago. It may also be the vent site for eruptions during the Timberline eruptive period about 1,500 yr ago. Crater Rock lies in the breached summit crater, which was formed by a debris avalanche, probably at the beginning of the Timberline eruptive period.

Most of the fan surface west of here, as well as the terrace along the east side of Salmon River downstream, is underlain by reddish-gray, coarse-grained diamicts of the ~1500-yr-old Timberline eruptive period (htc). The highly crystalline, dense prismatically jointed to inflated reddish-brown and gray clasts are typical of those derived from collapse of a growing lava dome. Evidence that the dome may have grown in the same area as Crater Rock is shown by paleomagnetic data for the dome lava at the southern base of Crater Rock that has the same secular-variation paleomagnetic direction as block-and-ash flow deposits of Timberline age (fig. 8). Dome collapses generated block-and-ash pyroclastic flows that melted snow and ice to form lahars that traveled down the Sandy and Salmon rivers to the Columbia. In proximal areas, deposits of pyroclastic flows and lahars are so similar that it is often difficult to identify the origin of a given diamict with confidence (Table 1). In this area, deposits of the Old Maid eruptive period consist only of discontinuous, thin gray sands and fine gravel. The great bulk of Old Maid deposits (hoc) are found in the White River valley to the east and the upper Sandy River valley to the west (fig. 1).

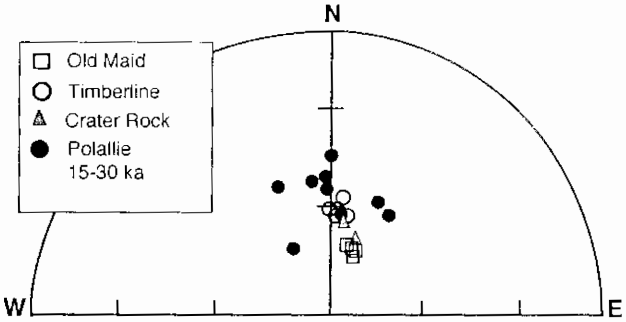


Figure 8. Paleomagnetic directions for pyroclastic-flow deposits and lava dome from Old Maid (~200 yr B.P.), Timberlin (~1,500 yr B.P), and Polallie (15-30 ka) eruptive periods. Mean direction for Ol Maid is D=18.5°, I=70° down; for Timberline, D=5° and I-62° down.

Gray diamicts of the latest Pleistocene Polallie eruptive period (hpc) capped by a yellowish-brown soil crop out locally downstream from the lava flow and below diamicts of Timberline age. Such deposits, which are of similar origin to those of Timberline age, also form the rolling surface upstream to the east of Salmon River. The disconformity on deposits of Polallie age marked by the yellowish-brown soil has tens of meters of relief in this area. Deposits of Timberline age filled canyons cut in Polallie deposits, and erosion over the past 1500 years has recut canyons down to the resistant lava flow. A series of falls downstream cut through the flow and head a much deeper Salmon River canyon in which deposits of Timberline age form a terrace about 60 m above the canyon floor.

Steel Cliff (62.2 wt. % SiO_2), the steep face on the southeast crater rim, is a lava dome of Polallie age that will be discussed further at **Stop 2**. A fan of diamicts can be seen below and east of the dome.

Illumination Rock (62.6 wt. % SiO_2), the prominent tower below and west of the summit, is part of a sequence of lava flows that is similar in age (144 ± 11 ka) to the lava flow here. The Illumination

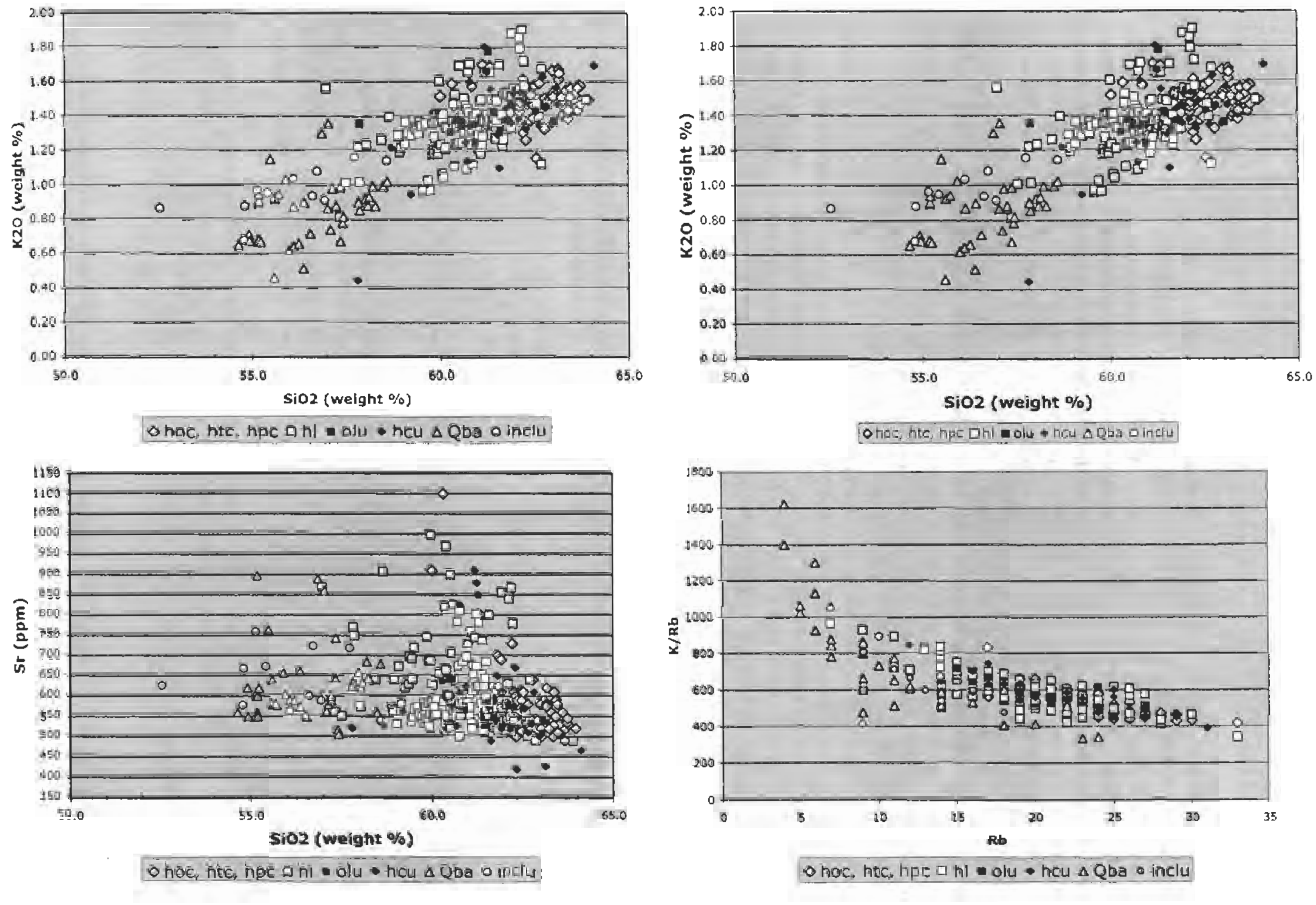


Figure 9. Silica-variation diagrams for selected major- and minor-element data. hoc, Old Maid diamicts; htc, Timberline dimicts; hpc, Polallie depsoits; hl, Hood lavas <500 ka; olu, Hood rocks >500 ka; hcu, clastic rocks > 30 ka; Qba, basaltic andesite lavas whose vents are on the flanks of Mount Hood; inclu, inclusions.

sequence extends west into the upper Sandy River valley and probably forms part of the western crater wall.

The lava flow (K-Ar age of 145 ± 8 ka) is one of a sequence of flows of similar age and composition that we will see exposed intermittently as we drive southward to U.S. 26 and eastward on U.S. 26 toward Oregon Highway 35. The lava is a typical Mount Hood andesite. Lava flows and clastic deposits from Mount Hood span from 57 to 64 wt.% SiO_2 (fig. 9); this flow has 60.0 wt. %. It contains 44.5% crystals (phenocrysts and microphenocrysts), composed dominantly of plagioclase with lesser amounts of orthopyroxene and minor clinopyroxene. As in most lava from Mount Hood, this flow contains some, mostly rounded, inclusions. We do not have a chemical analysis for inclusions from this site, but we have analyses on an inclusion from a likely distal equivalent of this lava flow that crops out on the Timberline Road. At that site, the lava flow contains 60.1 wt. % SiO_2, and the inclusion, 54.8 wt. % SiO_2. Although olivine is present in most basaltic andesite lava flows (<56 wt. % SiO_2) in the Mount Hood area, olivine is not present in the basaltic andesite inclusions, even those with silica contents <56 wt. % SiO_2.

Andesite lava flows and clastic deposits from Mount Hood show a relatively narrow range of chemical composition, mineralogy, and isotopic values (figs. 9, 10). Lavas and clastic deposits are typically phenocryst rich (most between 35 and 45 percent), with the mineralogy dominated by plagioclase with subordinate amounts of hypersthene and iron-titanium oxides ± augite, ± hornblende, ± olivine. There has been a general trend to slightly more silicic compositions during the last two eruptive periods (figs. 9,11), but otherwise it is difficult to discern any mineralogical or compositional trend over its entire eruptive history. $^{87}Sr/^{86}Sr$ values for Hood rocks younger than 150 ka range from 0.70328 to 0.70336 and $^{143}Nd/^{144}Nd$ from 0.51288 to 0.51293 (J. Arth, oral commun. 1994; fig. 10). The high Nd and low Sr isotopic values suggest little contamination of Hood magmas by more evolved crustal sources.

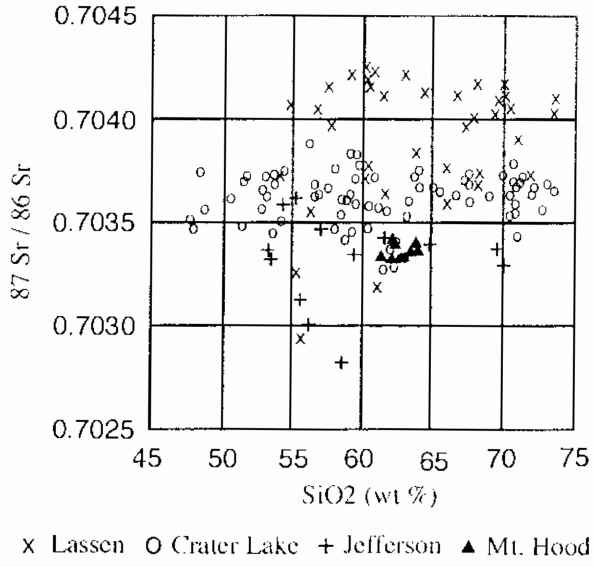


Figure 10. Plot showing $^{87}Sr/^{86}Sr$ versus SiO_2 for rocks from Lassen, Crater Lake, Jefferson and Mount Hood volcanoes. Figured modified from Conrey (1991). Mount Hood data from J. Arth, USGS, (unpublished data).

From trace-element data, White (1980) deduced that the Polallie, Timberline, and Old Maid deposits are unrelated to one another through simple crystal fractionation processes, a conclusion supported by our data. Basically, incompatible element values are higher in the slightly lower-silica Polallie deposits than the higher-silica Timberline and Old Maid deposits (fig. 11). 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 from available data if any one sequence is directly related to any other. A fundamental and presently unanswered question is how to produce such geochemically similar lavas of differing eruptive volumes and repose periods throughout the (at least) 0.5-m.y. life of the volcano. We will discuss further about the relationship of lavas during **Stop 4** where we will examine basaltic andesites from the flanks of Mount Hood.

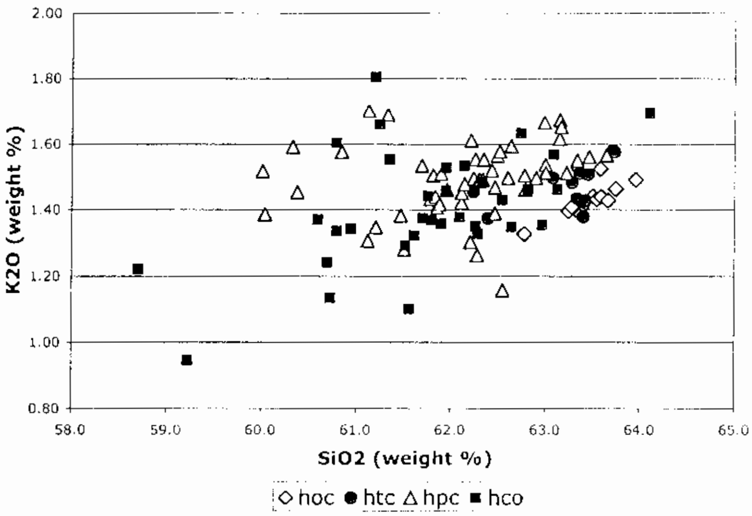


Figure 11. K_2O vs SiO_2 silica-variation diagram for pyroclastic rocks from Mount Hood. hoc, Old Maid (~200 yr B.P.); htc, Timberline (~1,500 yr B.P.); hpc, Polallie (15-30 ka); hco, older pyroclastic rocks.

Return to stream crossing and continue east along Timberline Trail towards the White River valley. The hike from **Stop 1** to **Stop 2** climbs through reddish diamicts of Timberline age onto the fan surface. Ahead the contact with deposits of Polallie age is marked by a change to grayer diamicts in which a yellowish-brown soil is formed and to more rolling terrain. The trail reaches the rim of the White River canyon and turns south. Continue on the trail through meadows and clumps of mountain hemlock and whitebark pine. About 500 m after reaching the rim (about 1700 m (5600')) the trail descends through loose sand. Leave the trail and walk east to the canyon rim.

Stop 2: Overview of the upper White River valley and Holocene ash-cloud deposits

The two western forks of White River are deeply incised in unconsolidated diamicts (fig. 12). The forks head at White River Glacier, a steep narrow glacier that is fed by snowdrift from the broad fan surface west of the glacier. The glacier is well known for sudden outbursts of meltwater that incorporate loose debris along channels to form debris flows. **Stop 3** will show the effects of such debris flows. White River Glacier is eroding a trench along the east margin of the south-flank fan leading up to Crater Rock, which insures that White River will be one of the principal pathways for pyroclastic flows if lava extrusion begins anew in the Crater Rock area.

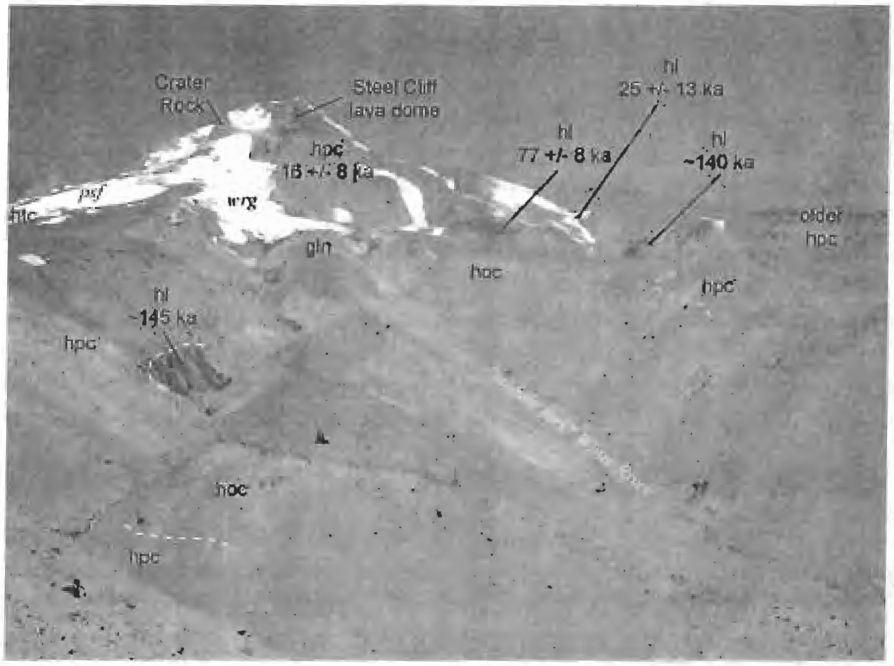


Figure 12. Upper White River valley showing contact relations between lava flows and pyroclastic-flow units. hl, Hood lava flow; hpc, Polallie diamicts (~15 – 30 ka); hoc, Old Maid diamicts (~200 yr B.P.); gln, neoglacial deposits; wrg, White River Glacier; psf, Palmer snowfield.

An andesite lava flow exposed in the informally named west fork of White River is probably of the same sequence, if not the same flow, as the 145-ka lava flow at **Stop 1**.

The lava flow is deeply buried by gray diamicts of Polallie age (hpc), which are well exposed in the cliff below and in terraces farther downstream. The diamicts occur in beds 1 to 3 m thick, are bouldery, poorly sorted, locally graded, and appear to have accumulated relatively rapidly as there is no sign of weathering or erosional disconformities between flow units. Prismatically jointed clasts occur in many beds. Diamicts of Timberline age cap the Polallie sequence upstream from the lava-flow exposure.

The wall of a paleovalley that was cut in Polallie deposits is visible below us where a soil that contains rooted snags is buried by diamicts (hoc) of the Old Maid eruptive period. The lack of charring of the snags is evidence that the initial diamicts that buried the paleovalley were not hot enough to burn vegetation. The snags yield radiocarbon ages of about 200 yr; detailed dendrochronology of trees killed or damaged during the Old Maid suggests that eruptions occurred during the last few decades of the 18th century (Pringle and others, 2002). The Old Maid deposits in the upper White River valley form two broad surfaces, the terrace in front of us that lies between the west and middle forks of White River and the surface east of the middle fork that terminates at a high ridge formed of deposits of Polallie age. A far- traveled block-and-ash pyroclastic flow of Old Maid age in the lower White River valley is the subject of **Stop 3**.

Diamicts of Timberline age have not been found in the upper White River valley. They occur on the west rim of the upper canyon, but are not found in the reach below us. Lahar, lahar-runout, and alluvium found 20 km downstream record some sort of disturbance of the watershed during Timberline time, but no proximal deposits are exposed. It is possible that a now-eroded low divide of Polallie diamicts protected the White River from most of the Timberline pyroclastic flows and lahars. Headward erosion of White River between Timberline and Old Maid eruptive periods breached the divide and exposed the canyon to flows of Old Maid age.

Figure 13. View looking down the White River valley from west rim about 1700 m (5600'), showing contact relations between lava flows and pyroclastic-flow deposits. hpc, Polallie diamicts (15-30 ka); hoc, Old Maid diamicts (~200 yr B.P.).

The view of the crater and summit area (fig. 12) is much like that from **Stop 1**, but here we have a better perspective of the fan surface of Polallie diamicts that was derived from growth and collapse of the Steel Cliff lava dome. A lava block from the fan deposits yielded a K-Ar age of 16 ± 8 ka. The deposits that form the high surface on the skyline along the east fork of White River have a patchy distribution that, along with other evidence, suggests they were emplaced at a time of considerable glacier cover during the last ice age (locally called the Evans Creek advance). Other deposits assigned to the broadly defined Polallie eruptive period were formed toward the end or immediately following the Evans Creek advance. Deposits we map as Polallie probably range from as old as 30 ka to as young as about 15 ka.

Other lava flows visible in the upper White River occur below or within the Polallie diamicts. The flow (hl) east of the terminus of White River Glacier (77 ± 8 ka; 60.2 wt.% SiO_2) has a well-preserved carapace of pinkish breccia. It apparently was encased in diamicts and spared erosion by late Pleistocene glaciers. A lava flow poorly exposed around snowfields above the 77-ka flow is correlative with the Texas lava flow (60.0 wt. % SiO_2; 25 ± 13 ka) that is well exposed over the far ridge and is probably interbedded in the Polallie diamicts. Downstream from **Stop 2** (fig. 13), andesite lava flows that form the prominent ridge east and north of White River have ages (140 ± 11 ka and 163 ± 14 ka) similar to those of lava flows on the south and west flanks mentioned at **Stop 1**. Figure 5 shows the broad area of the flanks of Mount Hood formed of lava flows 120 to 150 ka.

We have been walking over medium to coarse sand derived from eolian reworking of the matrix from the diamicts exposed in the White River canyon. Also exposed at the surface are fine-sand-and-silt-rich ash-cloud deposits. These deposits dominate the record of tephra falls around Mount Hood. Unlike Mount St. Helens, pumiceous fall deposits are few and Mount Hood has apparently never produced a voluminous pumiceous eruption. The fine-grained tephra-fall deposits originate as fallout from the billowing ash clouds that are elutriated from moving block-and-ash pyroclastic flows generated by lava-dome collapse. Some component probably also represents vent ejecta.

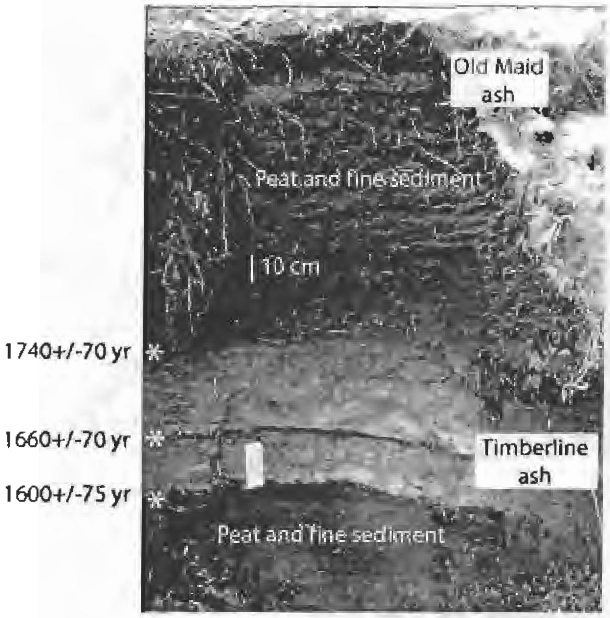


Figure 14. Ash-cloud deposits in peat exposed in Elk Meadows on the southeast flank of Mount Hood. A 2 cm thick peat layer separates the gray basal Timberline ash from the upper pink Timberline ash, indicating a break in activity during the Timberline eruptive period. Numbers on the left are radiocarbon ages from peat

The ash-cloud deposits exposed by extensive wind erosion of this surface are of Timberline age. Where not disrupted by root casts and burrows they consist of a basal unit composed of thin gray beds (many normally graded) that are slightly coarser grained than an upper pinkish-gray unit. Owing to erosion, the original thickness is difficult to estimate but is probably about 1m. The most likely source of these deposits is ash clouds of pyroclastic flows sweeping over the south-flank fan to the west, generally upwind, of here.

Figure 14 shows a well-preserved sequence of Holocene ash-cloud deposits in Elk Meadows, about 7 km ENE of here. The deposits of Timberline age include a 17-cm-thick basal gray unit separated from a 33-cm-thick upper pink unit by about 2 cm of peat. The peat represents a pause of some duration to allow meadow vegetation to become established.

Radiocarbon ages can't provide much precision, but secular-variation paleomagnetic data suggest that the entire sequence was deposited in less than 100 yrs because the paleomagnetic directions are indistinguishable (D=0°, I=61.2° and D=3.4°, I=62.6°). A 73-cm thick layer of peat separates the Timberline ash from a 7-cm-thick bed of gray ash of Old Maid age (~200 yr), which in turn is overlain by about 15 cm of younger peat. Average rates of peat formation estimated from the thickness of peat between dated horizons (about 0.5 mm/yr) suggest that the 2-cm peat within the Timberline sequence formed in about four decades. Actual time was probably less owing to the higher inorganic sediment concentration in the interbed compared with that in the peat above and below.

Return to the parking lot via the Timberline Trail (about 30 minutes).

The road log portion will start at Timberline parking lot, across from the entrance to the day lodge. Cumulative mileage is listed at left and interval mileages are given in boldface at the end of each entry.

ROAD LOG

Mileage

0.0 Leave Timberline parking lot and head south to U.S. 26. **0.5**

0.5 Andesite lava flow, likely correlative to that of **Stop 1**, overlain by diamict of Polallie age. **0.6**

1.1 Diamict of Polallie age on west side of road. **0.3**

1.4 Diamict of Timberline age that spilled down a narrow gully formed this small fan on the east side of the road. **0.8**

2.2 Andesite lava flow, likely correlative to that of stop 1, with view of Mount Jefferson to the south. **0.6**

2.8 Andesite lava flow, likely correlative to that of stop 1, overlain by Polallie diamict, west side of road. **0.4**

3.2 Polallie diamict on west side of road **1.3**

4.5 Waterfall over andesite lava likely correlative to that at mile 5.9 (optional stop). **0.7**

5.2 Junction with U.S. 26. Turn left. **0.7**

5.9 Mount Hood lava flow. Optional stop. **1.1**

Optional Stop. Mount Hood lava flow and inclusions

The Highway 26 lava flow is a typically middle-of-the-pack andesite flow (61.1 % SiO$_2$) from Mount Hood that contains abundant inclusions. The mineral assemblage of this flow is dominated by plagioclase and hypersthene with minor amounts of augite; total crystal content is about 34 percent. A paleomagnetic direction from this flow is distinct from that of lavas along the Timberline Road in accord a K-Ar age of 121 ± 13 ka. The lava flow, locally overlain by till of the Evans Creek advance, is one of a sequence that can be traced up to **Stop 1**, above which they are buried by diamicts of Polallie and Timberline age. Like many lavas from Mount Hood, this flow contains abundant, mostly rounded inclusions. Two types are seen here: a common fine-grained type (56.9 wt. % SiO$_2$) with a mineral assemblage similar to the host rock (plagioclase>>orthopyroxene and minor clinopyroxene) and a coarse-grained type (56.1 wt. % SiO$_2$) that is dominated by plagioclase with lesser amounts of orthopyroxene and likely former phenocrysts of hornblende that have been completely replaced by iron-titanium oxides. Most inclusions have lower silica contents than their hosts and more closely resemble basaltic andesites in chemical composition. Nonetheless, mineralogically the inclusions are more similar to their andesitic hosts in that they lack olivine, a common mineral phase of basaltic andesites. **1.1**

7.0 Junction with State Highway 35. Bear right onto OR 35. Highway is built on fan of diamicts of Timberline age that descended Salmon River canyon from **Stop 1**. **1.4**

8.4 Pre-Hood lava flow of Tertiary age on north side of road. **0.4**

8.8 Polallie-aged diamicts on both sides of road. **0.5**

9.3 Pre-Hood andesite, north side of road, slightly pyritized, probably 4 to 5 Ma. **1.2**

10.5 View of Mount Hood and upper White River valley. **0.7**

11.2 Driving across a fan of lahar and alluvial deposits ≤ 200 years old. **0.3**

11.5 Turn left into the White River Sno Park. Park at north end of parking lot. We will walk along White River to the prominent terrace that exposes pyroclastic-flow and lahar deposits of Old Maid age. **0.1**

Stop 3. Old Maid pyroclastic-flow deposit

Figure 15. Photograph of the Old Maid pyroclastic-flow deposit (~200 yr B.P.) about 0.8 km north of OR 35 in the White River valley on the southeast flank of Mount Hood. 165-cm-tall person at base of pyroclastic-flow deposit for scale. wrg, White River Glacier; hpc, Polallie diamicts ; hoc, Old Maid diamicts.

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 just 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 at least one and perhaps several pyroclastic-flow deposit(s) 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 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 emplacement. 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, the paleomagnetic direction from this unit is identical to 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. 8).

The Oregon Department of Transportation mined the deposit and crushed the rock for road sand for the winter. They recently ceased operations and regraded the area to produce a more natural topography. The upper 24 miles of the 46.5-mile-long White River are designated as Wild and Scenic.

Natural disturbances to the upper White River are common. In 1996, a large failure in clastic sediments on the west wall of the White River canyon sent sediment downstream, turning the river water chocolate brown for several days. Hot weather in late summer of 1998 resulted in a glacial outburst flood that triggered lahars that flowed down the river and damaged the east abutment of the OR 35 bridge. An intense rainstorm in October 2000 sent lahars down the river, which again threatened the bridge (fig. 16) and flowed through a Boy Scout Camp just west of the parking lot. The intense 2000 storm also affected the drainages of Newton and Clark creeks. Lahars from Newton Creek destroyed several miles of the northbound lane of OR 35.

Figure 16. Oregon Department of Transportation highway crews clearing sediment beneath the OR 35 bridge over the White River. Lahars, generated by intense rain in October 2000, filled the river channel and damaged the bridge.

11.6 Return to OR 35 and turn left. **0.1**

11.7 Cross White River; view to canyons in upper White River valley. Outburst floods from White River Glacier have taken out numerous 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. **0.4**

12.1 Roadcut in talus derived from Hood andesite lava flow that forms ridge on east side of White river. Ahead is highly fractured and locally altered Tertiary andesite. **1.5**

13.6 Ascend south side of Bennett Pass; outcrops of Tertiary volcanic rocks locally overlain by till. **0.2**

13.8 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. Optional stop. **1.3**

Optional Stop: 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 1). 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), as might be expected 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 not 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 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.

15.1 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 well-dated 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 yielded a meaningless age of 5±18 ka. **0.9**

16.0 Cross Clark Creek. Highway is built on lahar and alluvial deposits derived from erosion of diamicts of Polallie age on the east flank of Mount hood. **1.4**

Overview of east flank

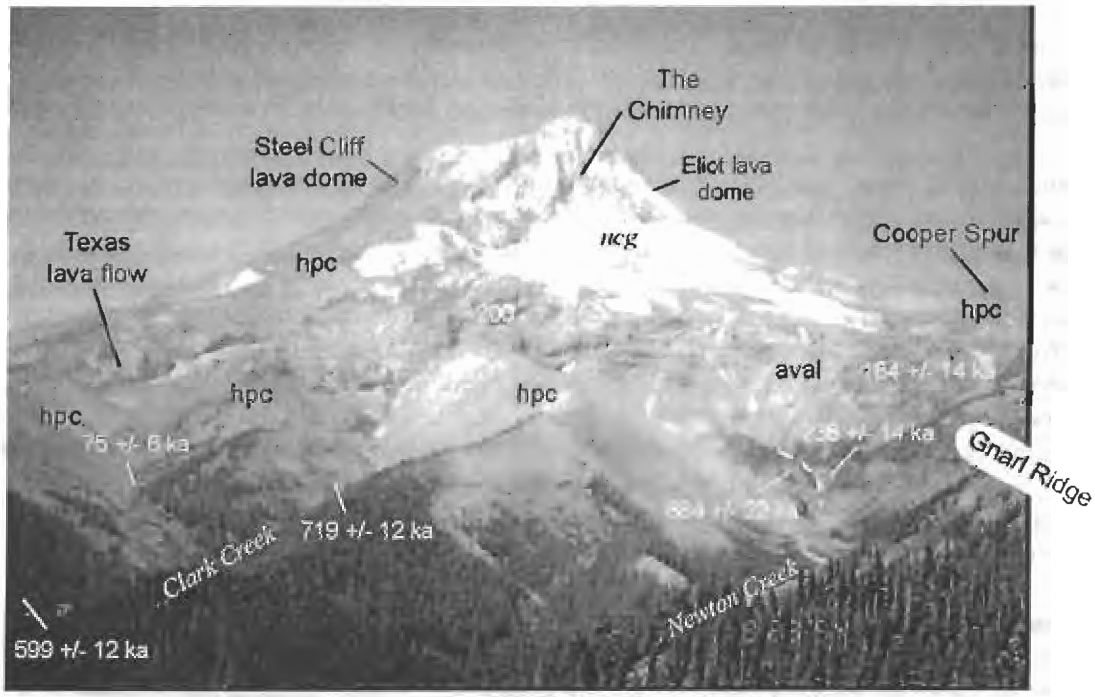


Figure 17. East flank of Mount Hood showing major geographic features and contact relations between deposits. hpc, Polallie diamicts; aval, avalanche deposit emplaced in the 20th century; ncg, Newton-Clark Glacier.

Bluegrass Ridge (Miocene and Pliocene volcanic rocks) blocks much of the view of Mount Hood from Oregon 35. Figure 17 is a view of the east flank of the volcano from Elk Mountain on the south end of Bluegrass Ridge. Steel Cliff lava dome and its fan of diamicts (hpc), which overlies or perhaps sandwiches the "Texas" lava flow (25 ± 13 ka), form the left skyline. A ridge composed of ~200 m of Polallie diamicts forms the divide between Clark and Newton Creeks. Polallie diamicts form the right skyline around Cooper Spur. Lava flows with field-determined reversed magnetic polarity crop out deep in both valleys (884 ± 22 ka and 719 ± 12 ka). The younger age falls within the Brunhes Normal Polarity Chron, but the lava is slightly altered and the age is considered only a minimum. A thick sequence of lava flows with ages from 184 to 238 ka forms the steep slope below Newton-Clark Glacier (ncg) and Gnarl Ridge. The Chimney, a steep slot formed in altered summit lava domes is a frequent source of rock avalanches, most recently in 2001. Reddish and yellowish avalanche debris (aval) at the terminus of the glacier at the head of Newton Creek was probably emplaced in the early 20th century. Newton Creek valley has been the site of numerous debris flows generated by heavy rains during the past few decades.

17.4 Cross Newton Creek; highway is built on a broad fan of alluvium and debris-flow deposits from Newton and Clark creeks. Newton Creek heads on the steep east face of Mount Hood and flows through a canyon whose south side is formed in diamicts of Polallie age (fig. 17). Debris flows generated by landslides and storms are common, especially in late autumn and early winter. Some flows have affected OR 35, most recently during an intense rainstorm in October 2000. Debris flows diverted the creek upstream of the bridge into a new channel. Where the new channel intersected the highway embankment, the stream turned to flow along the west highway ditch for hundreds of meters. The storm-swollen stream eroded a deep gully along the highway, destroying large parts of the southbound lane. **1.0**

18.4 Cross East Fork of Hood River. Columbia River Basalt is exposed in a 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. **2.5**

20.9 Junction with Forest Road 44; continue north on OR 35. The highway is traversing an apron of alluvial and debris-flow deposits derived from the east valley wall. Bluegrass Ridge forms the west valley wall and consists of much the same upper Miocene and Pliocene rocks as does the east valley wall. Roadcuts for the next several miles 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 ahead between Polallie and Cold Spring Creeks and ponding water above the level of the lake sediments in these exposures: the andesite lava flow of Tamanawas Falls (29 ± 11 and 44 ± 9 ka); an outwash fan of Evans Creek age from Polallie and Cold Spring Creeks; and a fan of lahar deposits emanating from Polallie and Cold Spring Creeks during the Polallie eruptive period. **1.5**

22.4 Lunch stop at Sherwood Campground on the west side of the road. **1.2**

23.6 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 (60.5 wt. % SiO_2), a Hood lava that has K-Ar age of 29 ± 11 and 44 ± 9 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. **0.5**

24.1 Mouth of Polallie Creek and junction with Cooper Spur Road, continue N on OR 35. 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. Roadcuts expose 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. **2.0**

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 in turn transformed into a debris flow (Gallino and Pierson, 1985). The debris flow entrained material scoured 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 was sleeping 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–causing a total of $13 million in damage.

26.1 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 of the highway is formed by 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. **1.6**

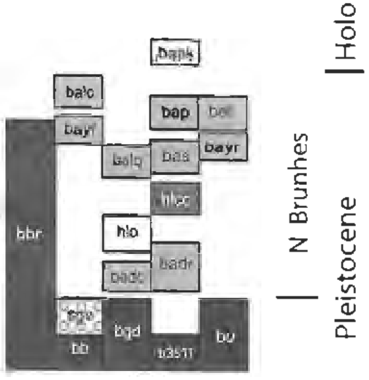
Rhododendron and Dalles Formations

Geologically, Mount Hood is not the first large andesitic volcano developed 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 nowhere 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, 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 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 26.1 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.

bapk	Basaltic andesite of Parkdale [7.7 ka]
balc	Basaltic andesite of Lady Creek [51 ka]
bap	Basaltic andesite of The Pinnacle [128 ka]
ball	Basaltic andesite of Lost Lake Butte
bayf	Basaltic andesite of Yocum Falls [175 ka]
bayr	Basaltic andesite of Yocum Ridge [287 ka]
bas	Basaltic andesite of Stump Creek [335 ka]
balq	Basaltic andesite of Ladd Creek quarry [380 ka]
hlcc	Basaltic andesite of Cloud Cap [424 ka]
hlo	Older andesite of Mount Hood near Cloud Cap [475, 492 ka]
badr	Basaltic andesite of Dog River [424-780 ka]
badc	Basaltic andesite of Devils Canyon [710 ka]
bgd	Basalt of Glacier Ditch
bb	Basalt of Bald Mountain
bbr	Basalt and basaltic andesite of Blue Ridge [>/= 220 ka]
sgv	Basalt to dacite(?) of Sandy Glacier volcano [>/= 1.2 Ma]
bu	Basalt and basaltic andesite, undivided
b3511	Basalt of Road 3511 [2.4 Ma]



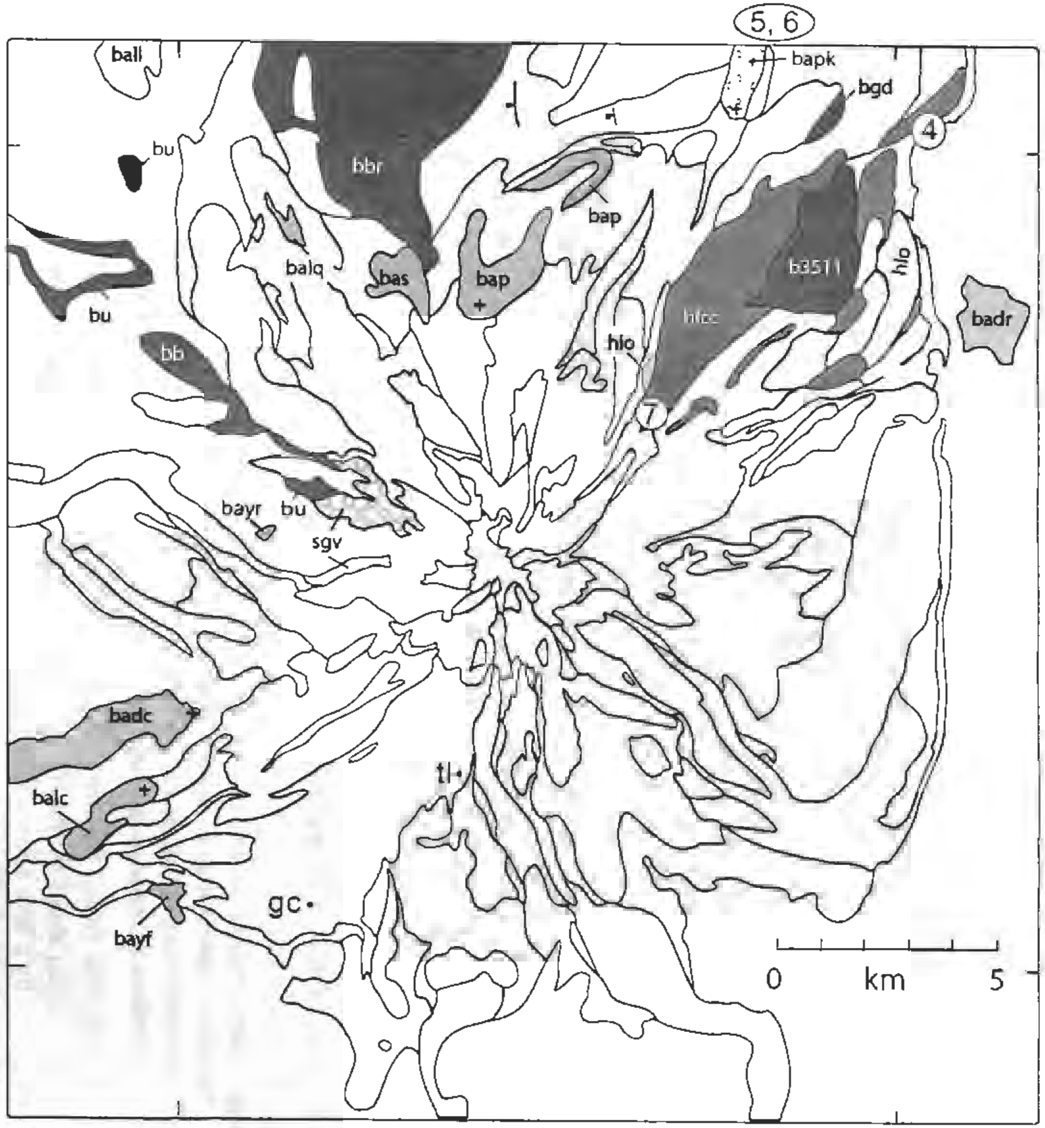


Figure 19. Map showing basalt and basaltic andesite lavas near Mount Hood. gc, Government Camp, tl, Timberline Lodge. Adapted from Sherrod and Scott (1995).

27.7 Stop 4: Basaltic andesite of Cloud Cap and discussion of Quaternary mafic lavas near Mount Hood

Caution: Watch out for rockfalls!

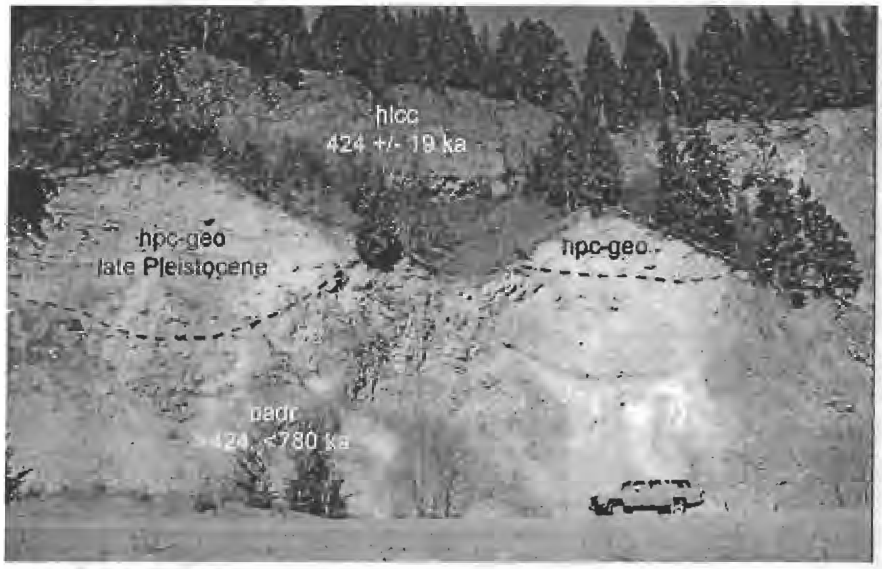


Figure 18. Outcrops on west side of OR 35, about 0.5 km north of junction with Dog River Road. Lower lava flow is from a vent on the east side of the valley. Upper lava flows are part of the Cloud Cap sequence of basaltic andesite to andesite lava flows that were erupted from vents on the northeast flank of Mount Hood. hlcc, basaltic andesites of Cloud Cap, hpc-geo, late-glacial outwash and Polallie-aged lahar deposits; badr, basaltic andesite of Dog River.

Cliff and roadcuts expose two sequences of intracanyon lava flows and a clastic unit plastered against them (fig. 18). The upper sequence (two or more flows here; 54.9 wt. % SiO_2) forms part of the normal-polarity, plagioclase-, orthopyroxene-, and olivine-bearing basaltic andesite to andesite lava flows of Cloud Cap (figs. 19, 20). The lower sequence (one flow here) is from vents high on the east rim of the canyon (basaltic andesite of Dog River; 56.3 wt. % SiO_2; figs. 19, 20) rather than from Cloud Cap. The clastic unit is composed of lahar deposits of Polallie age and glaciofluvial deposits of Evans Creek age. North along the exposure, Tertiary andesite crops out below lava of Cloud Cap.

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 advance. 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. 19). 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, which 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. 2), which is consistent with our age. Paleomagnetic results indicate that the entire sequence was probably emplaced within a few centuries (fig. 21).

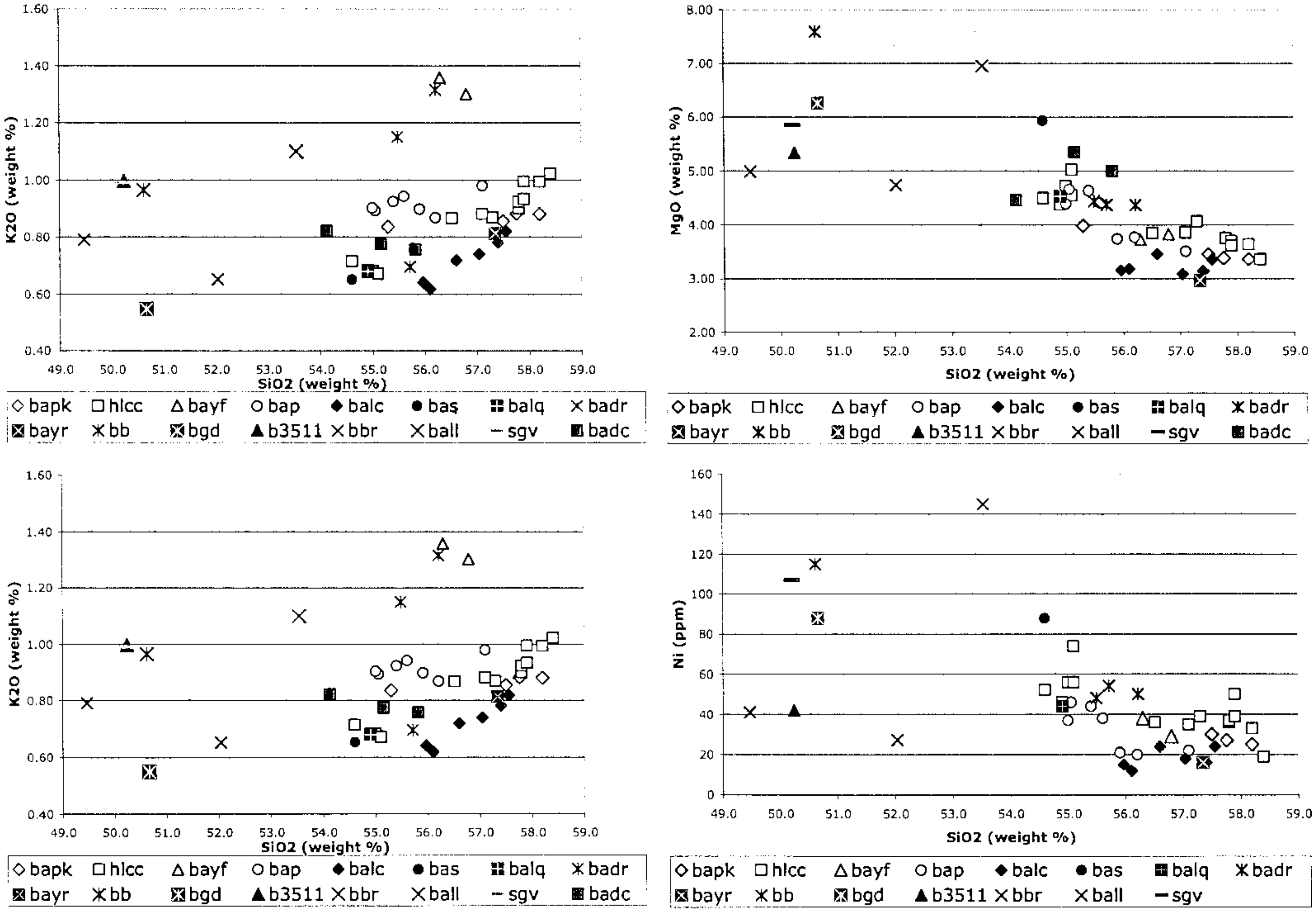


Figure 20. Silica-variation diagram of selected elements for basalt and basaltic andesites lava flows exposed on or near Mount Hood. See Figure 19 for explanation of units.

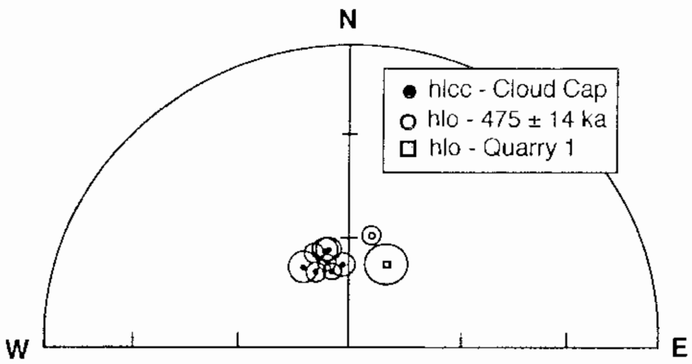


Figure 21. Paleomagnetic directions of Cloud Cap lavas (hlcc) and proximal older Hood andesites (hlo on Figure x). A sample from near the middle of the Cloud Cap sequence has a K-Ar age of 424 ± 19 ka. Quarry 1 andesite has an age of 931 ± 15 ka (discussion mile 43.7). The similarity of Cloud Cap directions indicates that the entire sequence was probable emplaced within a few centuries.

Cloud Cap lava ranges from basaltic andesite to andesite, 54.6 to 58.6 percent SiO_2 (Fig. 20). The less-silicic flows have plagioclase and olivine phenocrysts, whereas the more-silicic flows have plagioclase and orthopyroxene phenocrysts with rare olivine. However, 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. Cribb and Barton (1997), suggest that trace-element mixing calculations indicate that repeated cycles of mixing resulted in the eruption of compositionally similar lavas throughout the history of the volcano. At present we have not examined relations between the basaltic andesite and andesite using petrologic models, but we speculate that Mount Hood may be replenished episodically by small batches of mafic melt at depth and that the yearly seismic swarms at Mount Hood may be the geophysical expression of such episodic recharge. The composition of that mafic melt is likely variable considering the variety of basaltic andesite lavas that are vented at the surface. Mixing of mafic magma with residuum from previous eruptions likely occurs along with some crystal fractionation. Depending on the durations of repose periods, more than one mafic magma may intrude at depth. What eventually triggers an eruption and why the lavas produced are so similar in composition and crystallinity is not known. But if complex processes of replenishment, mixing, and crystal fractionation do occur it is likely that it will be difficult to match parent and daughter products, even assuming there is a genetic relation. Until further work, we can not discount a genetic linkage between the basaltic andesite and andesite, but at present we can not prove that there is one.

Cribb and Barton (1997) point out that Mt. Hood lavas are unusual in that they do not exhibit depletion of high field strength elements (HFSE) relative to large ion lithophile elements, a common characteristic of arc lavas. They argue that the absence of the HFSE depletion cannot be attributed to lack of interaction with slab-derived fluids and the source region because of pre-eruption water contents (6 wt. % H_2O), Rather, they suggest that the depletion may reflect negligible subduction of sediments and or negligible mixing between subducted sediment and the upper mantle source region. **0.3**

28.0 Cross East Fork Hood River. **2.4**

30.4 Turn left onto Baseline Drive towards Parkdale and Dee. **0.5**

30.9 Turn left on Culbertson Road. Rolling topography is underlain by several lahars of middle Pleistocene age. **0.8**

31.8 Junction of Cooper Spur and Culbertson roads, continue on Culbertson. **0.5**

32.3 Junction with Clear Creek Road, continue on Culbertson through intersection and park on the north side of the road just past the intersection. **0.5**

Stop 5. Overview of north flank of Mount Hood from the Upper Hood River Valley

The Hood River Valley is one of the major fruit (pears>apples>cherries) producing regions of Oregon. Mount Hood is an essential ingredient in this agricultural enterprise, beyond merely providing great logos for fruit crates. The soils in the upper valley, the Parkdale Series and its relatives, are formed chiefly in thick ash-cloud deposits of Polallie age (Harris, 1973). The soils are typically well-drained, have good moisture holding capacity, and allow deep rooting. Of probably greater importance, the perennial snow and ice on Mount Hood provide an ample and relatively low-cost supply of irrigation water during the summer. The valley is culturally diverse with a large permanent Hispanic population that has grown greatly over the past few decades to join the Anglo and Japanese-American residents from the late 19th and early 20th centuries. For several weeks in April, beginning in the lower valley near the City of Hood River, the valley is awash in blossoms.

In contrast to the smooth, broad fans of diamicts of latest Pleistocene and Holocene age that form much of the south flank of Mount Hood, the north flank is steep and rugged (fig. 22). The position of the Crater Rock vent south of the summit ridge has isolated the north flank from Holocene eruptive products other than tephra-fall deposits.

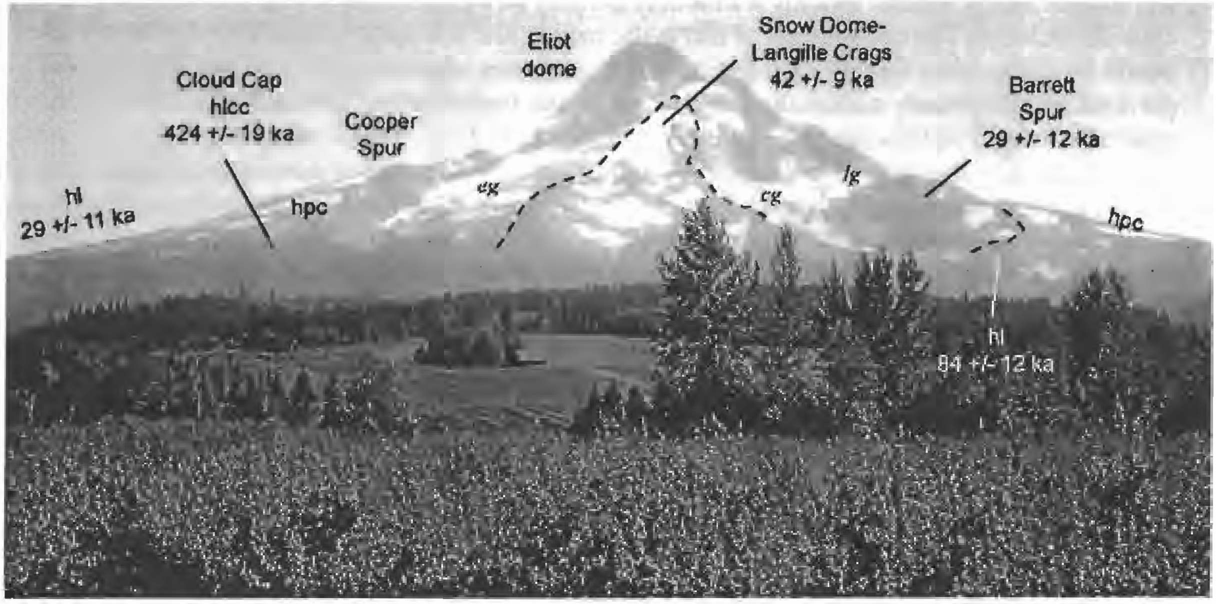


Figure 22. The north flank of Mount Hood showing K-Ar ages of prominent features. eg, Eliot Glacier; cg, Coe Glacier; lg, Ladd Glacier; hpc, Polallie diamicts (15-30 ka); hl, hood, lava.

A few remnants of fans composed of diamicts of Polallie age (hpc) are visible from here. Eliot lava dome, which forms the massive face above Eliot Glacier (eg), and its fan of diamicts that forms Cooper Spur occupy a large part of the northeast sector of the volcano. The fan is banked against and overlies an andesite lava flow dated at 29 ± 11 and 44 ± 9 ka, which is also overlain by end moraines of the Evans Creek advance (~20 ka). The Polallie diamicts below Cooper Spur have not been glaciated, although expanded snowfields verging on glaciers during neoglacial advances of the past few millennia managed to striate some boulders on the upper part of the spur. Downstream beyond the view in Figure 22, the Polallie diamicts overlie till and outwash of the Evans Creek advance. Few useful radiocarbon ages exist on Polallie deposits, but we suspect that the youngest diamicts on Cooper Spur are on the order of 12-20 ka. An additional patch of Polallie diamicts is banked against Barrett Spur (29 ± 12 ka; 62.4 wt. % SiO_2), a thick massive lava flow of which we will have a closer view and discuss further at **Stop 7**. The source dome for these Polallie diamicts is not known; it may be in the altered mass to the west of Snow Dome. It also may have been removed in a rock avalanche of Timberline age that descended to Barrett Spur and then split into lobes that followed Coe and Ladd glaciers.

A wedge-shaped mass of andesite lava flows between Eliot and Coe glaciers form the Snow Dome and Langille Crags, for which we have obtained several ages of about 40 ka. This sequence of lava flows was confined on the lower northeast flank by the basaltic andesite of Cloud Cap (hlcc; 424 ± 19 ka) and on the northwest flank by sequences of lava flows ≥80 ka.

Collectively, the relative youth (<50 ka) of the units above treeline on the north flank, the lack of exposures of older lavas, and evidence from lahars in Hood River Valley suggests that much of the upper north flank fills an ancient debris-avalanche scar. Several lahars in the Hood River valley have features characteristic of lahars derived from volcanic debris avalanches—clayey matrix, abundant clasts of hydrothermally altered lava, and megaclasts of lava flows and diamicts. At least two large-volume (order of 1 km^3?) avalanches are inferred from lahars. The older lies between a Hood andesite lava flow dated at 475 ± 14 ka and the 424-ka basaltic andesite of Cloud Cap. The younger contains juvenile(?) clasts dated at 61 ± 21 ka and 109 ± 9 ka and overlies an eruption-related lahar with clasts dated at 120 ± 11 ka. The younger lahar (fig. 23) can be traced down Hood River to the Columbia River and for several kilometers up the White Salmon River in Washington (Vallance, 1999). The lahar must have at least temporarily filled the Columbia River valley to a depth of several tens of meters.

Figure 23. The younger clayey lahar exposed along railroad in Lower Hood River Valley.

32.8 Arrive at Lava Nursery, proceed to office for permission. Best road for lava flow access is due west of the office complex.

Stop 6. Parkdale lava flow

The Parkdale lava flow, dated at 7.7 ka, is the youngest Cascade mafic eruption between Mount Adams and Mount Jefferson. It is about 7-km long and 0.3 km3 in volume. Like many of basaltic andesite flows from vents that border Mount Hood, the Parkdale lavas range from about 55 to 58 weight % SiO2. There appears to be a compositional gap between 55 and 57.5 weight percent (fig. 20), but analyses are too few to confirm it. There is no cinder cone associated with the Parkdale lava flow and thus we assume that it erupted from a subsurface fissure. Of all the basaltic andesites around Mount Hood, only the Pinnacle lavas are associated with a cinder cone.

Figure 24. Blocky surface of the 7.7 ka Parkdale basaltic andesite lava flow. This is youngest mafic lava flow between Mount Adams and Mount Jefferson.

Radiocarbon ages indicate that the Parkdale lava flow erupted around the time of the Mazama eruption of Crater Lake. On Mount Hood, original fall thickness of Mazama tephra is between 5 and 10 cm. However, it has not been found on the surface of the Parkdale lava flow, so presumably the Parkdale eruption shortly post-dates the Mazama tephra. Alternatively, the Mazama tephra may have blown off and (or) filtered down through the blocky surface of the lava flow. **3.0**

35.9 Intersection of Culbertson and Cooper Spur roads; turn right onto Cooper Spur Road. **0.8**

36.6 Junction with Laurance Lake Road, continue on Cooper Spur Road. **2.3**

38.9 Basaltic-andesite lava flow of Cloud Cap with basal breccia. This lava flow is one of the most mafic (55.2 wt. % SiO_2) lava flows from the Cloud Cap vent area and is olivine phyric. The basal breccia overlies an old lahar deposit likely correlative to those on the east end of Culbertson Road (mile 30.9). **1.8**

40.7 3511 Road on right leads up to small basaltic shield (50.2 wt. % SiO_2) whose west slopes we are driving past; K-Ar of 2.5 Ma, reversed polarity. **0.6**

41.3 Roadcuts in debris-flow deposits from Tilly Jane Creek. **0.3**

41.6 Basaltic andesite lava flow of Cloud Cap. **0.1**

41.7 Turn right onto Cloud Cap Road, across from the Cooper Spur Inn. **2.0**

43.7 Andesite lava flow in quarry (60.5 wt. % SiO_2; K-Ar age of 931 ± 15 ka with normal polarity. A flow on the NW flank of the volcano has very shallow reversed polarity and a K-Ar age of 932 ± 31 ka. The last magnetic reversal from reversed (Matuyama) to normal (Bruhnes) polarity occurred about 780 ka (Baksi and others, 1992). The Jaramillo, a normal polarity subchron within the Matuyama, occurred between 0.99 and 1.07 Ma. The lavas may belong to an excursion around 930 ka or the K-Ar age may be incorrect and the lava may belong in the Jaramillo Subchron (D. Champion, personnal communication, 2003). **0.5**

44.2 Roadcuts in diamicts of Tilly Jane Creek. **0.3**

44.5 Quarry in Cloud Cap basaltic-andesite lava (58 .2 wt. % SiO_2). Platey base with more massive interior. **2.2**

46.7 Dead trees along road are victims of a spruce bud worm infestation that has been affecting Pacific Northwest forests for the past few decades. **2.4**

49.1 Basaltic andesite lava flow of Cloud Cap. **2.4**

51.5 Junction, turn right towards Cloud Cap Inn. A precipitation gage station is on the north side of the road just past the junction. **0.8**

52.3 Quarry in basaltic-andesite lava flow of Cloud Cap; K-Ar age 424 ± 19 ka. **0.1**

52.4 Drive to the end of the road and park at the Cloud Cap Inn, built in 1889. Walk to front of the Inn for views of the north flank of Mount Hood

Stop 7. Cloud Cap

Construction of Cloud Cap Inn began in March 1889 and the first guests registered on August 6 of that year. The inn was operated by Sarah Langille, "Lady of the Mountain," and her two sons. The younger, Will, reportedly took only 10 hours to circle the volcano in 1893, crossing all 9 named glaciers. The inn was evidently a rocky business venture and never terribly successful. Attempts were made in the 1920s to build a more grandiose four-story inn, similar to Timberline Lodge, a cable railway from Cloud Cap Inn to Cooper Spur, and an aerial tramway from Cooper Spur to the summit. Environmentalists of the day opposed the idea, but it took the Great Depression to quash the proposed development. The inn languished until the 1950s when the Forest Service gave the Hood River Crag Rats, a mountaineering and search and rescue organization, use of the building. The Crag Rats saved the building from further decay and in 1974 the inn was declared an historic site.

With good visibility to the north are three other Cascade volcanoes: Mount St. Helens (100 km NNW), Mount Rainier (165 km N), and Mount Adams (90 km NNE).

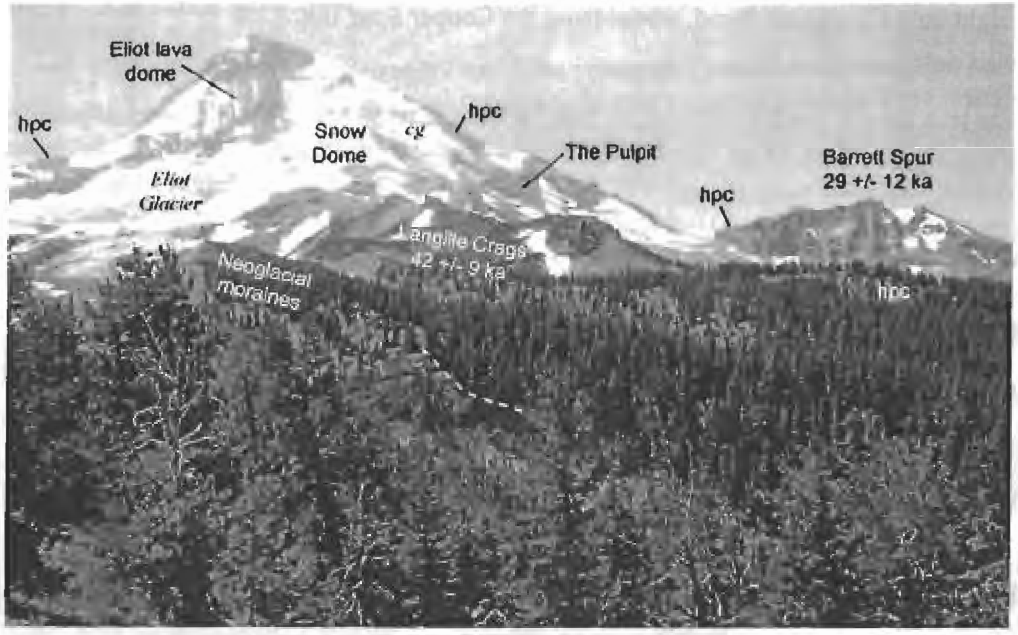


Figure 25. North flank of Mount Hood showing prominent features. cg, Coe, Glacier; hpc, Polallie-aged diamicts.

Several prominent latest Pleistocene units dominate the view of the volcano from Cloud Cap Inn (figs. 25, 26). The lavas of the massive face above Eliot Glacier can be traced into a lava flow (hpl) that is exposed at the east margin of Eliot Glacier (fig. 25). Block-and-ash-flow deposits that form Cooper Spur (hpc; 63.0 and 62.5 wt. % SiO_2) overlie the lava flow (60.3 wt. % SiO_2). These and related lahar deposits extend to the East Fork Hood River along Polallie Creek. The Snow Dome and Langille Crags are part of a sequence of ~40-ka lava flows that forms the divide between Eliot and Coe Branches and extends 10 km to the north. The canyon of Eliot Branch below Cloud Cap is a narrow U-shaped valley that was cut during the Evans Creek advance along the contact between the 40-ka lava flows and the 424-ka basaltic andesite lavas of Cloud Cap. The Cloud Cap lavas can be traced about 1.5 km farther south from the inn. The vent is not exposed, but it must lie within 4 km of the summit of Mount Hood. Barrett Spur is a narrow (62.7 wt. % SiO_2), ~300-m thick lava flow. It's odd shape suggests that it was probably constrained by glacier ice of Evans Creek age. Any evidence of ice contact (quenched glassy margins, hyaloclastite, etc.) has been removed by subsequent glacial erosion and mass wasting. The Pulpit is a lava tongue sandwiched in diamicts and may have an origin similar to that of the lava flow and diamicts of Polallie age on Cooper Spur. The Pulpit sequence may also be of Polallie age and correlative with diamicts on the south end of Barrett Spur and those visible west of Barrett Spur in Figure 22 (**stop 5**).

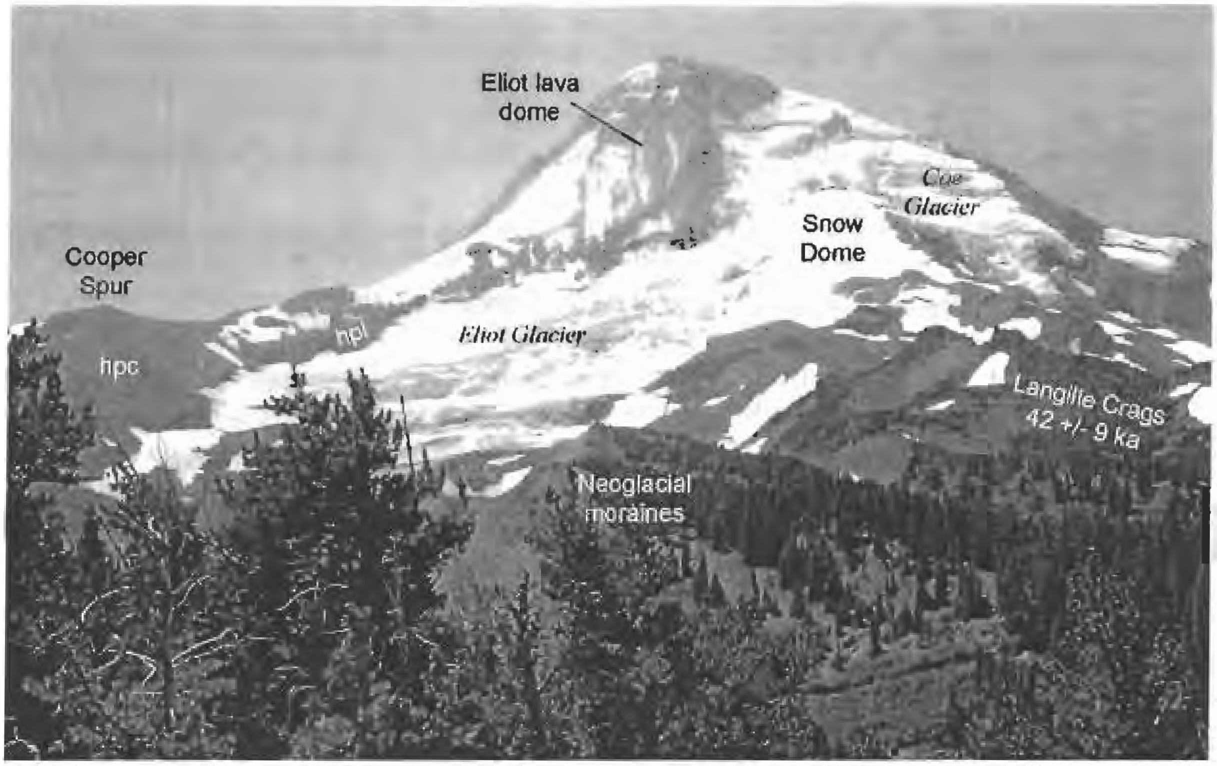


Figure 26. Photograph from the Cloud Cap Inn showing prominent features of the northeast flank of Mount Hood. hpc, Polallie diamicts (15-30 ka); hpl, Polallie-aged lava flow.

Conspicuous moraines of late glacial and neoglacial age flank the west margin of Eliot Glacier. In the mid- to late 19th century, Eliot Glacier terminated in the area of the vegetation trimline marked by the dashed white line in Figure 24. **10.3**

62.7 Turn right onto Cooper Spur Road. **0.4**

63.1 Andesite lava flow of Mount Hood (59.2 wt. % SiO_2); K-Ar age, 475 ± 14 ka. **1.1**

64.2 Platey basaltic andesite lava flow of Cloud Cap. **0.5**

64.7 Series of outcrops in outwash of Evans Creek age and diamicts of Polallie age. **0.3**

65.0 Turn right on OR 35 miles and return to Timberline Lodge. **30**

95.0 Timberline Lodge. End of field trip.

References:

Baksi, A.K., Hsu, V., McWilliams, M.O., and Farrar, E., 1992, ^{40}Ar-^{39}Ar dating of the Brunhes-Matuyama geomagnetic field reversal: Science, v. 256, p. 356-357.

Cameron, K.A., and Pringle, P.T., 1987, A detailed chronology of the most recent major eruptive period at Mount Hood, Oregon: Geological Society of America Bulletin, v. 99, no. 6, p. 845-851.

Conrey, R.M., 1991, Geology and petrology of the Mt. Jefferson area, High Cascade Range, Oregon: Pullman, Washington State University, Ph.D. dissertation, 392 p.

Conrey, R.M., Sherrod, D.R., Uto, Kozo, and Uchiumi, Shigeru, 1996a, Potassium-argon ages from Mount Hood area of Cascade Range, northern Oregon: Isochron/West, no. 63, p. 10-20.

Crandell, D.R., 1980, Recent eruptive history of Mount Hood, Oregon, and potential hazards from future eruptions: U.S. Geological Survey Bulletin 1492, 81 p.

Cribb, J.W., and Barton, M., 1997, Significance of crustal and source region processes on the evolution of compositionally similar calc-alkaline lavas, Mt. Hood, Oregon: Journal of Volcanology and Geothermal Research, vol.76, no.3-4, p. 229-249.

Fiebelkorn, R.B., Walker, G.W., MacLeod, N.S., McKee, E.H., and Smith, J.G., 1983, Index to K-Ar age determinations for the state of Oregon: Isochron/West, no. 37, p. 3-60.

Gallino, G.L., and Pierson, T.C., 1985, Polallie Creek debris flow and subsequent dam-break flood of 1980, East Fork Hood River basin, Oregon: U.S. Geological Survey Water-Supply Paper 2273, 22 p.

Gannett, M.W., 1982, A geochemical study of the Rhododendron and the Dalles Formations in the area of Mount Hood, Oregon: Portland, Oregon, Portland State University, M.S. thesis, 70 p.

Gray, L.B., Sherrod, D.R., and Conrey, R.M., 1996, Potassium-argon ages from the northern Oregon Cascade Range: Isochron/West, no. 63, p. 21-28.

Harris, B.L., 1973, Genesis, mineralogy, and properties of Parkdale soils, Oregon: Corvallis, Oregon State University, Ph.D. dissertation, 174 p.

Harris, S.L., 1988, Fire mountains of the West: The Cascade and Mono Lake volcanoes: Missoula, Montana, Mountain Press Publishing Company, 379 p.

Jones, J., and Malone, S.D., 2002, Constraints on Mt. Hood earthquake swarms from cross-correlation and joint hypocenter determination: Seismological Society of America, Abstracts On Line.

Jones, J.P., and Malone, S., 2002, Mount Hood earthquake activity: Volcanic or tectonic origins?: Eos, Transactions of the American Geophysical Union, v. 83, no. 7, abstract S12A-1179.

Keith, T.E.C., Donnelly-Nolan, J.M., Markman, J.L., and Beeson, M.H., 1985, K-Ar ages of volcanic rocks in the Mount Hood area, Oregon: Isochron/West, no. 42, p. 12-16.

Le Bas, M.J., and Streckeisen, A.L., 1991, The IUGS systematics of igneous rocks: Journal of the Geological Society of London, v. 148, p. 825-833.

Porter, S.C., Pierce, K.L., and Hamilton, T.D., 1983, Late Wisconsin mountain glaciation in the western United States, chapt. 4, *in* Porter, S.C., ed., The late Pleistocene, vol. 1 of Wright, H.E., ed., Late-Quaternary Environments of the United States: Minneapolis, University of Minnesota Press, p. 71-111.

Priest, G.R., Beeson, M.H., Gannett, M.W., and Berri, D.A., 1982, Geology, geochemistry, and geothermal resources of the Old Maid Flat area, Oregon, *in* Priest, G.R. and Vogt, B.F., eds., Geology and geothermal resources of the Mount Hood area, Oregon: Oregon Department of Geology and Mineral Industries Special Paper 14, p. 16-30.

Pringle, P.T., Pierson, T.C., and Cameron, K.A., 2002, A circa A.D. 1781 eruption and lahars at Mount Hood, Oregon—Evidence from tree-ring dating and from observations of Lewis and Clark in 1805-6: Geological Society of America Abstracts with Program, v. 34, no. 6, p. 511.

Scott, W.E., Gardner, C.A., Sherrod, D.R., Tilling, R.I., Lanphere, M.A., and Conrey, R.M., 1997, Geologic history of Mount Hood volcano, Oregon—A field-trip guidebook: U.S. Geological Survey Open-File Report 97-263, 38 p.

Sherrod, D.R., and Scott, W.E., 1995, Preliminary geologic map of the Mount Hood 30- by 60-minute quadrangle, Cascade Range, north-central Oregon: U.S. Geological Survey Open-File Report 95-219, scale 1:100,000.

Sherrod, D.R., and Smith, J.G., 1990, Quaternary extrusion rates from the Cascade Range, northwestern United States and British Columbia: Journal of Geophysical Research, v. 95, no. B12, p. 19,465-19,474.

Vallance, J.W., 1999, Postglacial lahars and potential volcanic hazards in the White Salmon River system on the southwest flank of Mount Adams, Washington: U.S. Geological Survey Bulletin 2161, 49 p.

White, Craig, 1980, Geology and geochemistry of Mt. Hood volcano: Oregon Department of Geology and Mineral Industries Special Paper 8, 26 p.

Wise, W.S., 1968, Geology of the Mount Hood volcano, *in* Dole, H.M., ed., Andesite Conference Guidebook: Oregon Department of Geology and Mineral Industries Bulletin 62, p. 81-98.

— — —1969, Geology and petrology of the Mt. Hood area: A study of High Cascade volcanism: Geological Society of America Bulletin, v. 80, no. 6, p. 969-1,006.