Northwest Geological Society

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Society Field Trips in Pacific Northwest Geology

Mount Rainier

2000

Trip Leaders:

Pat Pringle, Kevin Scott,
Carolyn Driedger, Jim Vallance,
Dave Frank and Richard Schroedel

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Mount Rainier
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Modified from “a Decade Volcano 1994 GSA Field Trip”

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Introduction

This trip circumnavigates Mount Rainier via the Duwamish, Puyallup, Nisqually, Cowlitz, and White River drainages (Fig. 1). Along the way we examine a wide variety of geologic features, deposits, and geologic hazards. Because of its hazards and increasing population pressures in the region, Mount Rainier was designated a Decade Volcano by the International Association of Volcanology and Chemistry of the Earth’s Interior in 1992. Within two years of the Decade Volcano workshop, the National Research Foundation published its report outlining a strategy for study of Mount Rainier. In keeping with this designation, researchers have made considerable progress since then in examining the history, behavior, structure, and hazards of the volcano with a main goal of mitigating risk. At the same time, a group called the Mount Rainier Volcanic Hazards Work Group (MORAWOG), composed of Federal, state, and local officials and members of the public, has met quarterly to educate themselves and others about the volcano and to prepare for future volcanic unrest. Within the past year the group completed a working draft of a Mount Rainier Response Plan.

This field trip provides an overview of what we presently know about Mount Rainier’s geologic and glacial history. During the trip, we also will hear about recent research at the volcano and will inspect the geologic evidence for debris flows, the most important class of geologic hazards at Mount Rainier.

This text is a compilation of the work of numerous researchers, many of whom are continuing their work at Mount Rainier. We also have relied heavily on the work of Crandell, Mullineaux, Fiske, Hopson, Waters, and others whose earlier efforts have provided an important foundation for further studies.

All units are metric except road-log mileage. A note about National Park Service (NFS) etiquette: please do not do any digging within the boundaries of Mount Rainier National Park. Permits, which can be obtained from the Park Superintendent, are required for sample collecting.

Geologic History of Mount Rainier

Mount Rainier is the highest and third most voluminous volcano in the Cascade Range. It is potentially the most dangerous volcano in the range because of the increasingly large population living along its lowland drainages. For example, more than 100,000 people live on, and more than 200,000 work on the Duwamish-Puyallup River valley plain. These riparian areas are at risk because of the mountain’s great relief and the huge area and volume of ice and snow on the cone (92 x 106 m2 and 4.4 x 109 m3 respectively; Driedger and Kennard, 1986) that could generate lahars during eruptions. In addition, enormous (>2 x 108 m3) sector collapses of clay-rich, hydrothermally-altered debris from the cone have occurred at least 6 or 7 times since the Mount Mazama layer “O” ash was deposited (6,845 ± 50 yr B.P.; Bacon, 1983; 6,730 ±40) and include the Osceola, Round Pass, and Electron Mudflows. Mount Rainier’s steep, glacially carved slopes, hydrothermally altered core, active hydrothermal system, bedding characteristics (thin lava flows and interbedded volcaniclastics on generally outwardfacing dip planes), and exposure to pulses of tectonic and/or volcanic energy make all valleys surrounding Rainier susceptible to future sector collapses.

Prior to the 1990's relatively little was known of the eruptive history, composition, and age of Mount Rainier volcano compared to most other Cascades Range peaks. The most complete description of the pre-Holocene volcanic history of Mount Rainier has been made by Fiske and others (1963). Most of the Holocene history has been pieced together in greater detail through studies of its fragmental deposits, chiefly tephra, lahar, and glacial deposits (Crandell, 1963b, 1971; Mullineaux, 1974; Crandell and Miller, 1974; Scott and others, 1992; Vallance, 1999, etc).

Mount Rainier rests on middle Tertiary volcanic rocks of the Ohanapecosh, Stevens Ridge, and Fifes Peaks Formations. In the immediate vicinity of Mount Rainier, these rocks were gently folded along northwest-trending axes and then intruded by granodiorite and quartz monzonite of the Tatoosh plutonic complex. Descriptions of these rocks are found in Fiske and others, (1963), Vance (1987), and Hammond (1989). New evidence further constrains the age, location, and structure of the Fifes Peaks volcano and its stratigraphic relations with the other middle Tertiary rocks (Hammond and Brunstad, 1993; Hammond and others, 1991, 1993). The Tatoosh rocks are predominantly the eroded roots of a volcanic complex, from which the welded tuff exposed at the Palisades in Yakima Park is inferred to have erupted (Fiske and others, 1963). Radiometric ages of the Tatoosh rocks range from 17.5 to 14.1 Ma, although several ages as old as 26 Ma have been reported (Mattinson, 1977).

An apparent hiatus in volcanic activity and plutonism of more than 11 m.y. precedes the first evidence of a proto-Mount Rainier. This early thick sequence of volcaniclastic debris west of the mountain is known as the Lily Creek Formation. Constraining radiometric ages of this formation are 2.9 Ma and 0.84 Ma (Easterbrook and others, 1981; Smith, 1987). Crandell (1963a) discovered two distinct Lily Creek surfaces whose tops have different elevations. He suggested that the deposits composing the higher (older) surface correlate with mudflows of Alderton age. These deposits are northeast of Cowling Ridge and were deposited in the ancestral Mowich River valley. After the upper Mowich valley was blocked by a lava flow from Mount Rainier, the lower depositional surface (southwest of Cowling Ridge) was created in the ancestral Puyallup River valley, and these sediments correlate with mudflow deposits of Puyallup age. The Alderton and Puyallup deposits are separated by the Stuck Drift of Crandell and others (1958). Sisson and Lanphere (1999) have noted a hornblende dacite of Panhandle Gap (shown as diorite on Fiske and Hopson's map) is 1.036—so perhaps some of Cliff Hopson's early speculations were right, and the Lily Creek was formed by eruptions from an earlier proto-Mt. Rainier. This 1 Ma dacite overlies Tertiary rocks unconformably and is overlain by typical Rainier rocks unconformably.

Construction and Destruction of the Mount Rainier Cone

Early lava flows of present Mount Rainier flowed onto a dissected surface of the Tertiary basement. Prior to the later 1990s, the only ages on lavas were only crudely known—the earliest lavas predated the Hayden Creek Drift (-140 ka) and had yielded (as of April, 1994) only two KAr ages, 320 and 600 ka (Crandell and Miller, 1974). Sisson, however (Sisson, 1999; Sisson and Lanphere, 1999) had now found ages for many of the Mount Rainier lavas (Fig. 2). Small amounts of basaltic andesite were erupted during the late Pleistocene from two satellite cones on the northwest flank of the mountain, Echo Rock and Observation Rock. The mineralogy of the mafic inclusions, cumulate textures, and presence of minor amounts of glass suggest that at least one of these is cognate, or genetically related to Mount Rainier; others may be xenolithic (McKenna, 1994). Approximately 140 km3 of lava has been erupted from Mount Rainier in the past 1 million years (Sherrod and Smith, 1989).

A thick, biotite-bearing pumice layer northeast, east, and southeast of the volcano is interpreted to have erupted from Mount Rainier about 384 ka (Sisson, commun., 1998). Although outcrops are limited, preliminary estimates suggest this "U"- tephra layer is an order of magnitude larger in volume than any Holocene tephra layer from Mount Rainier. Holocene explosive eruptions at Mount Rainier produced 11 major pumice or scoria beds (Mullineaux, 1974) and at least 20 to 25 lithic tephra layers (Vallance, 2000) totaling more than 0.5 km3)(Fig. 3). Roughly 30-40 percent of this volume (eight layers) was erupted between 6,500 and 4,000 radiocarbon years B.P. Some of the tephra layers (for example, layers S and F) are rich in lithic components and are thought to be the result of phreatic or phreatomagmatic eruptions. Layer F is unique among the postglacial tephras because of its large percentage of clay minerals (chiefly montmorillonite with some illite and kaolinite). The clay minerals were formed before deposition, and thus they were probably deposited by a violent phreatic or phreatomagmatic event that penetrated an area of hydrothermal alteration. Layer F is similar in age and clay content to the Osceola Mudflow (discussed below) but does not overlie the Osceola. The two deposits therefore seem correlative (Mullineaux, 1974).

Layer C, which accounts for about 60 percent of the volume of postglacial tephras, is also the most widespread, covering much of the eastern half of Mount Rainier National Park with 2-30 cm of lapilli, blocks, and bombs. It is also the coarsest of the Rainier tephras: 25-30 cm bombs can be found 8 km to the east of the summit. Apparently Columbia Crest, the 250-m-high summit cone (Fig. 4), is younger than 2,300-yr-old layer C because the tephra does not occur on its snow-free parts (Mullineaux, 1974).

During investigations of liquefaction in the City of Puyallup, one of the liquefiable sand units was identified as a lahar runout or laharic flood from Mount Rainier (Palmer and others, 1991; Pringle and Palmer, 1992). The presence of Mount Rainier "C" tephra and I4C age of 2,320 ± 120 yr from a twig found in the deposit correlates that unit with newly discovered lahar deposits in upper reaches of the Puyallup River (see stop 1-2) and with block and ashflow deposits noted by Crandell (1971) on the west flank of Mount Rainier. Deposits from that eruptive episode had not previously been discovered as far downstream as Puyallup.

Recent work on the C tephra (Venezky and Rutherford, 1993) provides evidence for magma mixing from analysis of phenocryst zonation, large temperature variations within and among pumice clasts, large matrix glass variations, physical mixing textures, and bimodal bulk rock compositions.In addition to the more pumiceous or scoriaceous tephras, more than 25 lithic tephra layers have not been investigated in detail (D.R. Crandell, written commun., 1992).

Postglacial deposits at Mount Rainier are dominated by lahars-more than 60 have been identified. Although relations between Holocene tephra and lahar deposits remain speculative, at least some lahars were probably eruption induced, such as the Paradise Lahar and **Osceola Mudflow** of Crandell (1971). The 5,700 ka Osceola Mudflow had a volume of more than 4 km3, inundated at least 485 km2, and flowed into Puget Sound more than 100 km channel distance Mount Rainier (Dragovich and others, 1994). As interpreted from well logs (neglecting minor relative sealevel changes), syn, and post-Osceola sedimentation has pushed the shoreline seaward 25 and 50 km respectively in two Puget Sound embayments, the Puyallup and Duwamish, and added more than 400 km2 of new land surface (Dragovich and others, 1994) (Fig. 5).

Wood from trees buried in the Round Pass Mudflow has been dated at about 2,600 radiocarbon yrs B.P. This clay-rich diamicton is characterized by great thickness (locally >250 m), hummocky surface, and megaclasts of lithologically homogeneous material. It probably began as a debris avalanche of hydrothermally altered material from high on the western slopes, and most of it was deposited in the upper 20 km of the Puyallup River valley. Another clay-rich lahar, the Electron Mudflow, has been dated at about 530 radiocarbon years B.P. This lahar, which evidently began as a failure of part of the western edifice, has not been correlated with any eruptive activity at Mount Rainier. It and most other cohesive lahars may have occurred without precursory eruptive phenomena.

The **Electron Mudflow** was very fluid and underwent minimal downstream attenuation of discharge. This behavior is demonstrated by the relatively high peak stage of the lahar about 36 km west of Mount Rainier, slightly downstream of Puget Power and Light's Electron Power Plant. There, the Electron Mudflow was more than 30 m deep as it exited the Cascade Mountain front and flowed onto the Puget Lowland. More than 40 trees were exhumed from Electron deposits at the town of Orting during the summer of 1993 and may provide clues to the exact age of the lahar.

Mount Rainier has a greater volume of snow and glacier ice than all of the other Cascade Range volcanoes combined (Driedger and Kennard, 1986). Several of Mount Rainier's 26 named glaciers (Fig. 6) have been the focus of classic studies of neoglacial moraine development and glacial dynamics (Sigafoos and Hendricks, 1961, 1972; Burbank, 1981; Porter, 1981; Heliker and others, 1984). Glacial outburst floods from South Tahoma Glacier have repeatedly scoured Tahoma Creek during the late 1960s and during the middle and late 1980s and early 1990s; the floods are usually associated with seasonally extreme weather either unusually warm or unusually wet conditions (Walder and Driedger, 1994). The Tahoma Creek events are discussed in detail in the field guide. Similar events have occurred in many other drainages, most notably Kautz Creek and Nisqually River during historical time (Driedger and Fountain, 1989). Future lahars pose the greatest risk to populated areas near Mount Rainier, particularly on downstream flood plains of the Nisqually and Puyallup River valleys and to sections of the White River valley upstream from Mud Mountain Dam.

Hydrothermal System and Hydrothermal Alteration

Studies of the hydrothermal system at Mount Rainier indicate that a narrow, central zone of heat emission maintains snowfree areas at the summit craters and forms the caves in the summit icecap (Moxham and others, 1965; Frank, 1985). Heat flux is substantial in comparison to most other volcanoes in the Cascade Range, comparable to that at Mount Baker and Mount Hood.

Hydrothermal activity has played an important role in the construction and destruction of Mount Rainier. Hydrovolcanic activity (phreatic or phreatomagmatic eruptions) produces fragmental deposits. Hydrothermal alteration produces secondary hydrothermal minerals from primary volcanic minerals and results in changes in the permeability of the primary rocks.

Hydrothermal alteration occurs both in currently active thermal areas and in prehistoric deposits that show no evidence of lingering hydrothermal activity. These Quaternary hydrothermal areas and deposits are significant because they influence edifice stability and the type and size of debris flows that may form (Scott and others, 1990; Zimbelman and others, in press). Generally, these areas contain argillization and silicification alteration types, both as pervasive masses and as selective pockets, lenses, and veins (Frank, 1985; Zimbelman and others, in press). Several representative areas of alteration are: Summit craters — An extensive area (> 12,000 m2) of heated ground and slightly acidic boilingpoint fumaroles occurs at East and West Craters on the volcano's summit. Maximum fumarole temperatures generally range from 76E to 86E C. Rocks in the summit area contain alteration products with major concentrations of clay minerals including smectite, halloysite, and disordered kaolinite. Silica phases include cristobalite, tridymite, and opal. Other prominent phases are alunite, gibbsite, and calcite (Frank, 1985).

Upper Flank — A small area (< 500 m2) of heated ground and subboilingpoint fumaroles lies on the upper flank at Disappointment Cleaver. Maximum temperatures at these fumaroles are about 60E C. Other areas of possible similar hydrothermal activity have been identified by infrared surveys, some of which have recently been field checked during a new USGS study as part of the Decade Volcano project. These occur at Willis Wall, Sunset Amphitheater, and the South Tahoma and Kautz headwalls. An area of fossil alteration is found at Sunset Amphitheater. There large areas of selectively to pervasively altered rock, are accompanied by minor veining.

Lower Flank—Sulfate, and carbon dioxideenriched thermal springs are present on the lower flank of the volcano on valley walls near the Winthrop and Paradise Glaciers. Maximum spring temperatures typically range from 9° to 24°C. The thermal springs deposit small amounts of calcite, opal, and gypsum as precipitation products that encrust gravel and cobbles in downstream channels.

Additional thermal activity occurs beyond the outcrop area of Mount Rainier andesite. Chloride and carbon dioxide enriched thermal springs described above issue from thin sediments that overlie Tertiary rocks in valley bottoms of the Nisqually and Ohanapecosh Rivers. Longmire Springs in the Nisqually River valley have maximum temperatures of 25°C and have produced an extensive area of travertine mounds and sulfiderich muds. The relative abundance of dissolved constituents at Longmire Springs is similar to that of higher altitude springs. All three sets of springs could conceivably be derived from similar acidic sulfatechloride waters that originate in a central, steam-heated hydrothermal system in the upper part of the volcano. Cooling of thermal waters during transit away from the hydrothermal system to lower elevations could take place by dilution with shallow cold ground water. The trend in composition from Winthrop to Paradise to Longmire Springs shows increasing ionic strength, progressive enrichment of calcium and chloride, and depletion of sulfate.

Hydrothermal alteration of Tertiary rocks in the Mount Rainier area is widespread. On Mount Rainier, the Glacier Basin area contains some of the most widespread alteration of Tertiary rocks found in the park. A copper-silver mining camp (now abandoned) was situated on vein and stock-worked areas of alteration in both Tertiary rocks and in surficial materials derived from those rocks. This area of alteration may have contributed some clay-size minerals to the Osceola Mudflow (Zimbelman and others, in press). Other areas of hydrothermally altered Tertiary rock are scattered throughout the park near the east and west sides of Winthrop Glacier, near the confluence of June Creek and the Carbon River, near Mowich Lake and the Mowich River, near Glacier Island and Pyramid Peak, and near the confluence of the Paradise and Nisqually Rivers

Seismicity

An average of about 30 small earthquakes occur under Mount Rainier per year, making it the most seismically active volcano in the Cascade Range after Mount St. Helens (Malone and Swanson, 1986). Malone and others (1991) note that more than 800 seismic events have been located within a 1,600 km2 area centered on Mount Rainier during the past 20 yr. It is expected that eruptive activity at Mount Rainier would be preceded by a systematic increase in seismic activity. Surficial events are another source of seismicity at Mount Rainier. The various types of events have been summarized by Weaver and others (1990).

Tectonic earthquake activity has led to the identification of a north trending fault zone west of Mount Rainier (Crosson and Frank, 1975; Weaver and Smith, 1983). The proximity of shallow crustal fault zones to Mount Rainier is significant because earthquake activity could cause slope failures at the volcano. For example, a debris avalanche at Ontake volcano in Japan was triggered by a regional tectonic earthquake (Nagaoka, 1987). Regional interplate or intraplate earthquakes also could trigger slope failures at the volcano. Trilateration and tilt networks established on the volcano in 1982 have shown no significant displacements (Chadwick and others, 1985), and seismic activity is probably within the range of normal for a quiescent composite volcano that has an active hydrothermal system.

Debris Flow Processes at Mount Rainier

Numerous debris flows and related floods have inundated valleys and adjacent terraces far from Mount Rainier. From a process perspective, these flows have been categorized as cohesive or noncohesive, representing a continuum of debris flow behavior that relates empirically to clay content (Scott and others, 1992).

Typically originating as deep-seated failures of the volcanic edifice, cohesive debris flows generally contain more than about 3 percent clay-size particles and travel great distances (>100 km), undergoing minimal rheologic change en route. Debris flows are a major destructional process of the Mount Rainier cone, and they can be initiated by tectonic or magmatic seismicity or hydrothermal destabilization. The stability of the Mount Rainier edifice is in a state of flux because of glacial and fluvial erosion, glacier mass and volume changes, and ground water (pore pressure) fluctuations.

Noncohesive debris flows, containing less than about 3 percent clay sized particles, commonly form when flood surges, triggered by eruption generated snow melt, incorporate sediment and become debris flows. They may also form by shallow slope failures that contain less than the critical amount of clay. In their distal phases these flows transform from debris flows (>60 percent sediment by volume) to hyper-concentrated flows (lahar run out flows) and then may be further diluted to normal stream flow (<20 percent sediment by volume). These types of debris flows may be a major source of liquefiable sands in valleys draining Mount Rainier (Palmer and others, 1991; Pringle and

Palmer, 1992).

Debris Flows on Tahoma Creek 1986-1992

Since 1986, debris flows along Tahoma Creek have repeatedly damaged the Westside Road, the principal access route to National Park trails and facilities on the southwest side of Mount Rainier. Debris flows have obliterated a picnic area, parts of the Westside Road, and the lowest 1 km of the Tahoma Creek hiking trail. Their suddenness and rapid movement down-valley make them dangerous to any objects in their path. Several individuals have witnessed the debris flows, but no one has yet been injured. However, about 60 persons were stranded on July 14, 1988, when a debris flow destroyed sections of the Westside Road.

As of July 1994, fifteen debris flows have been recorded in the sequence that began in 1986, and a total of 23 since 1967. Some of those earlier flows were described by Crandell (1971), and the sedimentology of two recent flows was described by Scott and others (1992).

These relatively small events, while posing a hazard mainly to areas in the national park, have frustrated efforts to keep the Westside Road open and served as a reminder of the much larger, less frequent debris flows.

Field Trip Log

(Mileage increments between points are given at the end of each entry.)

0.0 The field trip log starts at the intersection of State Route (SR) 516 and the valley freeway (SR 167) at Kent in the Duwamish valley. Go south on SR 167. The Duwamish valley was carved during and after the Vashon glaciation. An arm of Puget Sound extended up the Puyallup valley about as far as Sumner before deposition of the Osceola Mudflow about 5,000 yr B.P.. Tens of meters of debris flow deposits from Mount Rainier as well as fluvial deposits now underlie the valley floor. A study of well logs (Dragovich and others, in press) confirms that, at present sea level, a pre-Osceola Mudflow arm of Puget Sound in the Duwamish valley extended south to about 6 km north of the Sumner. Similarly, in the Puyallup valley an arm of the sound extended east to near the west side of the City of Puyallup. Increases in slope of the surface of the Osceola deposit and a dramatic decrease in thickness (from as much as 18 m slightly upstream of the delta top to <4 m on the delta front) mark the passage of the mudflow over deltas. Apparently there has been more than 400 km2 of alluviation in the Puyallup and Duwamish valleys since the Osceola Mudflow. Near Main St., and just west of the SR 167 in Auburn, a buried forest was discovered during excavations at the Emerald Downs Racetrack in 1995. The outer rings of a deciduous stump buried in a 0.8 m-thick pumiceous volcanic sand (laharic flood) deposit yielded a radiocarbon age of 1100 yr B.P.; an equivalent sand deposit was later discovered in the lower Duwamish River valley (Pringle and others, 1997)—these laharic deposit, which are correlative with the “Deadman Flats” lahar assemblage noted upstream, are the result of a moderatly explosive eruption of Mount Rainier (Scott and others, 1995).

13.1 Exit right onto SR 410. Head east on SR 410 for about 2 mi and exit onto SR 162. Go south (right) toward Orting. We cross the Puyallup River about 0.6 mi south of SR 410. The farthest downstream outcrops of the Electron Mudflow (channel-fill deposit) and the Osceola Mudflow are here. The top of the Osceola deposit is about 7 m below the bridge. Many eyewitness accounts of liquefaction were documented in this area during the M 7.1 1949 earthquake (Chleborad and Schuster, 1990). Black sands composing the sand boils had originated in lahar runout deposits from Mount Rainier (Palmer and others, 1991; Pringle and Palmer, 1992).

Lower(?) Pleistocene laharic deposits of the Alderton and Puyallup Formations of Crandell and others (1958) are exposed in the valley walls near Alderton. The two units are separated by the Stuck Drift of Crandell and others (1958); all are reversely magnetized (Easterbrook, 1994) and thus lie within the Matuyama Reversed Polarity Chron (0.8 to 2.4 Ma).

20.0 Stop 1-1 - Orting Buried Forest

At the town of Orting turn right near the Orting Elementary School or Whitehawk Subdivision. This area, about 50 km flow distance from the volcano, was inundated by the Electron Mudflow about 530 yr B.P.(Fig. 7). Recent excavations on the west side of the highway have exposed remnants of a buried old growth forest (mostly Douglas fir) that was preserved within as much as 6 m of mudflow (Fig. 8). Locally the deposit is only a 2-3-m thick where the flow inundated a preexisting terrace. Some of the excavated snags are now lying on the surface, and several in-place snags stick up in the storm water retention pond north of the subdivision entrance, although these are now being overgrown by vegetation. Large blocks of andesitic volcanic breccia, some as large as 5-m long have been excavated near here. Imagine these large boulders carried by the flow. Some huge logs as long as 19-m were lying horizontally in the lahar deposit, whereas many of the stumps were in growth position, having either had their tops broken off by flow or decomposed above the mean high groundwater level.

The four innermost rings of a giant Douglas fir stump that was about 358 years old when it died yielded radiocarbon ages of 1010 ±50 and 950 ±50 (Fig. 8). After calibrating and offsetting the ages to reflect number of rings in from the outermost ring under bark (last ring produced before death of tree), the data can be combined with other radiocarbon ages for the Electron Mudflow to show that the event probably occurred near A.D. 1400. However, wiggles in the radiocarbon calibration curve yield multiple intercepts that allow considerable error. Preliminary analysis of tree rings, particularly the “latewood” or dark, dense cells that form during the summer, may indicate that the Electron Mudflow occurred in the early 1400s. A matrix of provisional best-fit matches of tree ring and latewood indices for the several of the oldest trees included calendric ages of A.D. 1411 and 1433. However, a dearth of published master chronologies for this region and spanning this time interval make crossdating difficult.

Development pressures have been intense in this area of the Puyallup Valley, which was designated as an area of moderate volcanic hazards by Crandell (1973). Recent legislation, the Washington Growth Management Act, (Title 36.70A RCW) mandates that all qualifying jurisdictions will (among other things) designate “critical areas” including geologically hazardous areas. The Washington Department of Community, Trade and Economic Development developed “minimum guidelines” for defining volcanic hazard areas (Chapter 365190 WAC, Section (4fi)). Local geology professor Al Eggers (University of Puget Sound) served on a citizens advisory board to the Pierce County Planning Department and was influential in the appraisal of volcanic (and other) hazards that have been considered in designing the county comprehensive land use plan.

At this stop Richard Schroedel of Pierce County Dept. of Emergency Management will discuss the county’s role in preparedness efforts related to volcanic hazards. Pierce County has partnered with the US Geological Survey in a pilot project that involves the installation of a series of acoustic flow monitors (AFMs), essentially geophones that can detect vibrations in the range of 50-90 hz that would be produced by lahars coming down the Puyallup or Carbon River drainages (see attached USGS information sheet). When completed, the warning system will include sirens and a network of local FM radio stations that will broadcast hazards-related information in the case of an approaching lahar. Lahar warning signs are in the planning process.

The Mount Rainier Volcanic Hazards Working Group (MORAWOG) consists of representatives of federal, state, and local agencies, local governments, school systems, and members of the public and other organizations. This group has been meeting for more than 10 years and plans and sponsors educational and outreach efforts related to the hazards of Mount Rainier. The group has just completed a working draft of a response plan for Mount Rainier.

Continue south on SR 162 through the town of Orting.

24.7 Turn south toward Electron at the Orville Kapowsin Road turnoff. SR 162 continues to the east up the valley of Prairie Creek, interpreted by Crandell to be the pre-Osceola valley of the White River.

28.0 Brooks Road and Puyallup River Bridge.

28.1 **STOP 1-2 lahar deposits** exposed along the left bank of the Puyallup River.

Be Careful—this is a dangerous curve.
Turn left into a old logging road and park. Because of his own interest in the deposits, Brian Phillips, who owns the property, has graciously allowed us access to the river. Walk down the road a short distance (-20 m), take the left branch another ~20 m, then cut over to the river. Descend to a resistant outcrop of intrusive igneous rock and walk upstream.Here l-to-2-m-thick rubbly Electron Mudflow deposit overlies a 1.5-to-3 m thick noncohesive lahar. While these deposits are only a few meters above the river, their peak stage heights were undoubtedly much higher. Well logs in this vicinity show that the pre-Electron valley bottom may be as much as 8 m below the present floodplain. Judging by the elevation of nearby deposits of the Electron, it probably was as much as 25 to 30 meters deep as flowed through this constriction.

29.4 264 St. Local resident Emmet Chase observed that a large crack cut across this road as a result of slope movement during the 1949 (Mg 7.1) Olympia earthquake (Chleborad and Schuster, 1990, 1998). Chase observed other cracks along the valley of Brooks Creek and in the valley of the Puyallup River along the Electron flume. These events along with numerous incidents of liquefaction during the 1949 earthquake further demonstrates that present and future inhabitants of these valleys face riske from multiple geologic hazards.

31.6 Electron. The Electron Mudflow was named by US Geological Survey geologist Dwight “Rocky” Crandell, who described and dated its deposits at the Puyallup River Bridge near here. Deposits of the mudflow are exposed along the logging road adjacent to, and east of the main highway here. Electron Road leads to the Electron Power Plant and Flume, operated by the Puget Sound Power and Light Company.

31.8 Camp One Road. This road leads to the field office for the Kapowsin Tree Farm, presently owned by the International Paper Company. This tree farm extends to the western border of Mount Rainier National Park. Cross Kapowsin Creek, which drains Lake Kapowsin, shortly after passing this intersection.

32.4 Lake Kapowsin. Lake Kapowsin was dammed by the Electron Mudflow(Crandell, 1963). Before 1989 rowers and paddlers on the lake could pass over enormous snags standing in the lake. A harvesting operation in 1989 removed (possibly illegally) many of the trees.

33.8 Orville Rd. This winding road leads south through the Ohop valley to Eatonville, however, we will go there via SR 161, so continue forward through this intersection.

36.8 SR 161. TURN LEFT and continue south. 38.0 Mile post 12.

39.0 MP 11. Not long after the road curves to the southeast we begin a gradual descent into the valley of Tanwax Creek.

39.7 Tanwax Creek and Tanwax Lake—remnants of a large, late-glacial flood:
Clusters of andesitic and minor granitic boulders (Fig.9), some as large as 2 m, locally are scattered along a southwest-trending network of valleys that cuts across the generally north-south-trending fabric of the drumlinoid Vashon drift plain in the Puget Lowland. These boulders provide striking evidence of a local catastrophic flood from the sudden draining of an ice-dammed lake in the Carbon River valley in the Cascade Range northwest of Mount Rainier, “glacial lake Carbon” (Pringle and others, 2000 in press). The discontinuous train of boulders deposited by the flood extends from the Fox Creek valley, northeast of Electron, to the southwest, across, and along the general trend of the Ohop Valley. One distributary of the flood flowed through Tenino via the Mclntosh Lake and Scatter Creek valleys and probably flowed along the Skookumchuck River valley as far as the Chehalis River. Similar andesitic boulder clusters are scattered atop the Vashon glacial outwash south of the Nisqually River about 5 km southeast of Yelm.

The present day Tanwax valley, marked by Tanwax Creek and a line of lakes, and extending from slightly east of Lake Kapowsin southwest to its confluence with Nisqually River, marks the southernmost extent of the receding Puget Lobe at the time of the outburst flood. The floodway in the vicinity of the Ohop Valley-Nisqually River confluence extended from Tanwax Creek on the northwest to as far east as Eatonville (9 km wide), and no doubt backflooded up the Mashel River valley. The flood was augmented when meltwaters draining from glacial lake Carbon apparently undercut the southwest valley wall of Fox Creek, composed of thick, andesitic volcaniclastic deposits of the (1 Ma) Lily Creek Formation, and the resulting landslide created a temporary blockage in the glacial lake floodway. Andesite boulders that lie 120 m above, and east of present Lake Kapowsin in the Ohop Valley provide a minimum depth for the flood; we estimate the volume of glacial lake Carbon at about 107 to 108 m3. The Tanwax Creek-Ohop Valley flood may have been much larger than other floods from ice-impounded Cascade Range drainages blocked by the Puget Lobe because the Carbon River valley was being fed by runoff from Mount Rainier.

41.1 Northwest Trek. Andesitic boulder of the Tanwax-Ohop valley flood are scattered around this theme park.

43.8 Eatonville-Cutoff Road. Note the andesitic boulders along SR 161 and north of the service station on the comer. A noteworthy cluster of boulders lies along Tanwax Creek north of the Eatonville Cutoff Road.

44.0 Dogwood Park. This park has a good view of Mount Rainier’s west face, but don’t believe the interpretive sign, which says the Mount Rainier’s 3 peaks are cones.

44.8 Some of the large andesitic boulders of the Lily Creek Formation are visible along the right side of the road here, just past the 40 mph sign.

45.6 Orville Road, followed shortly by Ohop Creek.

45.8 More grey, andesitic boulders.

46.5 Enter Eatonville. Suggestion: go the speed limit.

46.7 Ohop Bakery.

47.0 TURN LEFT AT THE ARK.

47.4 **Mashel River**. The left valley wall of the Mashel River roughly marks the left edge of the Tanwax-Ohop late-gla cial floodway. Continue on the winding road to SR7.

54.0 SR 7. TURN LEFT.

54.7 The Wonderful World of Hardwoods. Ed Strauss, owner of WWH, has a great website on petrified wood at http://www.mashell.com/~estrauss/pwoodfx.html.

58.5 **Elbe**.

58.9 SR 7 turns right and crosses the Nisqually River. **CONTINUE STRAIGHT AHEAD ON SR 706.**

61.0 Ascend a small terrace. Most of this area was inundated by postglacial lahars from Mount Rainer. A controversial project called the "Mount Rainier Resort at Park Junction" has been proposed for this area, known locally as the "Succotash Valley"

.62.2 STOP 1-3. TAHOMA WOODS AREA LAHARS. After ascending another small terrace (composed of Evans Creek alpine outwash and veneered by a loessy soil) and **TURN RIGHT ONTO 238TH AV East**. Park along the edges of the service road near the turn, but please leave a lane down the middle for traffic. Hike to the south toward the Nisqually River (about 1/4 mi) along the road taking the righthand forks—the "road" becomes a jeep trail. Just after the trail turns left, take a right across from the shack onto a fisherman's trail and walk to the gravel bar. Go east to a spectacular assemblage of lahar and lahar runout deposits that were triggered during eruptive activity at Mount Rainier between 2,300 and 2,600 yr B P

Yakima Park Road to Sunrise veers off to southeast. View is up the White River which heads at Emmons Glacier and drains the east side of the volcano. The White River was a major pathway for the Osceola Mudflow. Orange diamicts in roadcuts along the valley floor are scattered remnants of the Osceola.

Junction of Yakima Park Road and White River Campground Road. Turn left into the campground and drive to the far west end. The clay-rich Osceola Mudflow overlies debris flow deposits at the road junction. Porter and others (1965) estimated that the mudflow was at least 210m thick here.

Road to Sunrise Park
The Osceola Mudflow is locally visible as a <10 m veneer for about the next 1.0 mi with tephra layers Yn, C, and Wn visible on top of it in some outcrops. Spectacular columns of Mount Rainier Andesite, as well as till, a tephra of pre-Evans Creek age (>38 ka), and beds of fine-grained material (glacial-lake deposits) are visible between road miles 1.7 and 2.1.

Pull-off to see tephra deposits underlying Evans Creekage glacial deposits.

Yakima Park flow of the Mount Rainier Andesite. This flow is one of the longer intra-canyon flows preceding the main cone-building stage of the volcano. (See Fiske and others, 1963.) The flow apparently followed the course of the ancestral White River and probably chilled against a glacier as noted earlier to form the picturesque columnar joints exposed in the road cut.

91.1 Sunrise Point switch-back parking lot. This is the type area of the Sunrise Point quartz monzonite of Mattinson (1977). At most outcrops the rock is a light-grey to greenish-grey, medium- to fine-grained, equigranular quartz monzonite composed of plagioclase in a granophyric matrix of K feldspar and quartz. Biotite, chlorite and hornblende are less common. Magnetite, ilmenite, titanite, and epidote are also present. The rock is commonly altered. UPb zircon data (Mattinson 1977) suggest an age of 24 Ma, considerably older than the White River pluton. From this last switch-back, the road to Sunrise cuts through granodiorite of the Tatoosh pluton.

95.8 Upper contact between Ohanapecosh Formation and Sunrise Point pluton. A complex upper and lateral boundary with the Ohanapecosh Formation is exposed here.

96.4 Roadcuts to north expose Mazama ash (layer O) overlain by blocky rubble of layer S and pumiceous layer C. This is the locality for Crandell's figure in Bulletin 1238 and is a good place for a short stop on the return from Sunrise (mi 10.9).

97.2 Stop 2-2 - Sunrise Parking Lot - Lunch and optional hike
This optional hike goes north from the parking area and up about 400 ft (120 m) onto Sourdough Ridge to a saddle. There we will view an outcrop of a biotite-phyric Sourdough Ridge pumice that may record the largest known explosive eruption of Mount Rainier. The 2m thickness of this unit 12 km northeast of the present Mount Rainier summit is greater than that of tephra layer Yn (3,600 yr B.P.) at an equivalent distance from Mount St. Helens (Mullineaux, 1986). The volume (dense rock equivalent) of layer Yn has been estimated at 4 km3 (Carey and others, 1989). The tephra clasts are crumbly and many represent fragments of much larger clasts. Sisson obtained a K/Ar age on the pumice of about 384 ka (personal commun., 1998). The origin of a fragmental deposit overlying the tephra is unclear. Is this explosion ejecta or possibly part of a glacial moraine?

The crest of Sunrise Ridge is composed of lavas and breccias of the Mount Fremont dome complex. The Mount Fremont aphanite (Fiske and others, 1963) is andesite to dacite in composition with plagioclase the only abundant phenocrysts. Rare augite and magnetite/ ilmenite are also found. This unit has not been dated; however, it is probably slightly older than the 25.1 Ma (Mattinson, 1977) tuff of the Palisades, exposed about 3 km to the north. Mapping of crumble breccia, vent-filling tuff breccia, aligned vesicles and flow foliation (Murphy and Marsh, 1993) reveals at least two vents in this vicinity, sub-parallel and NWSE trending. A good cross section of the dome complex can be seen during the short (4 km) hike to the Mount Fremont fire lookout. Fine-grained, laminated, well-indurated rocks are found on the tops of McNeeley Peak and Dege Peak, probably either Fifes Peak Formation-equivalent (Fiske and others, 1963) or associated with late-stage dome explosion or epiclastic degradation (Murphy and Marsh, 1993).

The optional 5-km loop hike to Frozen Lake transects the excellently exposed upper contact of the Sunrise Point pluton and the overlying dome complex. Look for the granitic rocks along the creek draining Frozen Lake, but try to stay on the trail elsewhere. The meadow biota are highly sensitive to foot traffic.

The Emmons Vista trail (0.3 mi round trip) leads to several scenic overlooks.

Silver Springs—one mile outside the Mount Rainier park border. A water supply well for a USFS ranger station penetrated the Osceola Mudflow at a depth of about 15m and was still in it when drilling stopped at 61 m. Nearby the mudflow also veneers the valley sides 38 m above the river (Crandell, 1971).

Town of Greenwater. Lahars have left abundant deposits in this area, perhaps because the valley is fairly constricted downstream of here. The West Fork White River joins the White River about 2 mi to the east. This river drains the north slope and heads at Winthrop Glacier. The West Fork valley was one of the pathways of the Osceola Mudflow.

Federation State Forest. The road here is on a terrace underlain by lahars of the Deadman Flat assemblage, noncohesive lahars from Mount Rainier, the largest of which has been dated at 1,120 ± 80 yr B.P. (Scott and others, 1992). The largest lahar in this assemblage was at least 18 m deep at this location (Fig. 9). As noted above, it is now known that the Deadman Flat lahars inundated the lower White River and Duwamish River valleys as far as the Port of Seattle.

At the Federation Forest State Park campground south of the highway, a water-supply wellpenetrated the Osceola Mudflow at a depth of 61 m; the top of the Osceola is 11 m above the White River (Crandell, 1971).

Last Stop: Mud Mountain Dam.

At the junction of SR 10 and the Mud Mountain Dam access road, drive 2.4 mi on the access road and then a short distance left to the dam viewpoint. In the recent clear-cut near the intersection of the entrance road with SR 410, note the small hummocks or mounds in the Osceola Mudflow deposit. The mounds commonly consist of mega-blocks of rock debris either from Mount Rainier, or composed of non-Mount Rainier rocks that were picked up by the Osceola en route down the valley. At the viewpoint, the Osceola deposit is the thick rocky diamicton that caps Vashon Till and advance outwash in the terrace exposed in a recent landslide scarp to the north. Note that this deposit has a flat bottom and uneven top. In their 1997 paper, geologists Jim Vallance and Kevin Scott, who have studied the Osceola Mudflow in great detail, note that:

“ *When it (Osceola) encountered a narrow gorge of the White River at Mud Mountain that is only 300 m wide, the Osceola Mudflow spread out over glaciofluvial [and till] terraces of Vashon age that are up to 110 m above the White River...As it continued westward, the mudflow poured over terrace scarps to form a spectacular pair of falls...The upper fall would have formed an arc more than 6 km wide and more than 80 m high, and the second would have been more than3 km wide and more than 110 m high.”*

Lower, inset terraces that are visible from the viewpoint are lahars of the Deadman Flat assemblage, noted earlier. Upstream of here about 1 km, these deposits, which mainly consist of sandy, noncohesive, probably eruption-triggered lahars from Mount Rainier, veneer terraces as high as 65 m above the White River. Mud Mountain Dam was built by the Corps of Engineers solely for flood control in the lower White River basin. The earthfill embankment dam was constructed between 1939 and 1942, although flood gates were not constructed until 1948. Additional information about the dam can be found in Galster (1989a, 1989b).

The Three Sisters, the cone-shaped peak to the southeast with a radio tower on it’s summit, has been identified by Tom Sisson of USGS (personal commun., 1998) as basaltic andesite vent with agluttinated spatter and possible feeder dikes. The volcano yielded a K/Ar age of 359 ka.

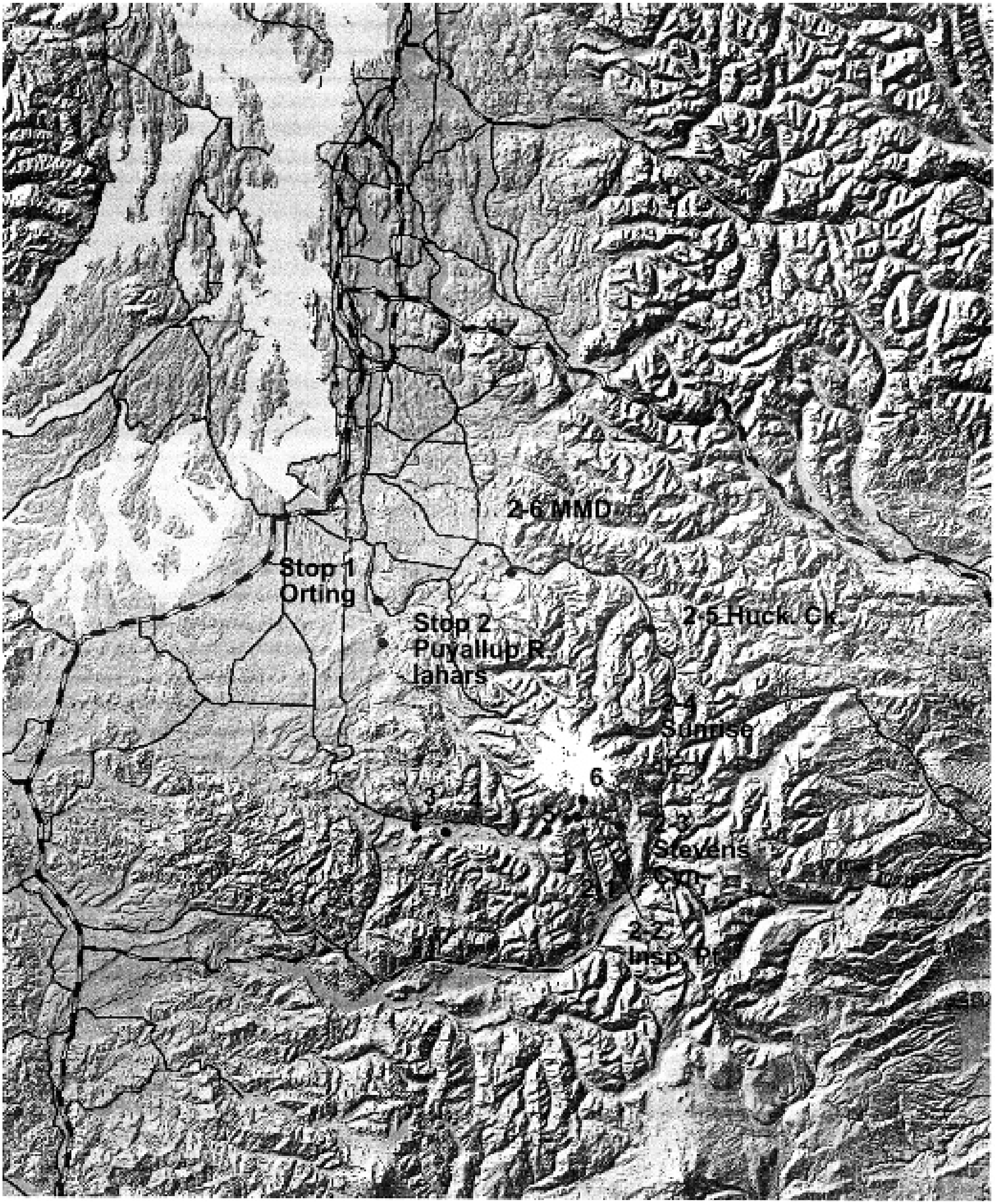
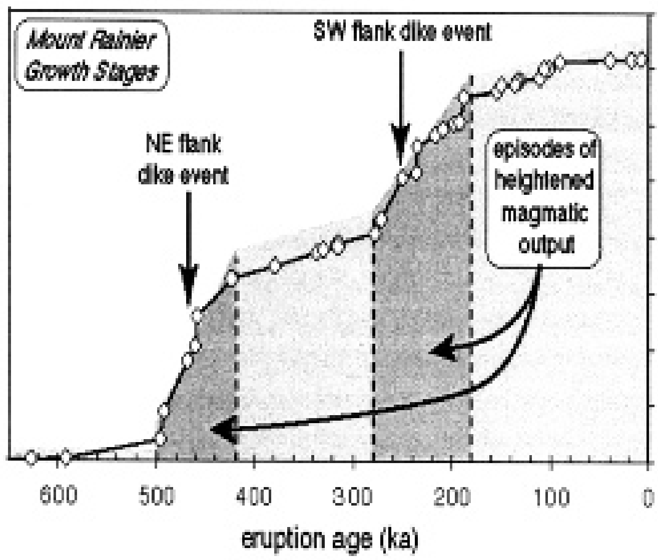
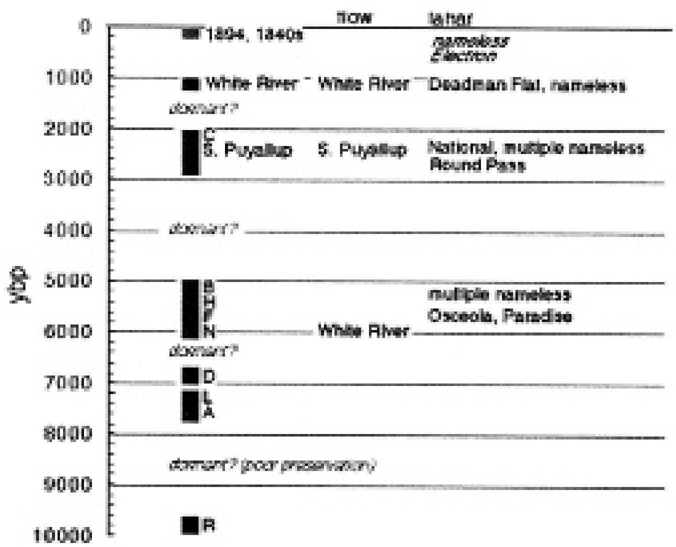

2-6 MMD
Stop 1
Orting
Stop 2
Puyallup R.
lahars
2-5 Huck. Ck.
Sunrise
6
3
4
Stevens
Insp. Pt.

Plate 1



2. Cumulative growth curve for flank lavas from Mount Rainier (Sisson and Lanphere, 1999). Each symbol represents a mapped, dated, flank flow, or flow group. Total edifice growth curve not shown because of imprecise volume estimates (this graphic from Sisson and others, in press)



3. Holocene eruptions and major lahars (>20 km long) from Mount Rainier. General eruptive periods (black bars) and named ashes (C, B, F, etc.) from USGS reports plus J. Vallance and S. Donohue (unpublished); lahar ages from Scott et al. (1995) and K. Scott (personal communication). Italics denote lahars outside known eruptive periods.

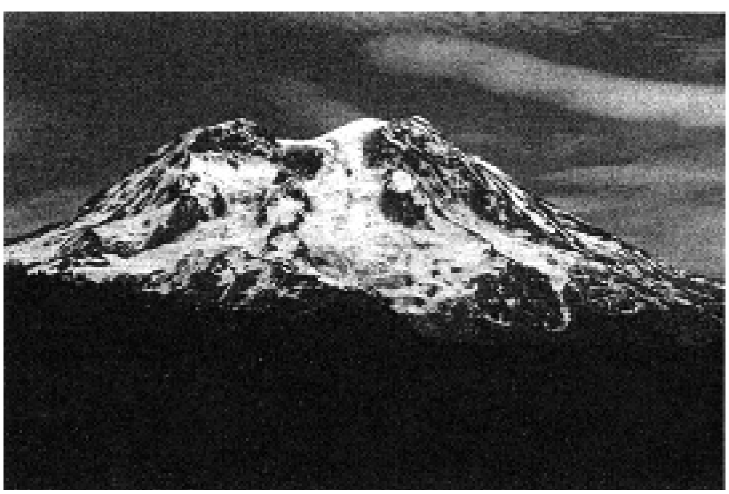


Fig. 4 The stunning view of Mount Rainier's west flank from Glacier View wilderness area. Tom Sisson has now dated the 30-m thick tephra layer at Sunset Amphitheater at ~ 200ka; the broad dike complex that forms a rib up the west side and such features as Tokaloo Rock is -SOOka; and the stack of thin flows in the upper right (Point Success) is <40ka. Columbia Crest cone is the result of eruptions of the past 2600 yrs.

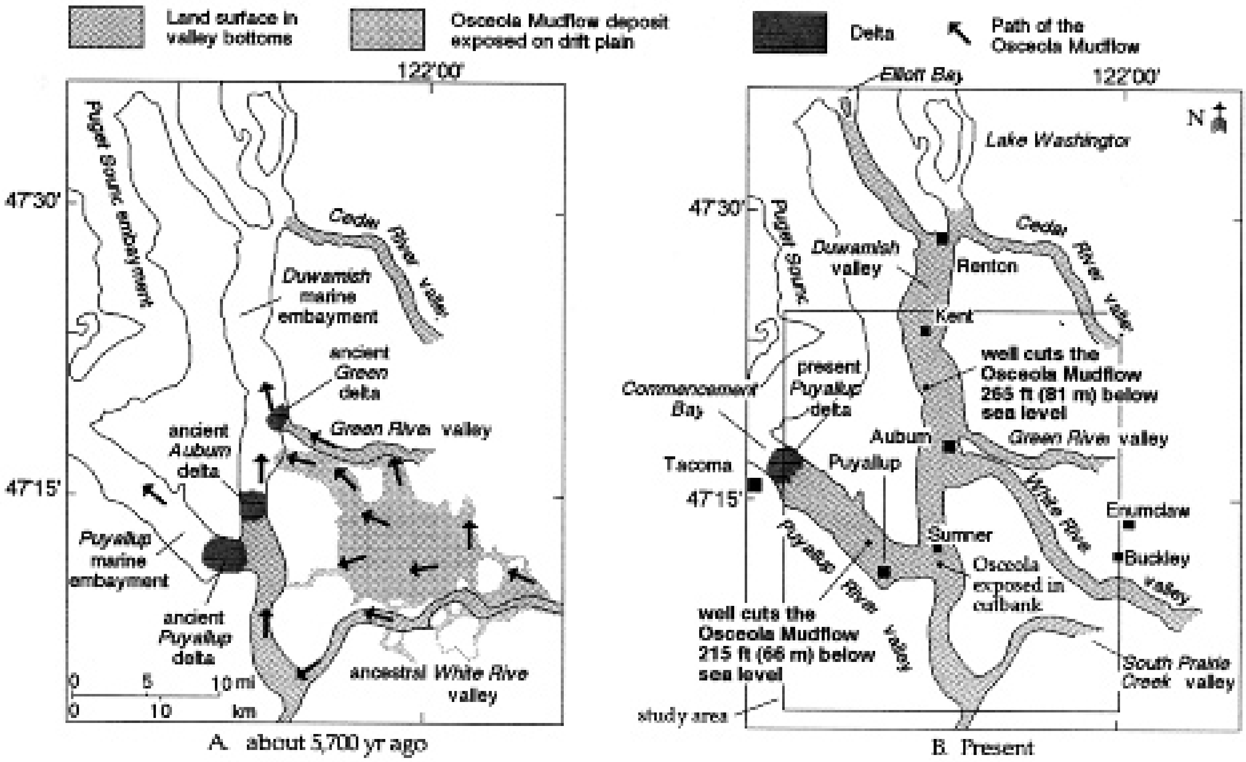


Fig. 5 Comparison of the modern shorelines (B) of Puget Sound with those at the time of the great Osceola Mudflow from Mount Rainier. Arrows show flow of the Osceola and gray area in A it's subaerial extent. Box B is left over from a previous study, but we forgot to edit it out. B is modified from Luzier (1969).

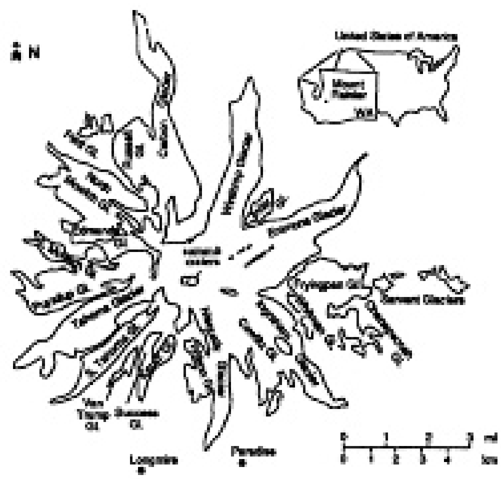


FIGURE 6. Glaciers of Mount Rainier, circa 1983.

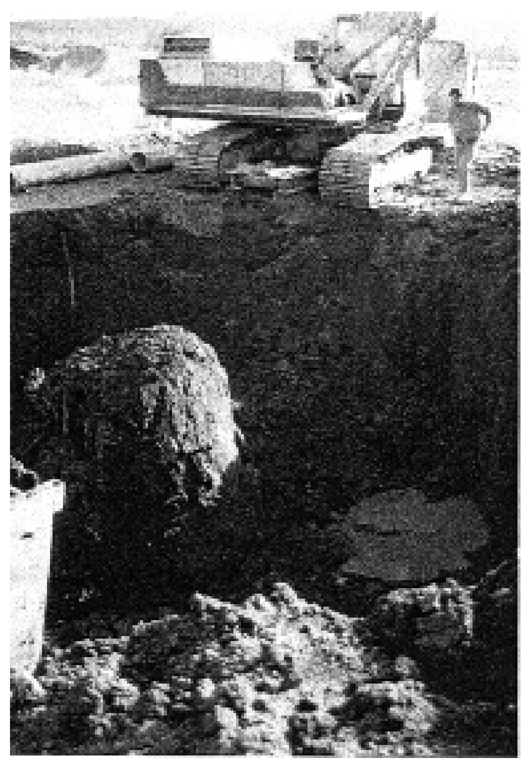


Fig. 7 The "big stump" (Douglas fir) on the right was dug up during construction at Whitehawk development in Orting in 1993. The stump is a member of an old growth forest buried as much as 20 feet by the Electron Mudflow about A.D. 1400

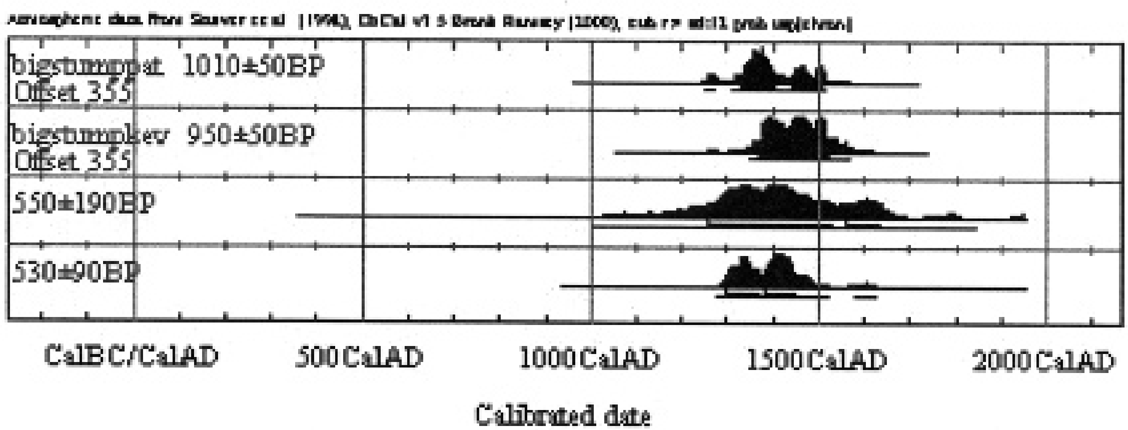


Fig. 8 Plots showing the range of probabilities of calibrated ages for four different samples from trees killed by the Electron Mudflow. Top two raw ages (left) were from the innermost rings of the "big stump" (Fig. 7). Note the difference in the top two, which are essentially from the same four rings, the probability spread, and the occurrence of multiple intercepts in the calibration curve (multiple line segments under curves).

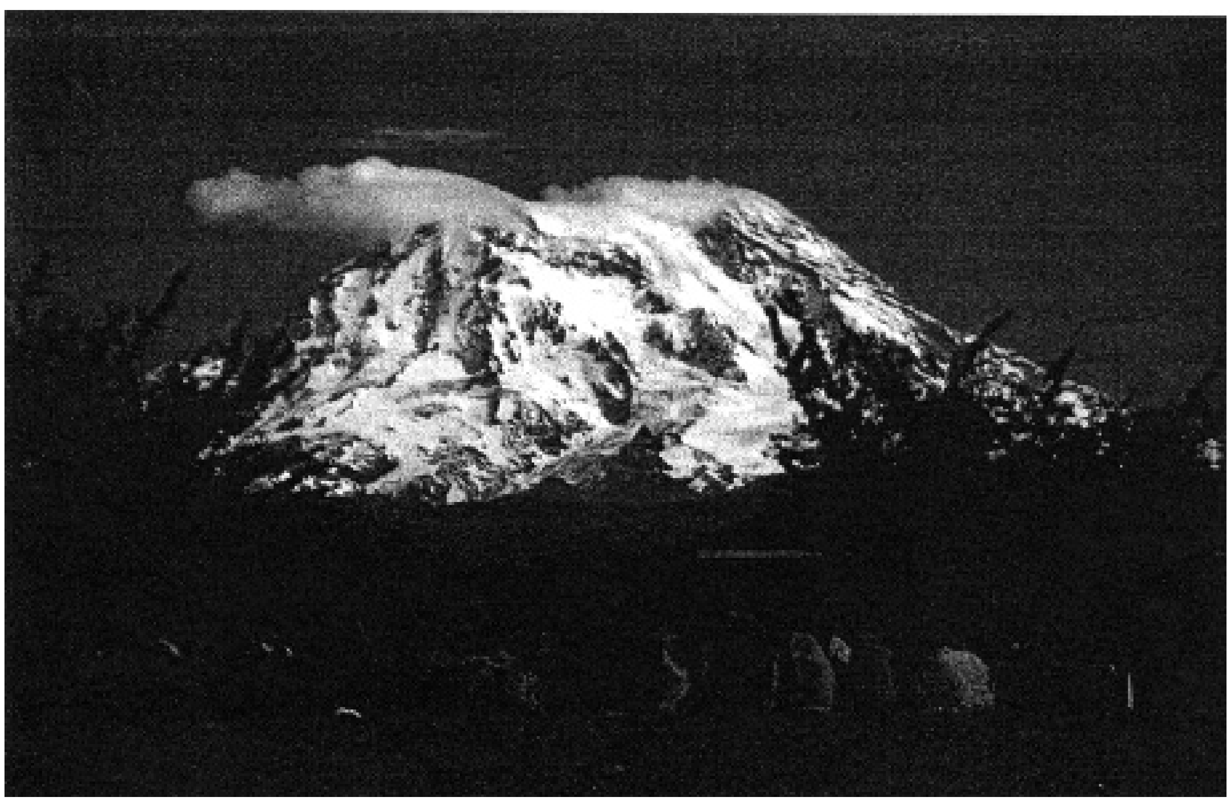


Fig. 9 Clusters of mostly andesitic boulders like these at "Stonehenge" along SR 7 are from the Tanwax-Ohop Creek late-glacial flood. Outwash from an ice-dammed lake in the Carbon River valley was augment-

Stop 1-3. Tahoma Woods area outcrop of the National lahar assemblage. These lahars were triggered by eruptive activity about 2,300 yr B.P.

Stop 1-3. Breadcrust bomb in the National lahar near Tahoma Woods

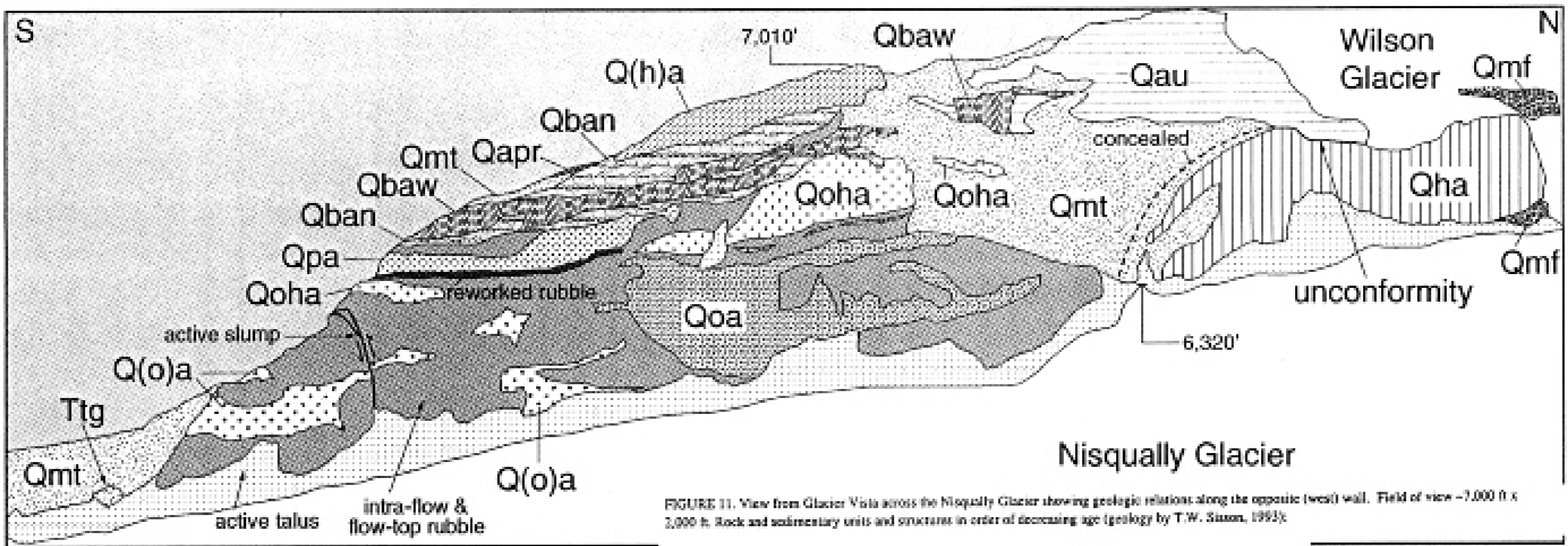


FIGURE 11. View from Glacier Vista across the Nisqually Glacier showing geologic relations along the opposite (west) wall. Field of view ~7,000 ft x 2,000 ft. Rock and sedimentary units and structures in order of decreasing age (geology by T.W. Sisson, 1993):

Tertiary

Ttg—Tatoosh granodiorite
unconformity (concealed)

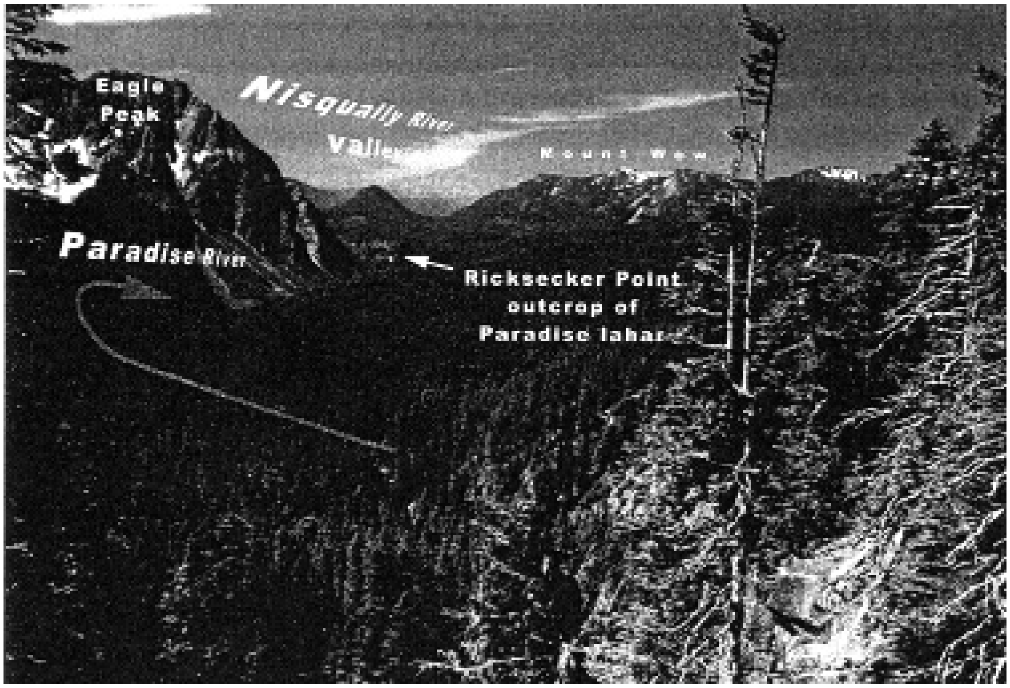
Quaternary—Pleistocene?

Qmf—volcanic mudflows;
Qha—hornblende-rich andesite with more than 10 quenched magmatic inclusions (QMI)/m^2 of outcrop area;
unconformity
Q(o)a—andesite with a trace of olivine and more than 10 QMI/m^2 of outcrop area;
Qoa—olivine andesite with <1 QMI/m^2 of outcrop area;
Qoha—olivine-and hornblende-bearing andesite with ~4 QMI/m^2 of outcrop area;
reworked flow-top rubble—possible disconformity;
Qpa—two-pyroxene andesite;
Qban— non-welded block- and ash-flow tuff;
Qbaw—welded block- and ash-flow tuff;
Q(h)a—andesite with a trace of euhedral hornblende and <1 QMI/m^2 of outcrop area;
unconformity

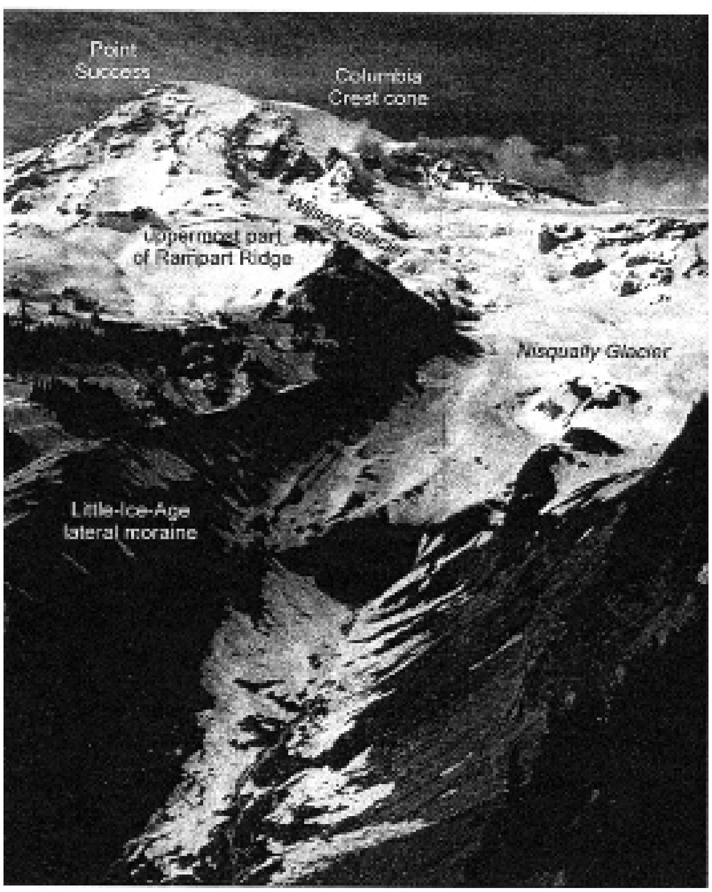
Holocene

Qmt—older Garda moraine (inactive) and associated talus;

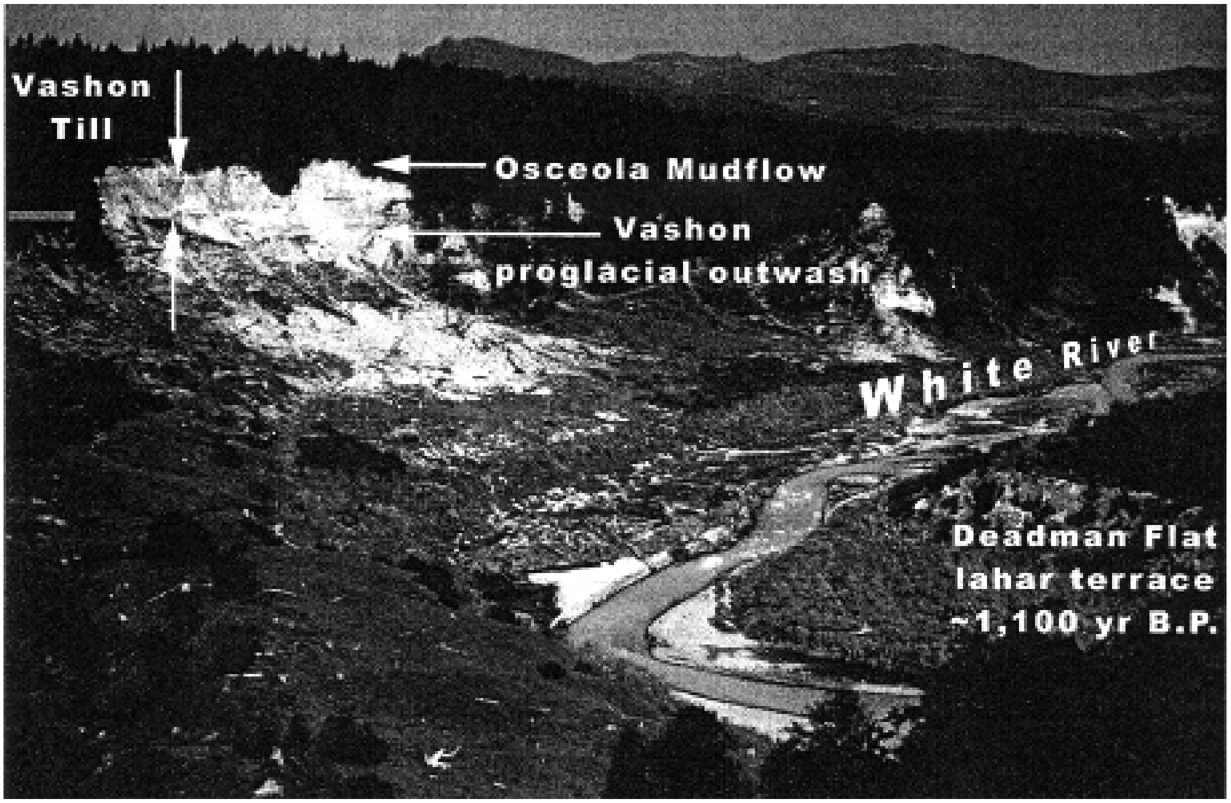
Pl. 6



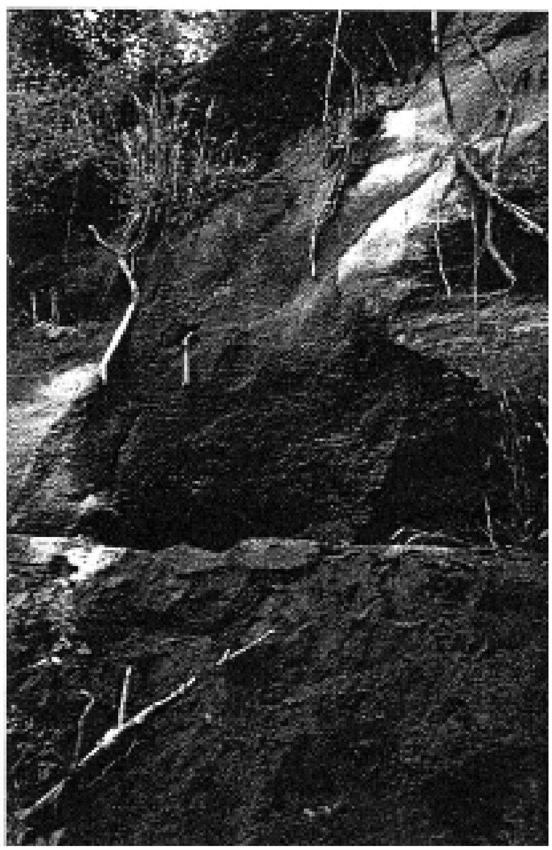
Stop 2-1: View to the southeast from Inspiration Point showing the location of Paradise lahar deposits at Ricksecker Point.



Stop 1-6: Glacier View at Paradise



Last stop: View from viewpoint at Mud Mountain Dam.



Lahar runouts upstream of Mud Mountain Dam. The upper one (and possible the lower one as well) is probably correlative with the Dead man Flat lahars. These were triggered by moderately explosive eruption at Mount Rainier that inundated as far downstream as the Port of Seattle about 1,100 yr. B.P.