72nd Highway Geology Symposium

MOUNT RAINIER FIELD TRIP GUIDE

August 16, 2023 • Tacoma, Washington

The contents of this field trip guide have been borrowed and adapted with permission from various sources
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Special thanks and acknowledgements to our primary source: Pringle, Patrick T., 2008, Roadside geology of
Mount Rainier National Park and vicinity: Washington Division of Geology and Earth Resources Information Circular 107.

ITINERARY

Which bus should I get on?

Your HGS welcome packet contains your bus assignment. You are welcome to trade with other attendees.

If you would like to go on a “strenuous” hike, we suggest Bus 4! If you were assigned to Bus 4 and you are not interested in a strenuous hike, please consider trading your bus assignment with someone who would like to go on a strenuous hike.

August 16, 2023

<table>
<tr><th>Time</th><th>Bus 1</th><th>Bus 2</th><th>Bus 3</th><th>Bus 4</th></tr>
<tr><td>7:30 AM</td><td colspan="4">Gather at Hotel Murano</td></tr>
<tr><td rowspan="2">8:00 AM</td><td colspan="4">8:00 AM – All Buses Depart Tacoma</td></tr>
<tr><td colspan="4" rowspan="2">Bus discussions: lahars, debris flows, Alder dam, rockfall</td></tr>
<tr><td rowspan="2">9:00 AM</td></tr>
<tr><td colspan="4">Arrive at Mt. Rainier National Park</td></tr>
<tr><td rowspan="2">10:00 AM</td><td>Bus 1</td><td>Bus 2</td><td>Bus 3</td><td>Bus 4</td></tr>
<tr><td colspan="2">Arrive at Paradise</td><td colspan="2" rowspan="2">Ricksecker Point</td></tr>
<tr><td rowspan="2">11:00 AM</td><td rowspan="2">LUNCH</td><td rowspan="2">LUNCH</td></tr>
<tr><td colspan="2">Arrive at Paradise</td></tr>
<tr><td>12:00 PM</td><td rowspan="2">Hiking and
visiting Paradise</td><td rowspan="2">Hiking and
visiting Paradise</td><td>LUNCH</td><td>LUNCH</td></tr>
<tr><td>1:00 PM</td><td rowspan="3">Hiking and
visiting Paradise</td><td rowspan="3">Hiking and
visiting Paradise</td></tr>
<tr><td rowspan="2">2:00 PM</td><td colspan="2">2:00 PM – Buses depart!</td></tr>
<tr><td colspan="2" rowspan="2">Ricksecker Point</td></tr>
<tr><td rowspan="2">3:00 PM</td><td colspan="2">3:00 PM – Buses depart!</td></tr>
<tr><td colspan="4">Travel to SR 7 Demonstration</td></tr>
<tr><td>4:00 PM</td><td colspan="4" rowspan="2">SR 7 Demonstration</td></tr>
<tr><td>5:00 PM</td></tr>
<tr><td>6:00 PM</td><td colspan="4" rowspan="2">Travel back to Tacoma (Hotel Murano)</td></tr>
<tr><td>7:00 PM</td></tr>
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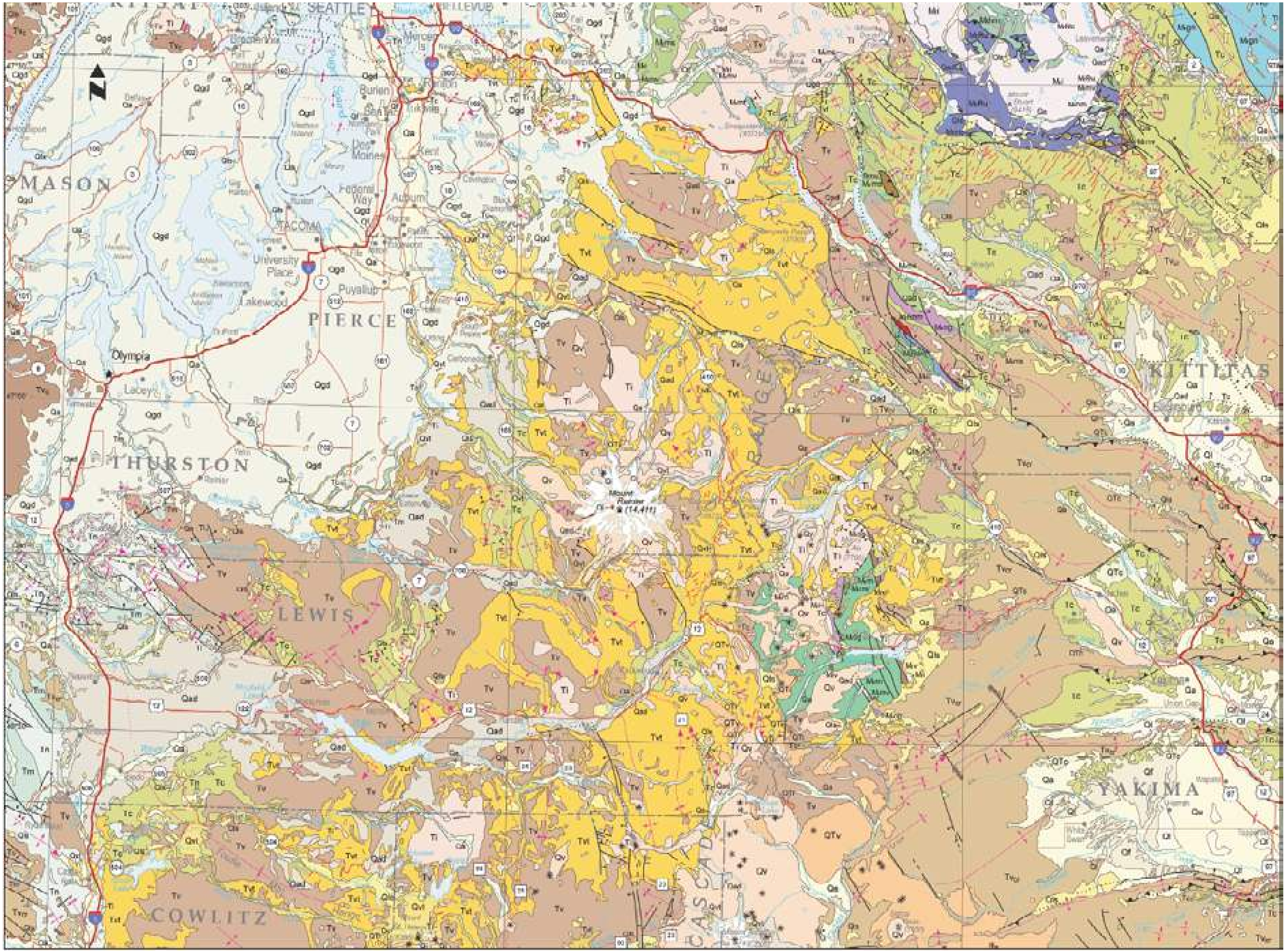

SEATTLE
MASON
TACOMA
University Place
Lakewood
Puyallup
PIERCE
Federal Way
Auburn
Kent
Des Moines
Burien
Olympia
THURSTON
LEWIS
COWLITZ
Mount Rainier
(14,411)
KITTITAS
YAKIMA

KEY TO GEOLOGIC UNITS

Unconsolidated Sediments

Qa	Quaternary alluvium
Qls	Quaternary mass-wasting deposits
Ql	Quaternary loess
Qf	Pleistocene outburst-flood deposits
Qgd	Pleistocene continental glacial drift
Qad	Pleistocene alpine glacial drift

Sedimentary Rocks and Deposits

QTc	Quaternary–Tertiary continental sedimentary rocks and deposits
Tc	Tertiary continental sedimentary rocks
Tn	Tertiary nearshore sedimentary rocks
Tm	Tertiary marine sedimentary rocks
Mm	Mesozoic marine sedimentary rocks

Volcanic Rocks and Deposits

Qv	Quaternary volcanic rocks
QTv	Quaternary–Tertiary volcanic rocks
Tvcr	Tertiary volcanic rocks of the Columbia River Basalt Group
Tv	Tertiary volcanic rocks
Tvc	Tertiary volcanic rocks
Mv	Mesozoic volcanic rocks
Qvt	Quaternary fragmental volcanic rocks
Tvt	Tertiary fragmental volcanic rocks

Intrusive Rocks

Qi	Quaternary intrusive rocks
QTi	Quaternary–Tertiary intrusive rocks
Ti	Tertiary intrusive rocks
Mi	Mesozoic intrusive rocks
MPu	Mesozoic–Paleozoic ultramafic rocks

Metasedimentary and Metavolcanic Rocks

Mms	Mesozoic metasedimentary rocks
Mmt	Mesozoic metasedimentary and metavolcanic rocks
Mmv	Mesozoic metavolcanic rocks
Pmv	Paleozoic metavolcanic rocks

Metamorphic Rocks

Mhm	Mesozoic heterogeneous metamorphic rocks
MPhm	Mesozoic–Paleozoic heterogeneous metamorphic rocks
MPam	Mesozoic–Paleozoic amphibolite
Mgn	Mesozoic gneiss
Mog	Mesozoic orthogneiss

Other Geologic Units or Features

Glaciers and ice fields

tz — Tectonic zones; areas of intense cataclasis, including mylonitization

Dike swarms; shown where dikes are too numerous to show individually at map scale; labeled as to geologic unit

Eruptive centers; volcanic vents of Quaternary to Miocene age, generally the same age and composition as the surrounding volcanic rocks

Dikes of Tertiary age

GEOLOGIC SYMBOLS

Contact

Anticline — Showing direction of plunge; dotted where concealed

Syncline — Showing direction of plunge; dotted where concealed

Overturned syncline — Dotted where concealed

Fault — Long-dashed where approximately located, short-dashed where inferred, dotted where concealed

Thrust fault — Sawteeth on upper plate; long-dashed where approximately located, short-dashed where inferred, dotted where concealed

Right-lateral strike-slip fault — Arrows show relative movement; short-dashed where inferred, dotted where concealed; arrows omitted in crowded areas

Left-lateral strike-slip fault — Arrows show relative movement; short-dashed where inferred, dotted where concealed; arrows omitted in crowded areas

Dip-slip fault — Bar and ball on down-thrown side; short-dashed where inferred, dotted where concealed

Normal right-lateral strike-slip fault — Arrows show relative horizontal movement, bar and ball on downthrown side; dotted where concealed

Communities

SEATTLE	More than 250,000 people
BELLEVUE	80,000 – 250,000 people
Puyallup	15,000 – 79,999 people
Tumwater	Fewer than 15,000 people or unincorporated
Yakima	County Seat
★ Olympia	State Capital

Scale

0 5 10 15 20 25 mi

0 10 20 30 40 km

Roads and Boundaries

Interstate Highway

U.S. Highway

Washington State Highway

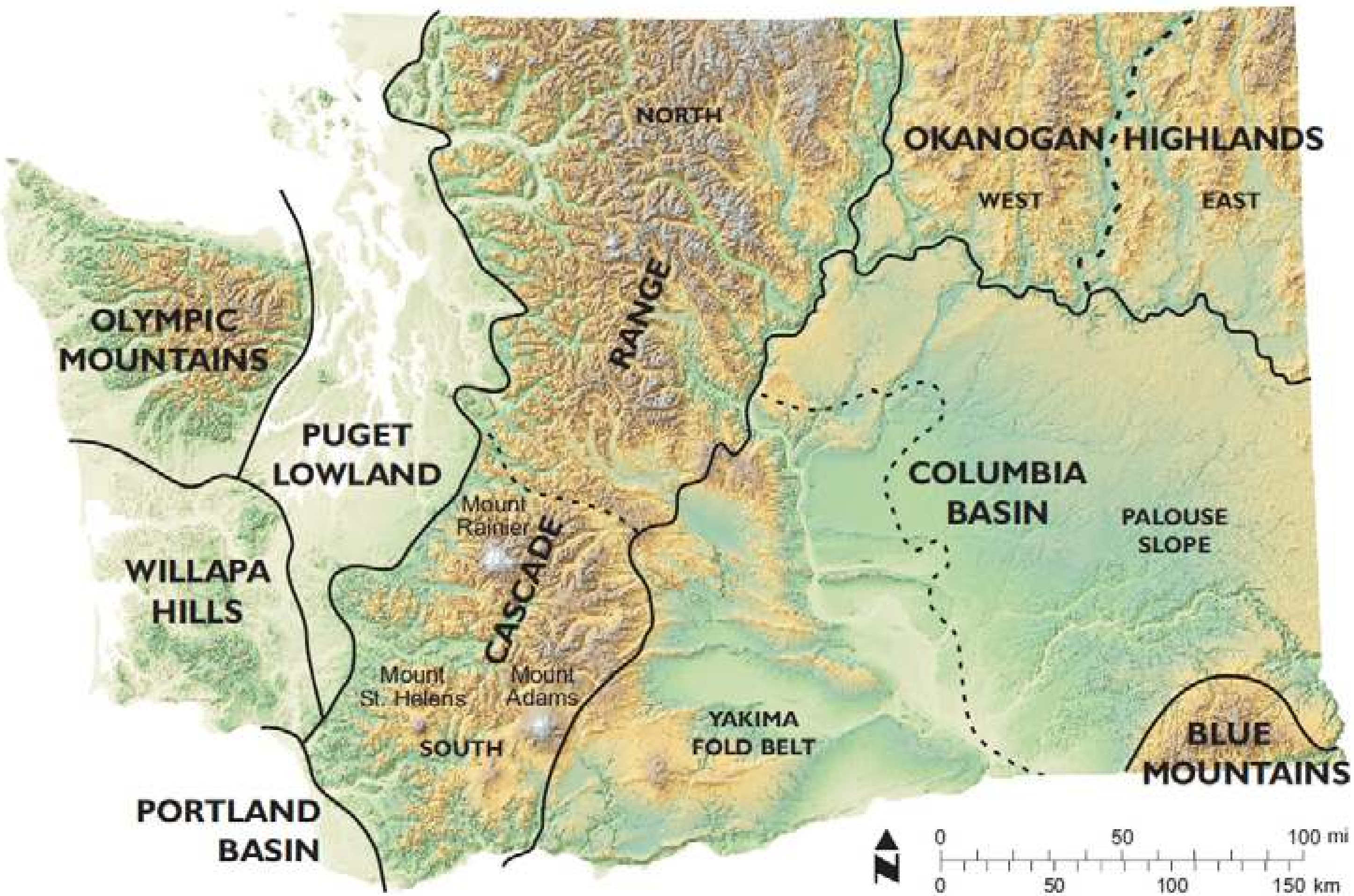
U.S. Forest Service Road

PIERCE — County boundary and name

PHYSIOGRAPHY OF THE SOUTHERN WASHINGTON CASCADES

To one standing on the flanks of Mount Rainier, the surrounding crests and ridges appear like the waves of a turbulent sea. Although infinitely divers in sculpture, none conspicuously out-tops its fellows and, at a distance, all seem to merge into one vast platform. Francois Emile Matthes (1916) … rivers, augmented by local glaciation near their sources, have bitten well over 3,000 feet into the Cascade upland. The valleys are noteworthy because of the low, flat bottoms, the remarkably steep sides, and the extremely low gradient they possess up to within a few miles of the main divide. Adding to this decided relief, the upland surface is a maze of pinnacles, spires, knobs, and knife-like ridges which have been sharpened by small alpine glaciers. It is upon these rugged westward trending ridges and valleys that the cone of Mount Rainier is superimposed.

~Howard Abbot Coombs (1935)



The Cascade Range is a north-trending volcanic arc that runs along the western edge of the North American continent. The volcanoes of the Cascades extend some 780 mi (1300 km) from southern British Columbia in Canada as far south as northern California. While this volcanic arc includes some noteworthy young volcanoes, such as Mounts Hood, St. Helens, Rainier, Baker, and Shasta, older volcanic and intrusive rocks and some sedimentary rocks, mostly of Cenozoic age (<65 million years old), make up the bulk of the mountains in the southern Washington Cascades. Mount Rainier sits on a glaciated and eroded foundation of these older rocks, which were faulted and gently folded after deposition and, in some areas, slightly metamorphosed (to clay minerals) by hot fluids and pressure during the time they were buried. Erosion-resistant granitic rocks and some welded fragmental volcanic rocks compose many of the higher peaks in the vicinity of the volcano.

At the latitude of Mount Rainier, these mountains composed of older rock are a formidable topographic barrier. The average elevation of the surrounding peaks in the area is roughly 4920 ft (1500 m); however, many peaks are 5248 ft to 6560 ft (1600–2000 m) in height, and some, such as Cowlitz Chimneys, 6.7 mi (10.7 km) east of Mount Rainier, are as high as 7544 ft (2300 m). The width of the Cascade Range near Mount Rainier is approximately 69mi (115 km), whereas slightly south of Rainier it is as wide as 90 mi (150 km).

The great height of Mount Rainier (14,410 ft; 4395 m) and of the adjacent Cascade Range peaks supports an extensive and richly diverse timberline parkland. While the forest line at Mount Rainier is generally at about 5200 ft (1585 m) elevation, scrubby alpine vegetation reaches as high as about 6800 ft (2073 m). The mountain's height and girth create a rain shadow on its east flank near Yakima Park, which results in less snow there and allows the timberline to extend to higher elevations in that vicinity (Arno and Hammerly, 1984). Mount Rainier and adjoining montane areas are so richly diverse floristically and bear so many ecological niches that the "arctic island" metaphor of early pioneering geologist Bailey Willis could be expanded to "arctic archipelago". Furthermore, the area's vegetation defies typical zonal or climate-related classification schemes because of the sheer variety of microclimates related to elevation and physiography, as well as the diversity of geology and the frequency of disturbances by volcanism and other geologic processes (Kruckeberg, 2002).

During the great Ice Ages of the Pleistocene Epoch, Mount Rainier and surrounding high-elevation Cascade Range peaks were the source areas of large glaciers that coalesced to form alpine ice caps and radiating valley glaciers that covered much of the montane landscape and occupied many of the modern-day river valleys of the Cascade Range. These glaciers profoundly sculpted the landscape, including some of the broad river valleys that at that time extended many miles outside the present boundaries of Mount Rainier National Park. The climate changes had their effects on the Mount Rainier area's ecosystems as well. Because the climate was colder, vegetation zones shifted, generally to lower elevations, in response, although ice-free refugia survived locally in places that remained above the glaciers (Pielou, 1991). Indeed, botanists have identified a refugium in the upper White River valley of Mount Rainier National Park as having one of the greatest numbers of tree species of any locale in the Pacific Northwest. It is amazing to ponder that certain species were able to maintain their footholds as climate fluctuated, ash from eruptions accumulated, and giant glaciers and lahars passed below.

Maximum stand of the Puget lobe, Cordilleran ice sheet, during the Vashon Stade of the Fraser Glaciation. At its maximum extent about 16,000 years ago, ice was about 5000 ft (1524 m) thick at Bellingham, 3500 ft (1067 m) thick at Seattle, and 2000 ft (610 m) thick at Tacoma. The ice had reached Olympia, and valley glaciers from Mount Rainier (not shown) extended many miles downstream of the National Park owing to expansion of glaciers in alpine areas. Glacial outwash from all the rivers draining Mount Rainier, except those of the Cowlitz River system, flowed into lakes dammed at the ice margin; overflow was shunted around the toe of the Puget lobe. The water then merged with meltwater from the Puget lobe, gathering all the drainage north and west of Mount Rainier into a stream near Eatonville that was about the size of the Columbia River at Grand Coulee Dam. Flow continued out to the Pacific Ocean via the Chehalis River valley. The Columbia has an average gradient of about 1 ft/mi (0.2 m/km); this steam had an average gradient of about 9 ft/mi (1.7 m/km). The direction of ice movement is indicated by the lines representing medial moraines on the ice surface. This figure shows the modern coastline, but when the ice was this far south, sea level was 300+ft (~100 m) lower, and the coast then was 30 to 50 mi (48–81 km) west of its present position. Not shown are late Pleistocene ice fields or ice caps in the Cascade Range and Olympic Mountains. Redrawn from Cary (1966).

The average distance from Mount Rainier to the rest of the Cascade Range to the east is about 15 mi (24 km). Because the Cascade crest or divide is to the east, all of the major river systems that drain Mount Rainier eventually flow to the west. Four of these, the Nisqually, Carbon, Puyallup, and White River systems, drain into Puget Sound, whereas the Cowlitz River system drains to the west-southwest into the Columbia River. During the Pleistocene, the upper reaches of all these valleys were greatly widened by huge valley glaciers originating at icecaps at and near Mount Rainier (Crandell and Miller, 1974). Additionally, all of these valleys have been partly filled by eruptions from Mount Rainier during its more than 500,000-year history, as well as by other volcanoes whose tephra has fallen over the area.

East of the Cascade crest, the Naches River system and its tributaries—the American, Bumping, and Tieton Rivers—head at various volcanic centers ranging from the early Miocene Fifes Peaks volcano (American), to the middle to late Miocene Ellensburg volcanic centers, to the Pliocene to Pleistocene Goat Rocks volcano (Tieton), to the still younger Tumac Mountain and Spiral Butte. The Naches River flows into the Yakima River at Yakima, which in turn flows some 105 mi (168 km) southeast into the Columbia River at Richland, Wash. Near the crest of the Cascades, erosion has stripped off the overlying younger rocks, revealing a mishmash of pre-Cenozoic rocks called the Rimrock Lake inlier, the oldest exposed rocks in the southwest Washington Cascades.

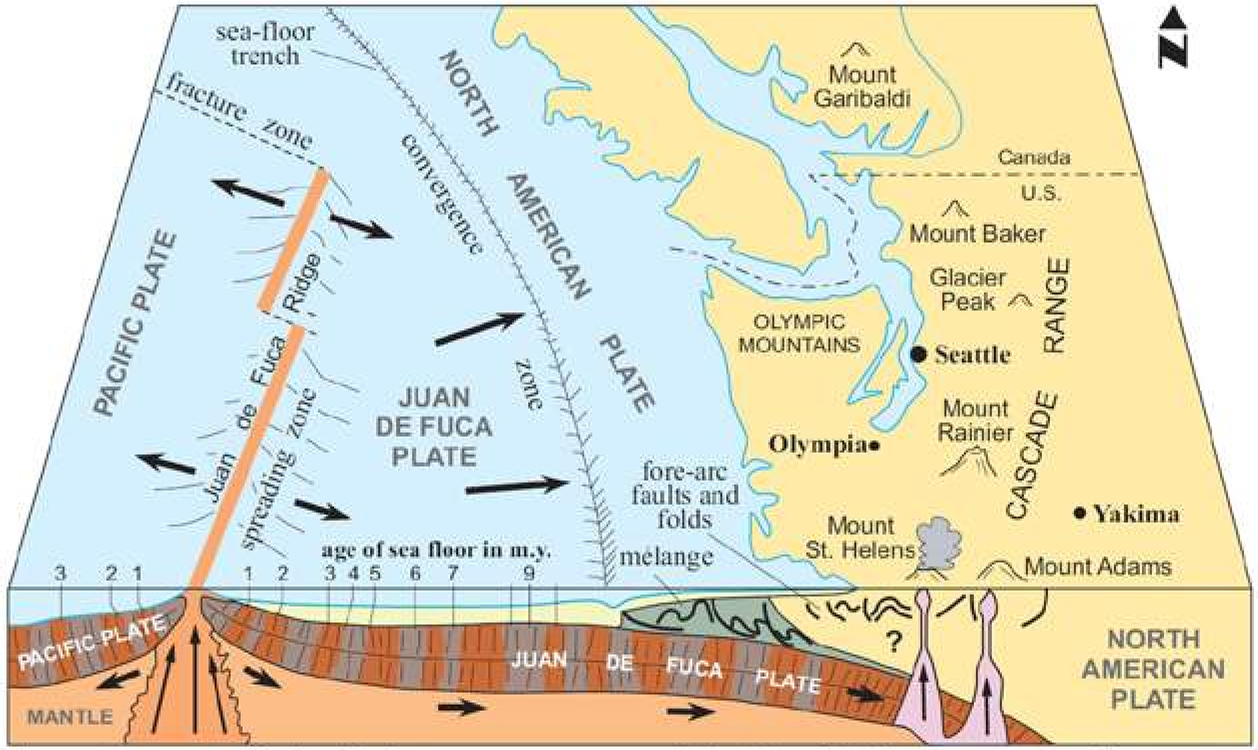
Rocks classified as granodiorites and, rarely, granites compose many of the most rugged Cascade peaks, such as those of the Tatoosh Range. These plutonic rocks rise in such majesty because they are harder and thus more resistant to weathering, mass wasting, and the chiseling effects of glaciers.

Oligocene or younger volcanic rocks can be found in the North Cascades, but in large part, they have been removed by erosion because of the greater amount of uplift in that region. In the southern Washington Cascades, the only visible evidence for terrane accretion is in the rocks of the Rimrock Lake inlier, because most of the older rocks are covered by a pile of younger volcanic rocks as much as 5 mi (7 km) thick.

The Puget Lowland physiographic province—a broad, glaciated trough—lies west of the Cascade Range and extends west to the Olympic Mountains. The lowland may owe its existence to faults in the shallow crust that bound the Olympic and Cascade ranges, and that may, in turn, be influenced by much deeper faults in the subducting oceanic lithospheric slab some 30 mi (50 km) below the surface. The Puget Lowland trough channeled enormous continental glaciers that originated in the Canadian highlands to the north and is believed to have endured at least six glaciations during the Pleistocene Epoch (Easterbrook, 1994). The most recent of these glaciations was the Vashon advance of the Fraser Glaciation. The main mass of the Vashon glacier reached the vicinity of Olympia, Wash., about 16,000 calendar years ago (Porter and Swanson, 1998).The ice advances and retreats produced humongous quantities of sediment that were transported into and through the lowland. The advancing glaciers shaped and streamlined the landscape with drumlins, and subglacial meltwaters carved deep linear troughs that we now recognize as embayments or filled embayments (Booth and Goldstein, 1994). After the ice receded, the troughs filled with water as sea level rose, but not before the glaciers and postglacial erosion had cut into the sediments, revealing many layers that recorded glacial and nonglacial geologic activity and even episodes of faulting.

GEOLOGIC HISTORY OF THE SOUTHERN WASHINGTON CASCADES

A diagrammatic cross section through the Juan de Fuca spreading ridge and the Cascadia subduction zone (the area from the trench east to where the Juan de Fuca plate sinks beneath the North American plate) showing the magnetic orientation of the sea floor recorded at the Juan de Fuca spreading ridge. Brown areas shown in the cross section of the sea floor indicate times when rock was created with a magnetic orientation of north; red-brown segments have reversed polarity. Notice that the age of the ocean floor is progressively older with distance from the spreading zone. The pattern of ages approximately parallels the ridge on both sides. The 'mélange' is a jumbled mixture of continental shelf blocks and oceanic sediments that is faulted and sheared at shallow depths in the subduction zone. The fore-arc folds and faults occur in a zone of crustal deformation between the subducting sea floor and the Cascade Range volcanic arc. Redrawn from Foxworthy and Hill (1982) and Uyeda (1978).



The physiography of the Mount Rainier area encompassed by this guide is itself a product of a rich history of geologic processes. Those who want to read more about the big geologic picture or find out about many of the geologic details can look to some good recent write-ups such as "Geology of the Pacific Northwest" by Elizabeth and William Orr (2001), or "The Restless Northwest" by Hill Williams (2002). Now, on to our focus on the geologic setting of the Mount Rainier area!

West of the modern Pacific coastline, the submarine volcanoes of the Juan de Fuca spreading ridge are actively creating new basaltic ocean floor. On the east side of this spreading ridge, the newly created oceanic lithosphere, moving as a component of an enormous convection cell, collides with the North American plate, and then sinks—or subducts—beneath it at a rate of about 1.5 in. (3.5 cm) per year. At the same time, the entire Pacific Plate is moving north. Thus, the subduction that deforms Washington State is a complicated oblique collision that occurs in a northeasterly direction with the Juan de Fuca plate. The collision process contributes to strains that energize fault zones in the subducting slab of ocean floor, the shallow crust of the North American plate, and at the boundary between the colliding Juan de Fuca and North American plates.

Around the world, subduction complexes— continental margins where one tectonic plate meets with and sinks under another— can be characterized by an array of specific structural traits. For example, subduction gives rise to a chain of volcanoes or a volcanic arc. Likewise, a fore-arc basin is commonly situated between the subducting ocean-floor slab and the volcanic arc, whereas a back-arc basin sits behind the volcanic arc farther from the boundary between colliding plates. Stratovolcanoes like Mounts Rainier and St. Helens, which are produced in such a volcanic arc called the Cascade Range, erupt along fault zones at the Earth's surface. These fault zones are situated directly above where the subducting oceanic crust becomes dehydrated as it reaches roughly 56 mi (90 km) depth. This is a depth at which partial melting of the subducting plate and of the overlying crust then gives birth to masses of buoyant magma that ascend through the crust along zones of weakness. Some of this magma eventually reaches the surface to erupt and form the many layers of tephra and lavas that comprise a stratovolcano.

The Cascade Range volcanic arc is bounded on the west by the Puget Lowland, a fore-arc basin. Interstate 5 runs through this basin; several of the routes in this road guide, such as Legs A, C, D, J, and K, begin in the Puget Lowland and take us across physiographic boundaries into the Cascades. The lavas of the Columbia River Basalt Group were erupted into a back-arc basin and lap onto the extreme eastern boundary of the southern Washington Cascades.

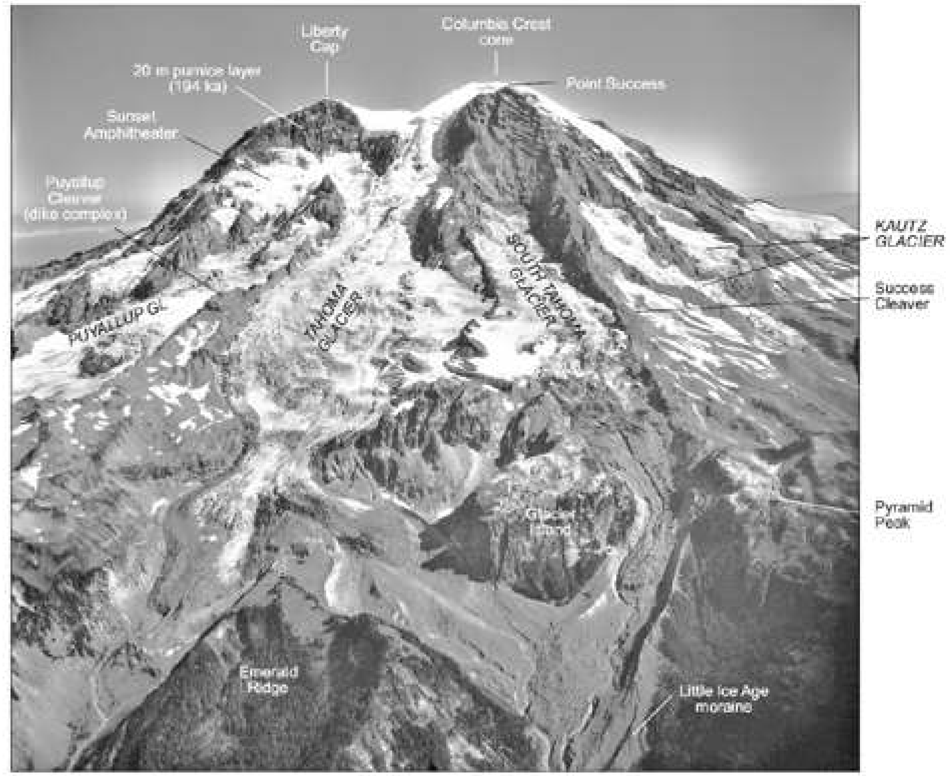
The Cascade volcanic arc has been active for about 27 m.y. The middle Tertiary volcanic rocks of the Ohanapecosh, Stevens Ridge, and Fifes Peak Formations, upon which Mount Rainier rests, have long been documented as relicts of past volcanism. However, volcanic unrest is recorded in many other rocks as well; at times this past volcanic activity existed on a scale that dwarfed that of our modern Cascade peaks. For example, the Miocene Columbia River Basalt Group, covering the Columbia Basin east of and adjacent to the Cascade arc, includes some of the world's most extensive lava flows. The geologic history and rocks of each of these geologic groups and formations are summarized below in the section on the history of the pre– and syn–Mount Rainier rocks (p. 19)

In the immediate vicinity of Mount Rainier, the rocks of Tertiary age were gently folded along northwest-trending axes and then intruded by the Tatoosh plutonic complex granodiorite and quartz monzonite during early to middle Miocene times. Other intrusions are found in the Cascades east of Mount Rainier. Rocks of the complexly faulted, folded, and sheared Rimrock Lake inlier, which are exposed on US 12 near White Pass, are considerably older than their neighboring rocks to the west and east. Somehow, probably as a result of largescale shearing, faulting, and folding, which assisted erosion, this block of older rock remnants has poked its head up through the cover of younger volcanic and sedimentary material. The Rimrock Lake rocks are described further on p. 19. Geologists continue to discover new evidence about the history of the rocks in the Cascade Range. For example, geologist Paul Hammond (Portland State Univ., written commun., 2003) has mapped more than 30 volcanic vents that range in age between 12 Ma and 1 Ma in the Cascades east of Mount Rainier. Hammond and other geological detectives have found that sedimentary rock units such as the Ellensburg Formation (Smith, 1988 a,b) provide ample evidence of volcanism even where the volcanoes themselves have been largely eroded away.

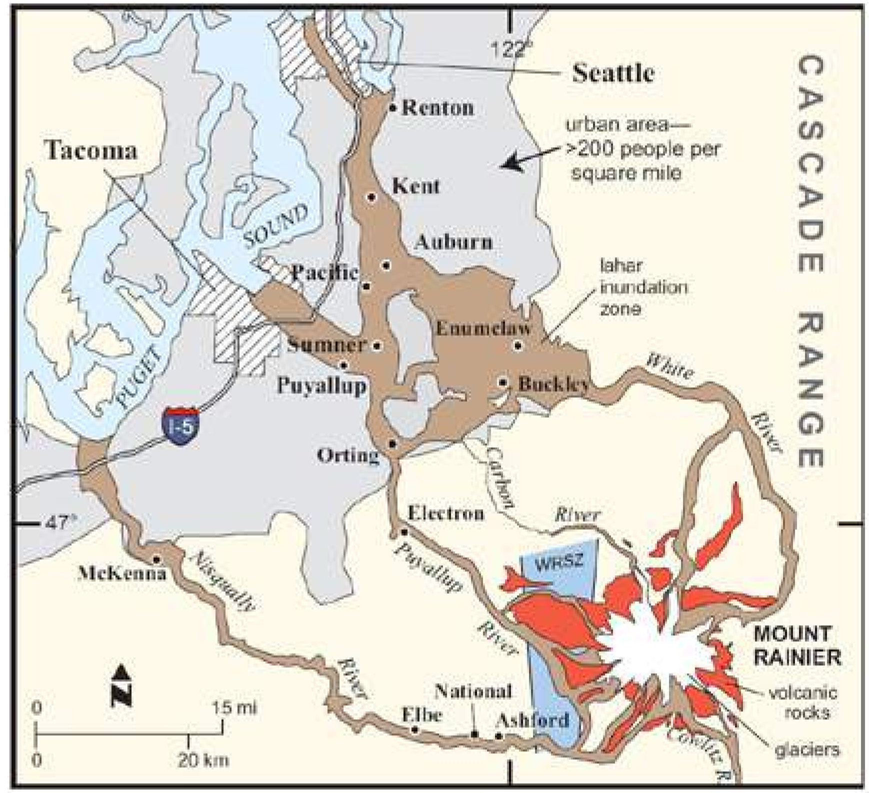
At the site of the present Mount Rainier cone, an apparent hiatus in volcanic activity and plutonism of nearly 10 m.y. precedes the first evidence of a proto– Mount Rainier. Geologist Cliff Hopson first suggested that the Lily Creek Formation was a sedimentary relict of a progenitor of Mount Rainier (Fiske and others, 1963). The Lily Creek rocks are a sequence of volcaniclastic or fragmental volcanic strata whose extensive deposits are found in the Cascade foothills west of Mount Rainier. Sisson and Lanphere (1999) recently estimated the age of the Lily Creek Formation to be 1.3 to 1.2 Ma. Sisson also identified a correlative in-place lava remnant 1.03 Ma in age at Panhandle Gap (~13,000 ft; 3965 m) on Steamboat Prow at Mount Rainier.

MOUNT RAINIER'S HAZARDOUS GEOLOGICAL PROCESSES

The impressive glacier-draped west flank of Mount Rainier. The Round Pass Mudflow (2,600 yr B.P.), a lahar about 1,000 yr B.P., and the Electron Mudflow (~A.D. 1502–1503) are major collapses that have eaten into this clay-rich upper portion of Mount Rainier. The Round Pass collapse breached the west crater wall left by the great Osceola Mudflow between Liberty Cap and Point Success, thus allowing andesitic pyroclastic flows to more easily spill down this flank of the mountain between 2,500 and 2,300 yr B.P. Geologists suspect that the Puyallup Cleaver dike complex, which was formed during a period of profuse eruptions from about 280 ka to 190 ka (Sisson and Lanphere, 1999), accelerated hydrothermal alteration and destabilization of the volcano's west flank when ground water interacted with hot magma. Both Emerald Ridge and Klapatche Ridge (out of view 1 mi [1.6 km] north-northwest of Emerald Ridge) are composed of lavas erupted from the Puyallup Cleaver dike system; however, Glacier Island and Pyramid Peak are composed largely of Miocene Stevens Ridge Formation rocks that underlie Mount Rainier. The positions of the Little Ice Age lateral moraines of the Tahoma and South Tahoma Glaciers (which once merged downslope of Glacier Island) show that these glaciers were significantly larger and extended more than a mile or kilometer farther downslope than they do today. The lowermost parts of the glaciers are covered with rock rubble. Glaciers not only help sculpt the mountain as they flow, but also are a source for ground water that plays a vital role in the eruptive and hydrothermal processes that shape the volcano. Photo by Austin Post, USGS, taken Sept. 18, 1967.



Areas inundated by lahars or laharic flooding (brown) from Mount Rainier in the past 6000 years. The Cowlitz River valley (lower right) was also flooded but is not shown. Hachured areas are city limits of Seattle and Tacoma; gray is the area of suburban development. Red areas are volcanic rocks of Mount Rainier; blue, the West Rainier seismic zone (WRSZ). After Sisson and others (2001).



What's past is prologue.

William Shakespeare, The Tempest (circa 1613), Act 2, Scene I

Modern Mount Rainier is the highest and third most massive volcano in the Cascade Range (Mounts Shasta and Adams are larger in volume). Until the late 1990s, we knew relatively little of the eruptive history, composition, and age of Mount Rainier volcano compared to most other Cascades Range peaks. Geologists Richard Fiske, Cliff Hopson, and Aaron Waters made the most complete description of the pre-Holocene volcanic history of Mount Rainier in their classic paper on the geology of Mount Rainier National Park (Fiske and others, 1963). Most of the Holocene history of Mount Rainier 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, 1995). These studies continue, and every year we find out more about the mountain's past history.

Largely as a result of our rapidly growing understanding of the volcano's past eruptive history, many geologists now recognize "The Mountain" as potentially the most dangerous volcano in the Cascade Range, particularly because of the increasingly large population living along its lowland drainages. These riparian areas are most at risk because of Mount Rainier 's great relief and the huge area and volume of ice and snow on its cone (92 million m2 and 4.4 billion m3 [110 million yd2 and 5.5 billion yd3], respectively) that could generate lahars, or volcanic debris flows during eruptions (Driedger and Kennard, 1986). Lahars can flow rapidly along valleys for many tens of miles.

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 a volcanic edifice, cohesive debris flows generally contain more than about 3% 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. 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 hyperconcentrated flows (lahar-runout 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

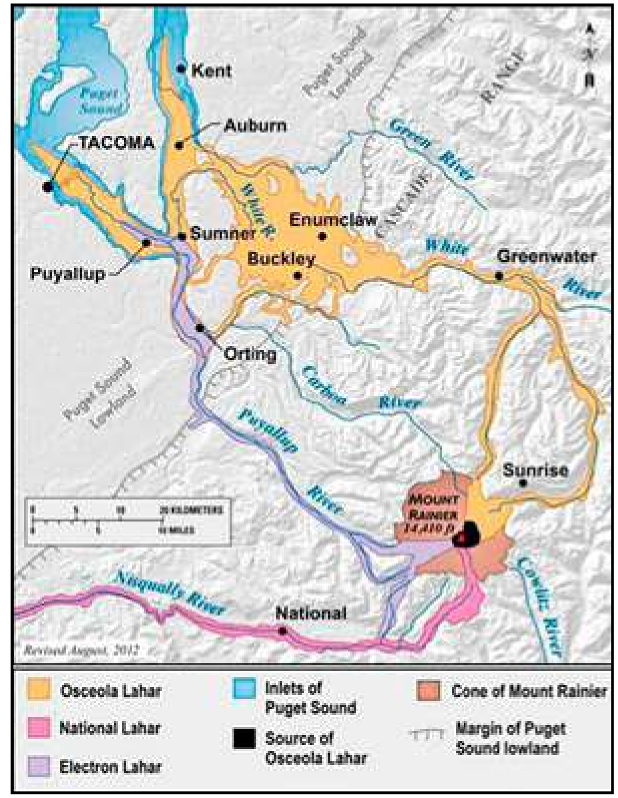
Since 1986, debris flows along Tahoma Creek have repeatedly damaged the Westside Road, the principal access route to National Park trails and facilities on the southwest side of Mount Rainier. Debris flows have obliterated a picnic area, parts of the Westside Road, and the lowest 1 km of the Tahoma Creek 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 have served as a reminder of the much larger, less frequent debris flows.

The Osceola Mudflow

The Osceola Mudflow began as a water-saturated avalanche during phreatomagmatic eruptions at the summit of Mount Rainier about 5,600 years ago. It filled valleys of the White River system north and northeast of Mount Rainier to depths of more than 300 feet, flowed northward and westward more than 75 miles along the White River valley, covered more than 49,000 acres of the Puget Sound lowland, and extended into Puget Sound. During the same time period the Paradise Lahar flowed down the south side of Mount Rainier, and the two lahars are likely related in timing if not originating event. Osceola Mudflow deposits comprise three facies. The furthest extending axial facies forms normally graded deposits 5 to 80 feet thick in lowlands and valley bottoms and thinner ungraded deposits in lowlands; the valley-side facies forms ungraded deposits 2 to 6 feet thick that drape valley slopes; and the hummocky facies previously interpreted as a separate lahar in the Greenwater, Washington area forms 6 to 30-ft thick deposits dotted with numerous hummocks up to 60 feet high and 180 feet in width. Deposits show progressive downstream improvement in sorting, increase in sand and gravel, and decrease in clay. These downstream progressions are caused by incorporation (bulking) of better sorted gravel and sand. Normally graded axial deposits show similar trends from top to bottom because of bulking. The coarse-grained basal deposits in valley bottoms are similar to deposits near inundation limits. Normal grading in deposits is best explained by incremental aggradation of a flow wave, coarser grained at its front than at its tail. The Osceola Mudflow transformed completely from debris avalanche to a cohesive lahar within 1.5 miles of its source because prior mobilizing as a debris flow the weak hydrothermally altered source rocks contained large volumes of pore water and a high amount of elevation relief.



All of the previous events mean one thing: Mount Rainier is the most dangerous volcano in the United States. Although Mount Rainier has erupted less often and less explosively in recent millennia than its neighbor, Mount St. Helens, the proximity of large populations makes Mount Rainier a far greater hazard to life and property. The continually growing population that is at risk has now has now been informed by sound science and data collection since 1993, and yet more than 150,000 people reside on the deposits of previous lahars. The size and frequency of mudflows capable of reaching Puget Sound during the past few millennia have occurred, on average, at least every 500 to 1,000 years. Smaller flows not extending as far as the lowland occur more frequently, and not all of those are associated with a volcanic eruption. If lahars of the future happen at rates similar to those of the past, there is at least a one in seven chance of a lahar reaching the Puget Sound lowland during an average human life-span. Even with the idea of an advance warning system in place, the roadway infrastructure required to quickly evacuate residents has not been improved. USGS research shows that some lahars occur with little or no warning. To date no major infrastructure improvements have begun for improving roadways or other egress options.

MOUNT RAINIER—ACTIVE CASCADE VOLCANO

Mount Rainier is an active volcano…

U.S. Geodynamics Committee (1994, p.1)

The above statement was made thematically in a National Academy of Science publication summarizing the Mount Rainier Decade Volcano workshop of 1992. As noted in this publication, the geological community had reached a clear consensus that Mount Rainier was an 'active' volcano. However, this classification has its limitations because Mount Rainier is obviously not erupting at the time of this writing. Therefore, perhaps we should more accurately describe the mountain as a 'dormant active volcano'. The American Geological Institute Glossary of Geology notes the lack of a clear distinction between active and dormant (Neuendorf and others, 2005). The Nuclear Regulatory Commission and other entities commonly have official or legal definitions of what is defined as geologically 'active'. For example, many define a fault as 'active' if it has ruptured within the past 10,000 years. Certain 'vital signs' demonstrate that Mount Rainier is active:

Seismicity: Mount Rainier averages 30 small earthquakes a year (mostly less than magnitude 2). These earthquakes are clearly focused in the plumbing system of the volcano.

Geothermal activity: Mount Rainier has fumaroles at or near the boiling point. Researcher David Frank measured temperatures as high as 180°F (82°C) at the east summit crater in 1994, and Francois Le Guern measured temperatures there as high as 187°F (86°C) in 1997 and 1998 (Le Guern and others, 2000). Because the boiling point of water at the summit of the mountain is about 187°F (86°C), the east and west crater rims are often snow-free within a day of snowstorm, and the bare summit rock is visible from as far away as Olympia, 60 mi (96 km) west-northwest of the volcano, suggesting an area of warm rock.

'Historical' activity: Mullineaux and others (1969) determined that a Mount Rainier tephra known as the 'X tephra' was probably erupted between A.D. 1820 and 1854, on the basis of the age of trees growing on the youngest neoglacial moraine on which the tephra occurs and the age of those on the oldest moraine on which it does not occur, respectively. (See mile 3.2 in Leg M, p. 156.) Ethnographic accounts suggest that the mountain was active around 1820 (Plummer, 1900), and there are some compelling accounts of eruptive activity in 1894 that were cited in the Tacoma and Seattle newspapers. Buried trees suggest inundation by debris flows or volcanic floods, certainly in Mount Rainier National Park and probably farther downstream about 200 years ago.

Late Holocene volcanic activity: By careful scrutiny of its deposits and discovery of numerous buried forests, several researchers have found that Mount Rainier has been much more active over the last 3000 years or so than previously thought. Much of this new information has only recently been published, such as in the selected abstracts in the 1999 Northwest Scientific Association proceedings of the Mount Rainier 100th Anniversary Symposium (Washington Division of Geology and Earth Resources, 2000) or in Sisson and others (2001).

Studies of tephra deposits by USGS geologist James Vallance and his colleagues Sue Donoghue and Jack McGeehin have revealed more than 40 eruptions took place in the past 10,000 years, including four or five between 2.7 and 2.2 ka, one about 1.5 ka, two about 1 ka, one about 500 yr B.P., and one in the early ormiddle part of the 19th century (the X tephra) that was also documented by Mullineaux and others (1969).

This rich evidence demonstrates that Mount Rainier has been active in recent geologic history, and thus geologists expect it to erupt again, perhaps even during the next century or two.

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. These riparian areas are at risk because of the mountain's great relief and the huge areas and volume of ice and snow (92 x 106 m2 and 4.4 x 109 m3, respectively) that could generate lahars during eruptions. In addition, enormous (>2 x 108 m3) sector collapses of clay-rich, hysrothermally 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) 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 outward-facing dip planes), and exposure to pulses of tectonic or volcanic energy make all valleys surrounding Rainier vulnerable to future sector collapses.

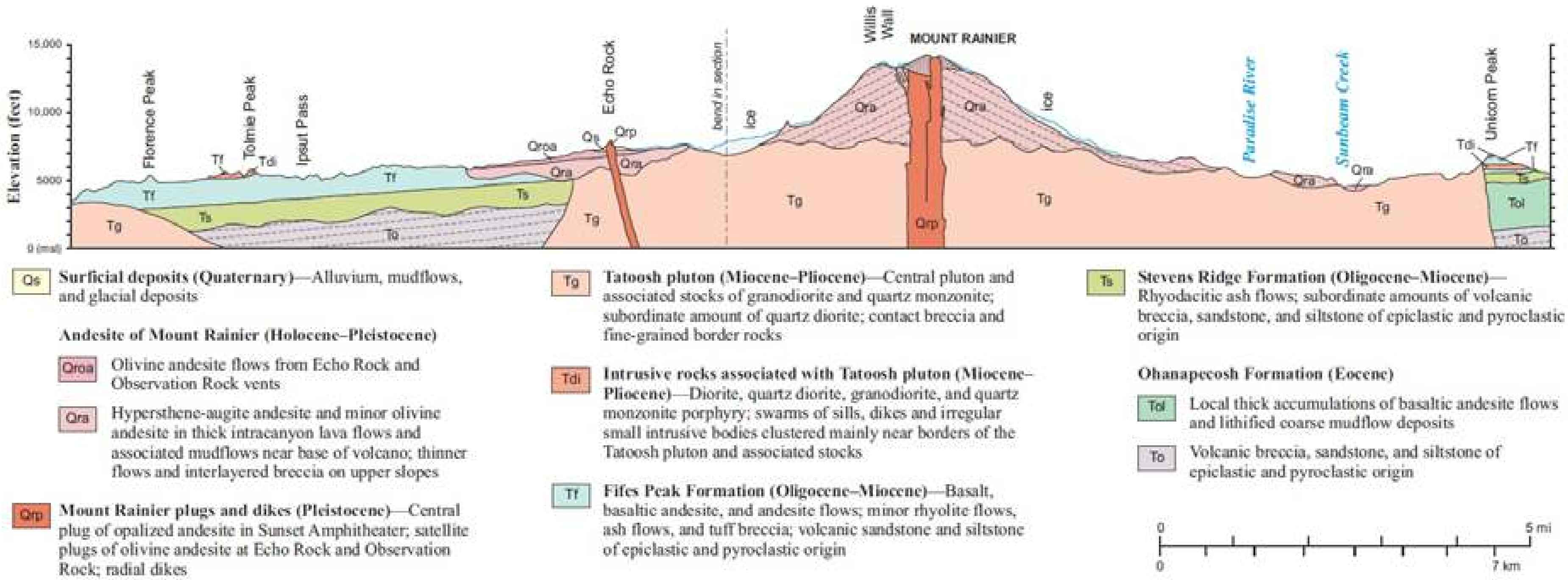
Relatively little is known of the eruptive history, composition, and age of Mount Rainier volcano compared to most other Cascades Range peaks. The most complete description of the pre-Holocene volcanic history of Mount Rainier was made by Fiske and others (1963). Most of the Holocene history has been 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).

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 rock (Hammond and Bronstad, 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 protoMount 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).

Early lava flows of present Mount Rainier flowed onto a dissected surface of the Tertiary basement. The earliest lavas predate the Hayden Creek Drift (70-140 ka) and have yielded (as of April 1994) only two K-Ar ages, 320 and 600 ka (Crandell and Miller, 1974). The present edifice is dominantly lava flows and breccias, 90 percent of which are composed of a petrographically uniform two-pyroxene andesite. However, recent work by one of us (Sisson) reveals local hornblende andesites and welded and nonwelded block and ash flows that were not previously recognized at Mount Rainier. Small amounts of basaltic andesite were erupted during the late Pleistocene from two

A generalized cross section of Mount Rainier and selected basement rocks. the section trends roughly east-west through the cone and is slightly more than 20 mi (32 km) long. Modified from cross section D of Plate I in Fiske and other (1963).



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 (J. McKenna). 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 between 140 ka and 30 ka; the age is indicated by its stratigraphic position on Sourdough Ridge. (See HobJitt and others, 1987.) Although outcrops are limited, preliminary estimates suggest this unnamed 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 tephra beds (studied by Mullineaux, 1974) totaling more than 0.5 km3. 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 montrnorillonite 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, 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 a 14C age of 2,320 ± 120 yr from a twig found in the deposit correlates that unit with newly discovered lahar deposits in the upper reaches of the Puyallup Puyallup River and with block- and ash-flow 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 from Mount Rainier (Dragovich and others, in press). 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, in press).

Wood from trees buried in the Round Pass Mudflow has been dated at about 2,600 radiocarbon yrs B.P. This clayrich 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 radio-carbon 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 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). Glacialoutburst 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 snow-free 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 forms 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:

1. **Summit craters** – An extensive area (> 12,000 m2) of heated ground and slightly acidic boiling-point fumaroles occurs at East and West Craters on the volcano's summit. Maximum fumarole temperatures generally range from 76° to 86° C. Rocks in the summit area contain alteration products with major concentrations of clay minerals including smectite, halloy-site, and disordered kaolinite. Silica phases include cristobalite, tridymite, and opal. Other prominent phases are alunite, gibbsite, and calcite (Frank, 1985).
2. **Upper Flank** – A small area (< 500 m2) of heated ground and sub-boiling-point fumaroles lies on the upper flank at Disappointment Cleaver. Maximum temperatures at these fumaroles are about 60° 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.
3. **Lower Flank** – Sulfate- and carbon dioxide-enriched 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 precipitate small amounts of calcite, opal, and gypsum that encrust gravel and cobbles in downstream channels.

Additional thermal activity occurs beyond the extent 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 valley have maximum temperatures of 25°C and have formed an extensive area of travertine mounds and sulfide-rich 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 sulfate-chloride waters that originate in a central, steam-heated hydrothermal system in the upper part of the volcano. Cooling of thermal waters during flow away from the hydrothermal system to lower elevations could take place by dilution with shallow 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 stockworked 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.

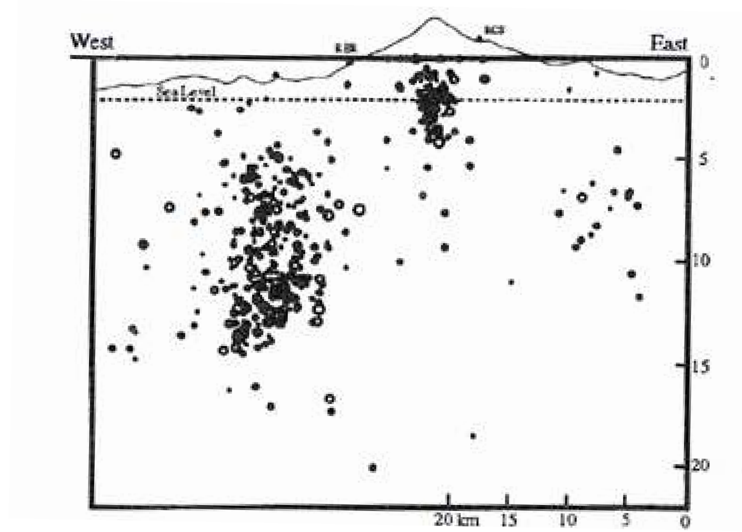
Seismicity of Mount Rainier

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. Eruptive activity at Mount Rainier would probably 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.



East-West profile of the Mount Rainier area showing hypocenters of earthquakes in the University of Washington's seismic network catalog from 1969–1990. Triangles RER and RCS are two of the five seismic stations now in operation on the flanks of the volcano. Zone of earthquakes located shown west of Mount Rainier delineate a north-trending crustal fault zone about 15 km west of Mount Rainier.

GROWTH AND ERUPTIVE STYLE OF MOUNT RAINIER

*by Thomas W. Sisson and Marvin A. Lanphere**

The early lavas of Mount Rainier flowed onto an erosion-dissected mountainous landscape composed mainly of rocks of Tertiary age and minor remnants of an ancestral Mount Rainier volcano, at a time when thick, extensive glaciers blanketed the terrain. Prior to the late 1990s, the ages of Mount Rainier 's lava flows were poorly known. Many flows were shown to be covered by, and thus older than, glacial sediments known as the Hayden Creek Drift that were deposited about 140 ka, But only two direct age determinations of 320 and 600 ka, made by the K-Ar method, had been produced for Mount Rainier and these were from the same lava flow (Crandell and Miller, 1974). We have since determined many new and more precise radiometric ages for Mount Rainier lava flows and fragmental deposits, and thus we have gained a much improved understanding of how and when the Mount Rainier cone was constructed over the past half-million years (Sisson and Lanphere, 1999).

Mount Rainier is dominated by lava flows, about 90 percent of which are similar appearing, plagioclase-rich two pyroxene andesites that range in chemical composition to plagioclase-rich two-pyroxene dacites. In detail, many rocks also contain trace amounts of the minerals hornblende and (or) olivine, and a few are sufficiently rich in hornblende or olivine to be classified as hornblende andesite or as basaltic andesite. There are no known flows of basalt erupted from Mount Rainier, despite several localities with “basalt” in their place names.

Lava flows high on Mount Rainier typically have massive interiors and rubbly tops, with combined thicknesses of 10 to 50m(~30–150 ft) per flow. Stacks of successive flows have been eroded into alternating cliff bands (flow interiors) and rubble slopes (flow tops), imparting the characteristic layered or stair-stepped appearance of Mount Rainier 's higher ridges and headwalls. The lava flows are fewer but much thicker (300 m or about 1000 ft) on the volcano's lower flanks, both because larger eruptions were necessary to advance lava flows to these distances and because the lower elevation lavas were confined against valley-filling glaciers and so accumulated to greater thicknesses (Lescinsky and Sisson, 1998). These lower elevation flows form the network of ridges that radiate from the volcano, much like the spokes of a wheel. Lescinsky and Sisson (1998) proposed that the glaciers that filled the flanking valleys at the times of eruptions prevented the lavas from reaching valley floors and caused them to advance along the margins of the ice streams. When the ice emptied from the valleys at the end of the Pleistocene, the lava flows were left perched high above the adjacent valley floors. Nearly all of the thick ridge-forming lava flows have lost their rubbly tops due to erosion, and some have glacial polish and striations on their upper surfaces showing that they were overtopped by ice. Besides lava flows, recent fieldwork has revealed local welded and non-welded block-and-ash flow deposits—evidence for explosive volcanism—that (with one exception) were not previously recognized at Mount Rainier.

A total of approximately 140 km3 (34 mi3) of magma is estimated to have erupted from Mount Rainier in the past half-million years (Sherrod and Smith, 1989). Mount Rainier 's lava flows extend as far as 22 km (~14 mi) radially from the present summit location, and individual far-traveled flows have volumes of as much as 9 km3 (about 2 mi3). However, far-reaching lava effusions of such large volume were limited to periods from 500 to 420 ka and from280 to 190 ka when the volcano was especially active; such voluminous and extensive lava flows would be unlikely today. More Probably, lava flows would travel no farther than 10 km (~6 mi) from the summit and would have volumes less than 0.5 km3 (0.1 mi3), as has been typical for the volcano for the last 40,000 years. When lava next erupts from Mount

Rainier, the flows will probably emanate from the summit and will likely remain within the region of, or extend just beyond, present-day glaciers (6–10 km). In doing so, the lavas would entrench into and melt snow and ice, spawning floods and lahars.

But first, an ancestral Mount Rainier

The mountain we call Mount Rainier is not the first volcano to have grown at that location. Construction of an ancestral Mount Rainier was taking place from about 2 to 1 million years ago, as is shown by a remnant of a lava flow dated at 1.03 Ma, preserved at Panhandle Gap on Mount Rainier 's east slope, and by an extensive apron of fragmental volcanic debris to the northwest of Mount Rainier that makes up the Lily Creek, Puyallup, and Alderton Formations. Volcanic clasts from the Lily Creek Formation are dated directly by the 40Ar-39Ar method at 1.2 and 1.3Ma. Ages of the nearby Alderton and Puyallup Formations have not been measured directly, but the deposits predate (are covered by) the Lake Tapps tephra (Blunt and others, 1987) produced from the 1.15 Ma eruption of Kulshan Caldera near Mount Baker (Hildreth, 1996) and are younger than 2.4 Ma as is indicated by their reversed magnetic polarity (Blunt and others, 1987). Ancestral Mount Rainier was a large volcano, similar to that of today, as is shown by the radial system of ridges and deep canyons that had developed prior to the inception of the modern volcano (Hopson, 1966), as well as by the voluminous volcanic sediments shed from it that form the Lily Creek, Alderton, and Puyallup Formations. It was similar to today's Mount Rainier in additional respects, having produced andesite and dacite lava flows, lahars, and pumiceous lahars. Lahars were likely generated by the interaction of lavas and pyroclastic flows with glaciers. Although ancestral Mount Rainier 's volcanic activity waned after 1Ma, eruptions did not cease entirely. Small remnants of lava flows with ages between those of the ancestral and modern edifices are exposed locally in the headwaters of the Carbon and Cowlitz drainages. Nevertheless, eruptive output declined to the extent that erosion stripped away nearly all of the ancestral edifice.

Off to an effusive start—Mount Rainier's lavas of 500 to 400 ka

The birth of modern Mount Rainier began about 500 ka with pyroclastic flows burying the deeply eroded remnants of the ancestral volcanic center (Sisson and others, 2001). Deposits of these early pyroclastic flows are exposed as breccias in the Glacier Basin area on Mount Rainier 's northeast flank and extend up to Steamboat Prow. The birth of the modern volcano is placed at 500 ka because lava flows, pyroclastic flows, and other volcanic products were emplaced nearly continuously and voluminously from that time onward, unlike the earlier sparse volcanic record. The large (3–4 km3 or 0.7–1 mi3) Burroughs Mountain andesite lava flow erupted shortly after and partly buried the initial pyroclastic flow deposits (Stockstill and others, 2002). Other large lava flows also erupted during this period. These include those that form Grand Park, Old Desolate–Marjorie Lake, the unnamed ridge between the North and South Mowich River valleys, the large unnamed ridge between the Mowich River and Rushingwater Creek (8–9 km3 or ~2 mi3), and the Colonnade. All of these ridge-forming lava flows have ice-contact features preserved high above deep valleys; therefore, the adjacent valleys must have been ice-filled canyons at the time of the eruptions, rather than having been largely excavated by later erosion Some radial dike systems, which contributed to hydrothermal alteration of the volcano, formed at this time and likely fed vents on the mountain's flanks.

From about 400 ka to 280 ka, Mount Rainier 's volcanic output diminished substantially. Exceptions are the 370 ka lava flow that makes up Rampart Ridge and Cushman Crest and that underlies the toe of the Wilson Glacier—again with ice contacts locally on the margins. Another noteworthy deposit from that time period is the thick pumice layer exposed on the north side of the crest of Sourdough Ridge, immediately north of Sunrise. This more than 2-m (6.6 ft)-thick fallout pumice is the only known deposit from Mount Rainier that contains abundant biotite. Crandell (1971), who first identified this pumice, thought its volume must have been similar to some of the larger Mount St. Helens pumice layers (1–4 km3 or 0.24–1 mi3 as bubble-free dense rock). Our new age for this pumice of about 380 ka, and its excellent preservation suggest that the crest of Sourdough Ridge has not been under ice for the last 300,000 years (Sisson and Lanphere, 1999).

Another period of accelerated volcanism—Mount Rainier from 280 to 190 ka

From 280 to about 190 ka,Mount Rainier volcano again erupted copiously. The lava flows of Sunset Park, Klapatche Ridge and St. Andrews Park, Mount Ruth, Meany Crest, Cowlitz Park, and Whitman Crest were erupted during this time. Outpourings of lava also constructed the upper northwest sector of the volcano, including the Mowich Face and Liberty Cap. All of the large flank flows have ice-contact features that indicate the volcano erupted when the valley systems were filled with glacial ice. The happenstance of their eruption next to glaciers demonstrates what many paleoclimatologists have noted in their documentation of the Earth's climate during the Pleistocene Epoch: warm interglacial periods like the one we now enjoy have been relatively short intervals separated by lengthy periods of glaciation. The volcanic record atMount Rainier indicates that large glaciers filled the immediate valleys around Mount Rainier except perhaps during the strongest interglacial periods. Though impressive, Mount Rainier 's present day glaciers are shrunken remnants of the great ice streams that dominated the landscape during most of the growth of the volcano.

The largest radial dikes on the west flank of Mount Rainier intruded during the 280 to 190 ka period of voluminous eruptions, and along with dike emplacement came intense hydrothermal alteration in the adjacent rocks as well as in the conduit system. This alteration would later help destabilize the volcano. A prominent white pumice band exposed in Sunset Amphitheater (p. 158) was erupted toward the end of this high-output interval, at about 190 ka. This pumice is also preserved locally on the uppermargins of Burroughs Mountain, showing that the upper surface of that plateau has not been glaciated since about 200 ka. The pumice is also exposed along the road to Sunrise where talus covered and preserved it (Leg E). This pumice layer, too, was as voluminous as some of the larger Mount St. Helens pumice eruptions. Walsh and others (2003) have identified "richly pumiceous sand" on the southern tip of Ketron Island in south Puget Sound, 75 km (45 mi) to the northwest of Mount Rainier. The chemical compositions of the Ketron Island bulk pumice and of its constituent glass andmineral grains match those of the pumice exposed in Sunset Amphitheater, indicating that they probably result from the same eruption. Walsh and his co-authors note that the Ketron Island deposit has features that imply transport from the east and southeast (roughly the direction of Mount Rainier) along river channels, and they surmise that Cormorant Passage, the water body that separates the island from the mainland, did not exist at the time the tephra-bearing sand was deposited. Evidently the depression now occupied by Cormorant Passage was carved out by the Puget lobe of the Vashon glacier, which advanced into the southern Puget Sound region about 13,500 years ago (Borden and Troost, 2001).

To the present

The volcanic interval from280 ka to 190 ka waned gradually: the stack of lava flows that composes Little Tahoma Peak commences with a large basal flow about 195 ka in age, large flows at mid-heights having an age of 150 ka, and one at the summit with an age of 130 ka. Thin dikes with contiguous areas of hydrothermal alteration and locally altered fractures cut these lava flows. Some of these dikes possibly fed high flank vents, which would have produced an oblong shape in the upper edifice, accounting for the displaced position of Little Tahoma Peak east of Mount Rainier 's central vent. The volcanism during this time also produced lava flows of upper Ptarmigan and Emerald Ridges. Also at 130 ka, the dacite of Bee Flat erupted from a vent nearWindy Gap, 7 km (4 mi) north of Mount Rainier. The magma that formed the Bee Flat lava flow was atypical for Mount Rainier in having abundant hornblende. This eruption was probably too far from the central conduit to have been fed by a dike from Mount Rainier itself.

After about 120 ka, Mount Rainier 's lavas became relatively small in extent and volume, and erosion, possibly accompanied by collapses of the volcano's flanks, again incised the upper edifice. The ice bounded lava flow atop Mazama Ridge that extends into Stevens Canyon erupted at about 90 ka (Lescinsky and Sisson, 1998), immediately after eruption of a thick (200 m or ~600 ft) pyroclastic flow that filled in what is now the headwater of Kautz Creek and that welded to form Basalt Cliff, Pearl Falls, and the area below Mildred Point. The anomalous thickness of the pyroclastic flow deposit is possibly due to its having melted through and embanked behind thick ice that filled the lower Kautz drainage. Basaltic andesite lavas erupted from flank vents at Echo and Observation Rocks at about 100 ka and built up the lava flow field of Spray Park. The basaltic andesites of Spray Park are unlike typical Mount Rainier magmas in their chemical compositions and in their abundance of olivine. Like the Bee Flat lava flow, the vents at Echo and Observation Rocks were probably fed from magmas that arose adjacent to, rather than emanated laterally from, the nearby Mount Rainier magmatic system.

Eruption frequency and volume increased again from 40 to about 20 ka, though not to the same degree as the earlier stages that produced multiple, far traveled lava flows. The dacite lava flow that makes up Ricksecker Point and Narada Falls (again with evidence of ice contacts) is the sole lava flow from this young episode to extend much beyond the edifice flanks. This 40-ka dacite is overlain unconformably by another 40-ka lava flow (more ice contacts) that shallowly floors the Muir Snowfield, that is in turn overlain by the slightly younger high-elevation lava flows that make up the upper south flank of Mount Rainier 's edifice: at Camp Muir, Point Success and Success Cleaver, Gibraltar Rock, and Tahoma Cleaver. Similar-aged lava flows on the north flank form upper Curtis and Liberty Ridges, and much or all of the Willis Wall. These numerous upper edifice lava flows bury the post-120 ka erosion surface. Rarely, some of these young lava flows drape the steep side of a high ridge, such as on Success and Tahoma Cleavers, with glassy ice-contact features on the flow top facing the adjacent valley. Relations like this show that the cleavers were flanked with thick ice when they were constructed, and that recession of the glaciers at the end of the Pleistocene, rather than deep erosional incision, accounts for much of the ridge-and-headwall form of the upper mountain. An easily accessible ice-confined lava flow from that time forms a broad bench west of Cushman Crest, and its ice-contact margins, consisting of cliffs of glassy columns, overlook the trail leading to Comet Falls.

Details of Mount Rainier 's volcanic history in the period from about 40,000 years ago to the time of the great Osceola Mudflow collapse of about 5,600 years ago are very poorly known. Stacks of successive thin lava flows form high headwalls and ridges. These lava sequences are cut by few deep erosional breaks, possibly indicating that eruptions followed one another in rapid succession with little time for erosional incision. Unfortunately, nearly all of the rocks in those high-elevation localities are too young and glassy to date accurately by current K-Ar or 40Ar-39Ar methods. Plant material is effectively absent in those alpine regions, precluding radiocarbon age measurements. What details are known come mainly from studies of postglacial (<10 ka) tephras and lahars, as opposed to the edifice itself. Deciphering Mount Rainier 's latest Pleistocene and early Holocene volcanic history remains a challenging research problem.

Thumbnail sketch of Mount Rainier's eruptive personality

Effusions of andesite and low-silica dacite lavas dominated Mount Rainier 's eruptive history, which also included subordinate block-and-ash pyroclastic flows; lava domes and large tephra falls were rare. This eruptive style contrasts with that of Mount St. Helens, whose history is characterized by growth of lava domes with associated collapse-generated aprons of talus and small pyroclastic flows, large pumiceous tephra eruptions, and some lava flows. The striking difference in eruptive behavior between the volcanoes probably results from subtle differences in their magma types. On average, Mount Rainier 's magmas are slightly hotter and more fluid, promoting lava flows and allowing the quiescent escape of otherwise explosive volcanic gases. Excepting the Osceola Mudflow and a few other events, Mount Rainier 's eruptions would not have been particularly impressive from the standpoint of their explosive violence, but the extensive lahar deposits, including some containing abundant alteration products and others composed of fresh rocks, show that its eruptions can be devastating. Lava and pyroclastic-flow eruptions can generate lahars though interaction with snow and glacial ice. Pyroclastic flows can generate lahars by sweeping across, scouring, incorporating, and melting snow and ice and thereby transforming directly into lahars. Lava eruptions onto glaciers can also generate lahars by meltwater sluicing off flow-top rubble and shattered flow margins and by mobilizing periglacial debris. Minor tephras deposited on snow high on a volcano can also generate destructive lahars, such as took place at Nevado del Ruiz in 1985, destroying the town of Armero, Colombia, and killing ~23,000 people. The thick stacks of lava flows on upper Mount Rainier, with few interrupting erosional breaks, as well as multiple thin tephras deposited during the Holocene are evidence that Mount Rainier has periods when small-volume eruptions recur frequently over extended time intervals (perhaps >100 years). Although individually small, the cumulative effect of years of ongoing eruptions and lahars would be costly and disruptive to anyone living nearby.

Of equal concern is the possibility that portions of the upper edifice could collapse. The far-traveled and voluminous (~4 km3 or 1 mi3) Osceola Mudflow that floors much of the Puget Lowland between Tacoma and the southernmost outskirts of Seattle began during a modest eruption when clay-rich, hydrothermally weakened rock collapsed from the volcano's summit and eastern flank, accompanied by a Mount St. Helens-style directed blast. The collapse removed altered rock from the volcano's east flank and probably from most of the upper mountain, leaving an amphitheater-shaped crater open to the east that subsequent eruptions have largely filled, but a region of intensely altered and weakened rock remains on the upper west flank above the Puyallup River system. Strong shaking by earthquakes during renewed volcanic activity, or deformation of the upper edifice by magmatic intrusions, might cause that altered region to collapse, creating lahars capable of reaching densely populated areas. Such failure could take place very early during build-up to an eruption, would be largely independent of the nature of the eruption, and possibly could happen during noneruptive times due to simple gravitational collapse of weakened rocks or dislodgement by a large regional earthquake. Since the end of the Pleistocene, all but one of Mount Rainier 's far traveled lahars took place during eruptive periods. Mainly for this reason, spontaneous collapse, or collapse triggered by a regional earthquake, are not considered as highly likely events, though these possibilities cannot be ruled out entirely. Because of the multiple processes that could trigger collapse and their uncertain timing, edifice flank failure is the most difficult hazard to predict and monitor at Mount Rainier, although considerable progress has been made in identifying collapse-prone areas.

GLACIERS OF MOUNT RAINIER

Glaciers, as it turns out, are the architects of Mount Rainier; they are the ultimate sculptors. Their fluctuations visible within a human lifespan, no matter how dramatic at first glance, are well within the range of normal glacier behavior. With virtual certainty, minor changes to climate will continue, as will the fluctuations of glaciers.

Carolyn Driedger, USGS geologist, quoted by Craig Welch in the Seattle Times, July 15, 2002

Mount Rainier 's glaciers are among the most fascinating and changing geologic features on the volcano. They have played an important role in eroding the cone, and, by giving birth to a ground-water system within the volcano, they also contribute to the alteration of the volcano, its susceptibility to collapse, and its style of eruption. In addition, the glaciers generate vital stream flow for major northwest rivers, some of which are tapped for hydroelectric power and irrigation.

Mount Rainier has a volume of snow and glacier ice equivalent to that on all the other Cascade Range volcanoes combined. Including the perennial snow bodies, glaciers cover about 35 mi2 (91 km2) of the mountain's surface—about 9 percent of the total park area—and have a volume of about 1 mi3 (4.2 km3) (Driedger and Kennard, 1986). For comparison, this volume would fill Seattle's Safeco Stadium 2600 times (Driedger and others, 2006). Several of Mount Rainier 's 26 named glaciers have been the focus of classic studies of neoglacial moraine development and glacial dynamics (Sigafoos and Hendricks, 1961, 1972; Crandell and Miller, 1974; Burbank, 1981; Porter, 1981; Heliker and others, 1984). As shown by Emmons' statements in 1871, above, early geologists observed Mount Rainier 's glaciers as they were just beginning to recede from their advanced positions during the Little Ice Age. (See "Neoglacial Advances", p. 30.) At that time, the toes of these expanded glaciers extended "into the forest". The Nisqually Glacier, for example, had moved to a position 650 to 800 ft (198–244 m) downvalley from the present site of the uppermost Nisqually River bridge (Driedger, 1986). Driedger goes on to note that during this time, Tahoma and South Tahoma Glaciers merged at the base of Glacier Island and the terminus of Emmons Glacier reached within 1.2 mi (1.9 km) of the White River Campground (Driedger, 1986) . The glaciers kept retreating into the 1920s, then faster until about 1950, when many began to advance again because of lower temperatures into the 1980s.

Nylen and others (2000) found that Mount Rainier's glacial cover shrank 18.5 percent between 1913 and 1962. This rate slowed significantly from 1971 to 1994. Nylen documented that glaciers smaller than 5 km2 (~2 mi2) decreased by about 35 percent between 1913 and 1994 (Nylen, 2004). Nylen and his colleagues also observed that the glaciers on the southeastern and southwestern flanks suffered the greatest losses.

Glacial-outburst floods from South Tahoma Glacier repeatedly scoured Tahoma Creek during the late 1960s and the middle 1980s to early 1990s and continue sporadically from year to year. The floods are usually associated with seasonally extreme weather—either unusually warmor unusually wet conditions (Walder and Driedger, 1994). The Tahoma Creek events are discussed in detail in the road guide for Leg M. Similar events have occurred in many other drainages, most notably Kautz Creek and Nisqually River, during historical time (Driedger and Fountain, 1989).

FIELD TRIP GUIDE

The Drive from Tacoma to Fort Lewis

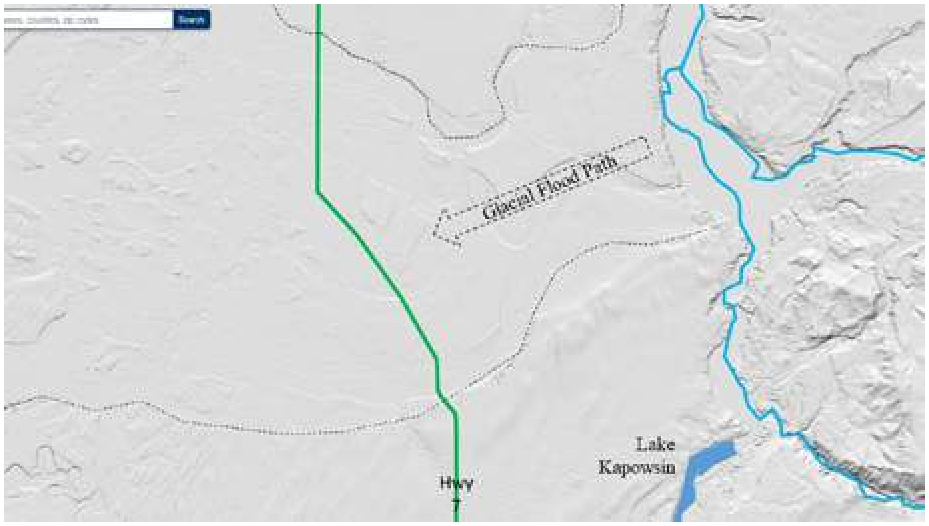
Driving South from Tacoma the Hwy 7 corridor crosses terrain created by massive glacial ice and outwash floods from the last Ice Age. The present topographic shape and form of the southern Puget Sound Lowland has been largely influenced by the most recent glacial advance and retreat. The passage of the glacier from north to south left distinctive landforms, such as ice contact, north-south-trending depressions, outwash channels, kettles, and drumlins. The last extensive glaciation of the southern Puget Sound was the Vashon Stade of the Fraser Glaciation. This glacier advanced from the north into the Puget Sound Lowland about 18,000 years ago, impounding rivers, creating glacial lakes, and diverting drainage southward to the Chehalis River and then west to the Pacific Ocean to create extensive outwash plains that Hwy 7 passes over. At its maximum extent, the glacier stretched from the Cascade Range to the Olympic Mountains and extended south as far as Tenino in Thurston County, occupying all of the lowland area and lower mountain valleys. The glacier is estimated to have reached altitudes up to 3,000 feet near Seattle to 2,200 feet near Tacoma to less than 1,000 feet near Olympia. The Vashon Stade began retreating from its terminus about 17,000 years ago and as it retreated meltwater from the glacier would become impounded behind the ice, forming large proglacial (formed by damming action of moraine or ice dam) lakes. Several proglacial lakes have been identified and named as forming along the terminus of the ice lobe, including glacial lakes Puyallup, Russel and Carbon.

Discharge from these lakes cut glacial outwash flood channels into the glacial outwash deposits west of the ice dammed lakes which would discharge water and coarse sediment over the central and western region south of the Puget Ice lobe. Large volumes of water from the lake flowed south, originally through the Ohop Valley Spillway. As the ice retreated northward lake levels dropped, and successively lower channel spillways were used including the drainages of Clover Creek, Muck Creek and Tanwax Creek. Of the multiple glacial advances and flood events, we will focus primarily on the features created by the Tanwax Flood as we travel towards the Ohop Valley.

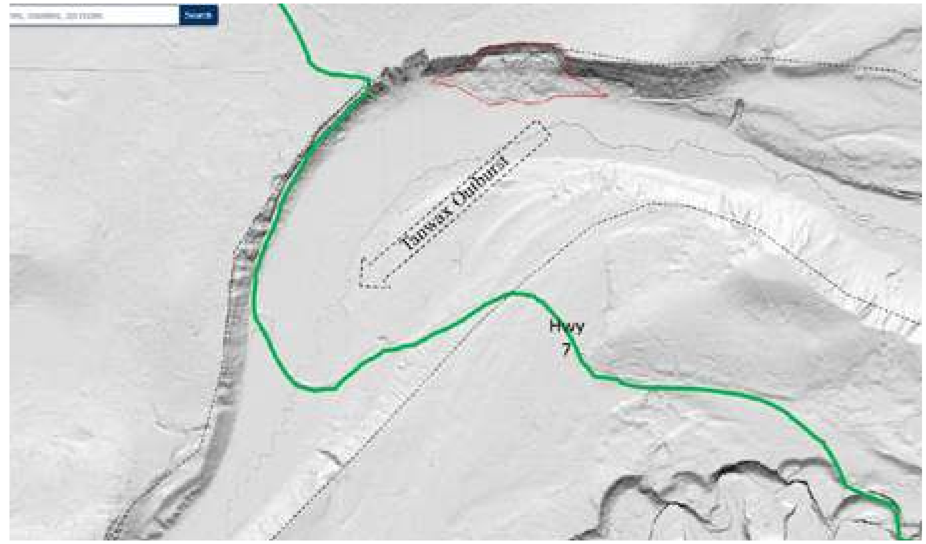
The predominantly flat ground along Hwy 7 is the glacio-fluvial Steilacoom Gravel. The gravel deposit occupies an area of about 60 square miles and on its western boundary with Puget Sound is terminates as a formidable 200 ft bluff. The term Steilacoom gravel should be understood to mean gravel and sand, since the material as it occurs in the area actually is a well-graded mixture of stream-worn boulders, cobbles, pebbles, and sand, so uniformly distributed that sized products can be produced only by screening. The Steilacoom gravel is made up of a heterogeneous mixture of igneous and metamorphic rocks transported by ice of the latest continental glacial advance in Pleistocene time. It was deposited as glacial outwash, and appears to have been reworked by a large amount of melt water, which washed it clean of silt and clay. As a material resource the Steilacoom gravel was of such superior quality that as the area developed the general rock strength, lack of alteration and deleterious matter, and low abrasion loss meant that mines produced quality borrow material.

Though human development and infrastructure are hiding the evidence to support this, there are some other clues to indicate the glacio-fluvial origin of the area along the driving route. Following the retreat of the last glaciers the first vegetation to reclaim the land consisted of grass prairies, which provided good forage for megafauna. As the climate shifted and soils developed it led to the endemic prairie-oak ecosystem of the Pacific Northwest. Found here is the Northwest's only native oak species Quercus garryana, also known as Garry Oak or Oregon White Oak. Living to over 500 years old, this drought tolerant tree flourished in the well-drained glacio-fluvial outwash soils found in the South Puget Sound area and greater Pacific Northwest. As the oak forests grew it provided shade for Douglas Fir, Western Hemlock and Western Redcedar forests which arrived later and the camas prairies which provided food for multiple First Nations of the Pacific Northwest. Though we will not be seeing it today, the Fort Lewis artillery impact area is one of the last remaining vestigial prairie-oak savannahs, effectively a relic of the Pleistocene.

As you drive along south of Parkland, look for rounded cobbles and boulders from excavations or in open cuts. These are remnants of glacial outwashes that tended to cut southwest between the margins of the end of the Puget Glacial Lobe and the Cascade Mountain landforms to the south. Multiple outwash events occurred, sourcing from Glacial Lake Carbon and carrying the andesites from Mt Rainier and other older deposits south around the toe of the ice until it was able to turn back north toward Rocky Prairie and Mima Prairie. Andesite cobbles and boulders which originated from volcanic sources in the Cascade Range are present in the Muck Creek, Tanwax and Ohop valleys. Though we will not see the landslides on our drive, the outwash events carved deep channels into the previously deposited glacial flood deposits which led to unstable slopes forming along the banks of the channels. Multiple landslides can be easily identified when viewing Washington Department of Natural Resources LiDAR data of the Ohop valley. In addition to the slides, kame terraces formed along the ice lobes which added to the sediment load to some floods or have been overprinted by landslide deposits.



All of these andesitic rocks, some of them very old, are typical of the outwash which all lead to the Mima Mounds sitting on the same stratigraphic horizon as the flood deposits. As the flood waters turned back north around the ice lobe, the outwash left mega-scale graded bedding deposits with andesite gravels at Rocky Prairie (80% andesite) and Mima Mounds (45-50% andesite). These recently identified findings indicate a source and creating event for the roughly 370 acres of Mima Mounds found at its namesake nature preserve (all credit due to Pope, Pringle and Harris, 2020 and Tabbutt, 2016). Clustering in the thousands along proglacial terraces, the Mima mounds are domelike ellipsoids composed of a sandy loam overlying relatively impermeable coarse-bedded gravels (Pope et al., 2020; Pringle and Goldstein, 2002; Goldstein and Pringle, 2020). Up to 2 m high and 12 m in diameter, the mounds are elongated parallel to the downslope gradient of the host terraces. In addition to the namesake preserve it has been found that every one of the channelized flood valleys contains mima mounds. Naturally, origin stories for geologic deposits are a traditional way to stir up controversy so this theory is one of many ranging from gopher mounds to seismic separation to aeolian aggradation.



Driving down into the Ohop Valley outwash channel

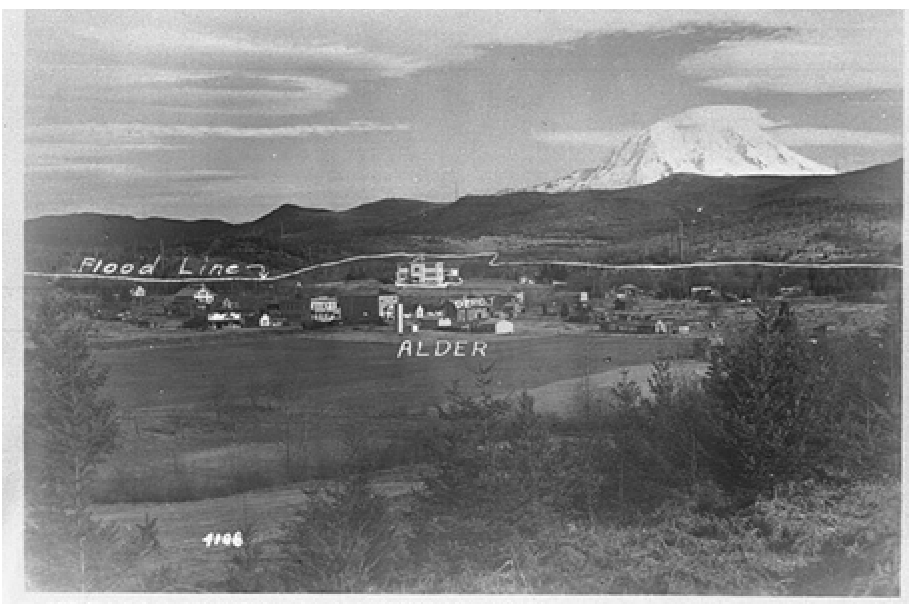
Dropping down off the outwash deposits south of Muck Creek and Tanwax Creek drainages, we are entering the roughly 2,000 to 3,000-ft wide Ohop Valley outwash channel. Formed after multiple flood events between 17,000 years ago to 16,000 years ago originating from Glacial Lake Carbon, this flat bottomed channel fed into the Chehalis Valley spillway which was the principal outflow terminus channel beyond the limits of the Puget Ice lobe. Derek Booth of the UW has calculated that the average outwash was roughly 112,000 cubic feet per second average discharge (credit to Pat Pringle's Tanwax Flood YouTube video). For comparison the 2007 record-setting flood event on the Chehalis River peaked at 80,000 cubic feet per second and buried I-5 in 14 feet of water at Exit 77.

The tranquility of the Ohop Valley floor is a stark difference from the apparent carnage that was the Tanwax-Ohop outwash flooding. In the road cut along the Ohop Valley slopes you can see large round boulders of andesite left by the many outwash floods. These are deposits typical of the coarser sediment loads left higher up in the valley by the floodwaters. As the boulders were carried down the channel they were constantly bashing into each other and the rock-to-rock abrasion marks are still evident today on some boulders. We can see this today in the roadcuts with boulders outcropping from the glacio-fluvial, debris-flow materials or in the well-rounded landscape rocks in every cleared property along the route. Further down the road and lower in the stratigraphic column is an outcropping of fine-grained silts and sands, typical of a braided glacial outwash delta. The thin layering captures the calmer periods of glaciation when the aggrading sediment deltas south of the ice terminus carried fine-grained silts and ice pulverized rock flour.

Further north is Lake Kapowsin the headwaters source for Ohop Creek and we are not passing this along the route. Lake Kapowsin was formed by volcanic processes that split the prehistoric Ohop valley, permanently separating the Puyallup River and Ohop Creek. Approximately 500 years ago the Electron Mudflow began as an avalanche of hydrothermally altered rock high on Mount Rainier's west flank near Sunset Amphitheater. There is no direct correlation to the lahar being correlated with a volcanic eruption, but beneath the ice Mount Rainier is known to be constantly hydrothermally altering the in-situ rock. Theorized triggers include an eruption so small its tephra is not preserved (steam explosion), hydrothermal explosions, or an earthquake. Regardless of triggering mechanism, the Electron avalanche was aided by hydrothermally weakened and voluminous water-saturated clay-rich rocks west of the summit area. The lahar was highly fluid and flowed along the Puyallup River drainage 60 miles downstream to the Puget Sound lowland. When it entered the Puget Sound lowland in the community of Electron, it was 100 feet deep. Today the formerly rural agricultural and dairy communities of Orting, Sumner and Puyallup have been heavily developed on top of Rainier's most recent lahar deposit.

Driving by Alder Lake; Sedimentation and storage capacity loss

The Nisqually River drains the southwest slopes of Mount Rainier, a glaciated stratovolcano in the Cascade Range of western Washington. The Nisqually River was impounded behind Alder Dam when the dam was completed in 1945 and formed a reservoir which also erased Alder, WA from existence. This report quantifies the volume of sediment deposited by the Nisqually and Little Nisqually Rivers in their respective deltas in Alder Lake since 1945. Four digital elevation surfaces were generated from historical contour maps from 1945, 1956, and 1985, and a bathymetric survey from 2011. These surfaces were used to compute changes in sediment volume since 1945. Based on research by the USGS the estimated annual sediment load of the Nisqually River drainage suggest that a basin draining a glaciated stratovolcano yields approximately 15 times more sediment than a basin draining forested uplands in the Cascade Range.



A 2012 USGS report on Changes in Sediment Volume in Alder Lake, Nisqually River Basin, Washington 1945-2011 (OFR 2012-1068) presented findings on how much capacity storage loss has occurred in Alder Lake. Originating from a glacier of the same name the Nisqually River is one of several treacherously cold, sediment laden rivers on the westside of the Cascade Mountain range. Alder Lake dam was built as a hydropower producer for the City of Tacoma, along with the smaller La Grande hydropower reservoir immediately below. Since its completion in 1945, Alder Lake dam has effectively trapped all sediment delivered to the lake inlet located by Elbe, WA. In addition to a continuous delivery of glacio-fluvial sediment there have been 51 (known) debris flows from Mt. Rainier between 1926 and 2006. Of these debris flows the most notable have been the result of atmospheric river currents slamming into dense Cascade snowpack, known by locals as a “pineapple express”. The other source of major debris flows has been from glacial outburst floods, including a large 1947 event from the Kautz Creek tributary that buried a small forest of fir and cedar. The remaining trees are in various states of decay, with the cedars far outlasting the firs.

As part of the sedimentation study the USGS evaluated older topographic map contours and also performed three bathymetric surveys between Oct 2010 and April 2011. As any local would tell you, the lake is highest during wintertime on account of the increased runoff. But as a navigable lake it is treacherous on account of the numerous submerged stumps that remain on the formerly timbered slopes and the Nisqually River depositional delta is littered with deadhead, sinker logs. If that hazard isn’t enough for the hearty fisherman, the water contains glacial rock flour which renders the water opaque meaning boats in shallow waters more than likely will ground or strike hidden objects.

Cumulative changes in the volume of the Nisqually River delta in Alder Lake were computed by the USGS for the three periods between 1945 and 2011 by subtracting the 1945 surface from each of the more recent surfaces. Comparison of elevation profiles along the historical channel prior to the damming of the Nisqually River and 2011 surfaces

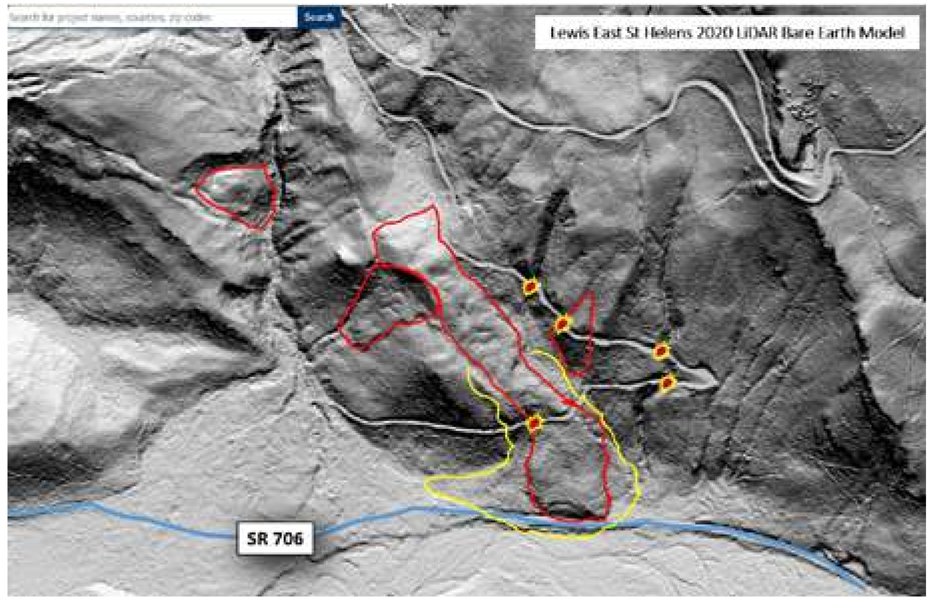
showed the general change in elevation of the bed of Alder Lake, with a maximum increase in the thickness of the delta deposit of approximately 92-ft near its furthest extent.

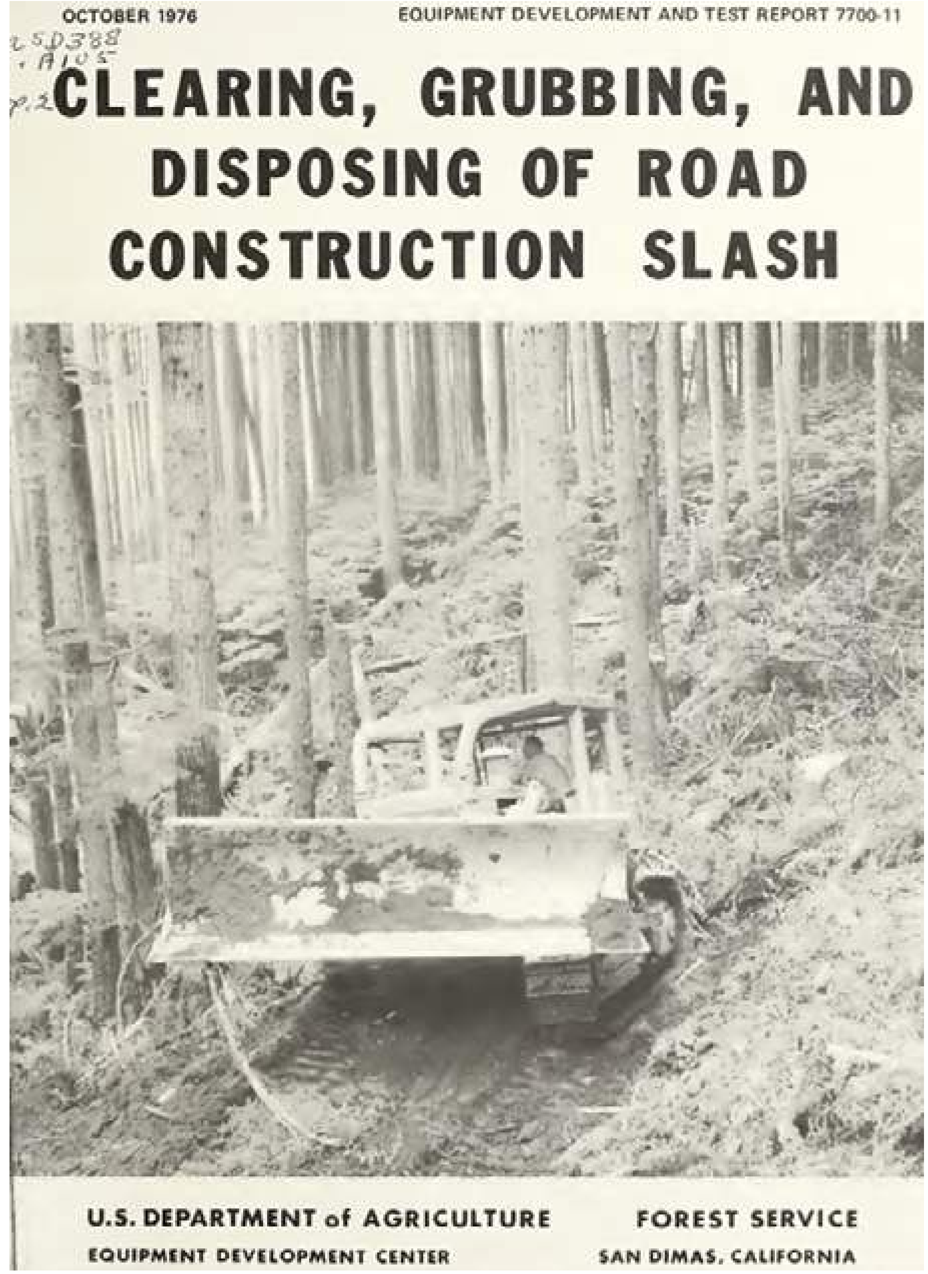
Based on the bathymetry measurements and fluvial inflow, the annual rate of sediment accumulation is 825,000 cubic yards per year (510 acre-feet) at the Nisqually depositional delta next to Elbe, WA. This estimate suggests that any basin draining a glaciated stratovolcano yields approximately 15 times more sediment than a basin draining forested uplands in the Cascade Range. Given the cumulative net change in sediment volume in the Nisqually River delta in Alder Lake, the total capacity of Alder Lake since 1945 decreased by about 15 percent by 2011. Given the rate of sediment deposition for 1945-2011 in Alder Lake, the total capacity of Alder Lake may decrease by 50 percent by 2175, assuming the conditions during the last 66 years will be representative of future conditions.

Copper Creek Forest Road 59

As we pass the cinnamon rolls and blackberry butter of the Copper Creek Inn and Restaurant, we will see evidence of the debris flow that closed Hwy 706 on February 10, 2020. The debris flow was actually a combination of two events that started on Forest Road 59 and coalesced into one runout fan that buried 706 with rocks and logs. The FHWA is currently developing repairs through the Emergency Relief for Federally Owned Roads (ERFO) program and will be putting in retaining walls or fill slopes in five of the six failure sites. All but one damaged section was evaluated in the emergency response and unfortunately for the partner agency they will not be receiving assistance for that missed site.

The 59 Road was constructed in the late-1950s with the then acceptable cut-and-sidecast method of road building, which generally consisted of a Cat D9 bulldozer and timber fallers. Trees were cleared and the stumps left to be used as bracing for rip rap or logs of no market value to serve as a key for the fill slope. A fun historic read is the 1976 Equipment Development and Test Report 7700-11 “Clearing, Grubbing, and Disposing of Road Construction Slash” which describes how to windrow and bury slash under sidecast soils. Evidence of this practice was visible in the stumps and logs exposed by the debris flow scouring out the fill sections.





OCTOBER 1976

EQUIPMENT DEVELOPMENT AND TEST REPORT 7700-11

CLEARING, GRUBBING, AND DISPOSING OF ROAD CONSTRUCTION SLASH

U.S. DEPARTMENT of AGRICULTURE

FOREST SERVICE

EQUIPMENT DEVELOPMENT CENTER

SAN DIMAS, CALIFORNIA

Bedrock underlying the road and steep slopes is adversely oriented Tertiary age sandstone. After the storm damage intensely scoured the overburden soil out of the drainages, almost the entire steams now cascade over sandstone bedrock, except where debris pockets remain or the channel slopes have collapsed to fill the void. In addition to the recent storm induced failures, the Washington Department of Natural Resources LiDAR datasets provide evidence of prehistoric landslides and unstable slopes along the 59 Road and surround area. Regionally this site is not geologically significant other than it closed a State Highway and it is another example of how geology influencing topography can make or break a road repair budget.

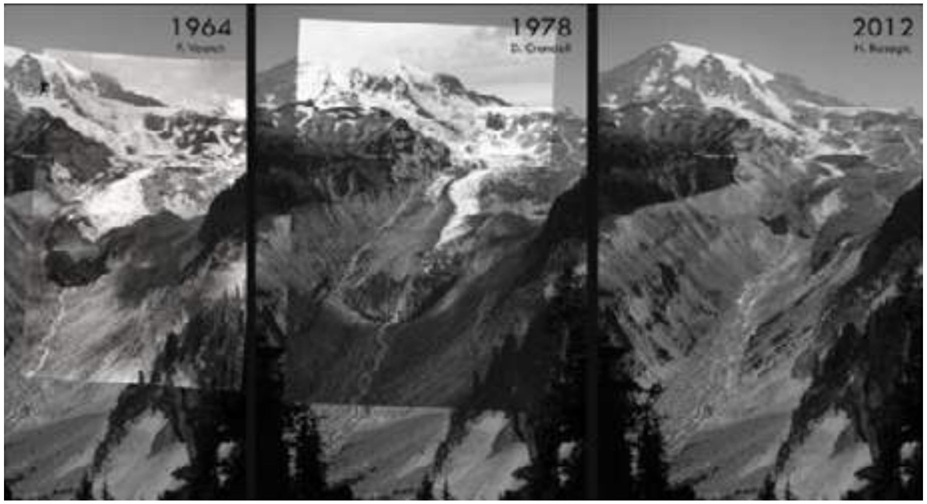
Nisqually Glacier view from the Nisqually River Bridge:

From the bridge over the turquoise waters of the Nisqually River, one can take in dramatic views upstream of the receding Nisqually Glacier. The glacier's terminus feeds the braided channels and suspended sediments that flow under the bridge. Swaths of glacial outwash spread across the valley floor. Moraines and trimlines mark the glacier's maximum 19th century advance. Since then, the glacier has retreated nearly a mile, exposing more of the underlying rock.

The Nisqually Glacier is perhaps the most visited, best-surveyed glacier on Mount Rainier. Because of easy access and prominent location, the glacier has been studied since the mid 1850's. In 1857, Lt. August Kautz crossed Nisqually Glacier during an attempt to climb the summit. Then in 1884, Allen Mason photographed the glacier for the first time, laying the foundation for a photographic record of Nisqually that spans over 130 years. During the 1930's, Tacoma City Light Department (TCL) and U.S. Geological Survey (USGS) began a series of measurements of glacier surface elevation, to determine the impact of Nisqually's shrinkage on water supplies for hydroelectric power production.

In 1857, Kautz wrote in his journal that the terminus reached a narrow rock throat underneath the present highway bridge. By the time Mason began photographing the glacier, the terminus had retreated up the valley 0.3 kilometers (0.2 miles). Photographs taken early in the twentieth century show national park visitors posing near the highway bridge with the glacier clearly visible over their shoulders. By the 1950's, such photographs were not possible since the glacier had retreated up the valley nearly two kilometers (1.2 miles), meaning that it was lost from view to anyone on the road. Then a few years later it was visible again from the bridge over Nisqually Creek. However, in 1970's the glacier resumed its retreat and again disappeared from view.

Text above was adapted from A Visitor's Guide to Mt. Rainier Glaciers by Carolyn Driedger (1986).



Nisqually Glacier triptych assembled by Hassan Basagic, who also took the most recent photo in 2012. (Photo courtesy of Andrew Fountain, Ph.D.)

Glacial Retreat on Mount Rainier

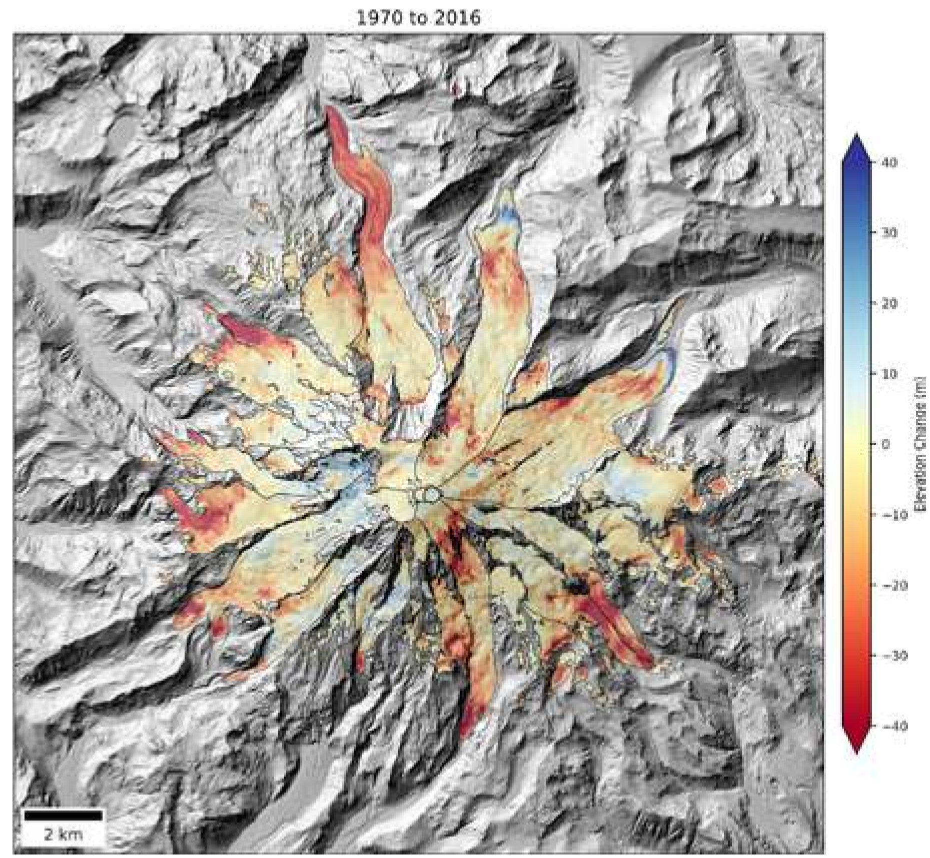
One hundred years ago, Mount Rainier's glaciers were far more extensive, with some glacier snouts reaching within a few miles of Paradise. Since then, most of the park's named glaciers have retreated substantially, losing as much as a mile or more of their length.

Scientists estimate Rainier's glaciers have lost 25-30% of their volume just since the 1980s, with faster melting rates observed in recent decades as regional temperatures have risen. Iconic glaciers like the Emmons, Carbon, and Nisqually have all pulled back dramatically, leaving newly exposed rocks and valleys in their wake.

The shrinkage has been captured in photos comparing current glacier size to early 20th century surveys. Emmons Glacier, the largest in the contiguous U.S., has withdrawn over a mile, while the Muir Glacier is now a small disconnected patch rather than a continuous ice field descending from Rainier's summit.

This rapid glacial retreat is visually evident from many Paradise area overlooks, with once merging glaciers now separated by rocky ridges. Signs placed by park scientists also mark how far downvalley glacier tips reached in previous decades compared to today.

Three glaciers on Mount Rainier have lost so much of their mass that they have recently been declared extinct. These were the Pinnacle, Unicorn, and Williwakas glaciers (now just snowfields).



This map shows the elevation change of Mount Rainier glaciers between 1970 and 2016. The earlier observations are from USGS maps, while the recent data use the satellite stereo imaging technique. Glacier surface elevations have dropped more than 40 meters (130 feet) in some places. David Shean/University of Washington

Ricksecker Point

Ricksecker Point is a promontory ridge between Rampart Ridge and the Tatoosh Range. The Nisqually River valley lies to the northwest of the ridge and the Paradise River valley is to the southeast. A one-way scenic loop drive traces the edge of Ricksecker Point. The third of a mile-long road has two main pullouts featuring views of Mount Rainier, the Nisqually and Paradise river valleys, and the Tatoosh Range. Both pullouts have wayside exhibit panels about the glaciers and lava flows that have shaped the geology of the mountain. Ricksecker Point is accessible by vehicle during the summer only. The road closes during the winter, typically from early November through mid-May.

Ricksecker Point is a contributing component to the Mount Rainier National Historic Landmark District. Ricksecker Point is named for Eugene Ricksecker, an Army Corps of Engineers supervisor who surveyed the route to Paradise in 1904. The survey team originally named the feature "Gap Point", but it was renamed after a road was constructed in 1909. Part of the original road to Paradise, the section around Ricksecker Point was considered one of the most dangerous stretches. It was narrow, bordered by steep cliffs, and prone to rockfall. Over the years the road was widened, resurfaced, and parking was included at viewpoints. A detour constructed in 1930 replaced the original route and became the main Paradise Road, while Ricksecker Point Road was left as a scenic bypass. In addition to providing excellent views, Ricksecker Point is an example of rustic style architecture that sought to blend with the natural environment. The road follows the curve of the ridge and guardwalls along the road use roughly cut, native stone. The stone guardwalls were constructed during the 1930s in part by the Civilian Conservation Corps.

The Ricksecker Point promontory is composed mostly of a Mount Rainier lava flow that now caps the ridge because of topographic inversion. The promontory is composed mostly of a thick Mount Rainier lava flow, whose steep and rubbly edges border the road between the Nisqually River bridge and the turnoff to Stevens Canyon Road. Geologist Tom Sisson has found that this is the youngest large lava flow at the volcano, with a radiometric age of about 40 ka.

The flow is covered by Evans Creek Drift and Holocene deposits. The Paradise Lahar, described in detail by Crandell (1963a, 1971), is unusual because of its initial huge peak flow wave and rapid downstream attenuation. Crandell noted that it generally is a very thin deposit and lacks constructional topography except at Reflection Lakes, where hummocks are visible and the lakes occupy shallow depressions in the deposit. At this site, the Paradise lahar deposit sits on tephra layer O from Mount Mazama (6,845 ± 50, Bacon, 1983), which rests on the Evans Creek Drift. The glacial drift overlies a lava flow breccia. Mount St. Helens tephra layers Yn and Wn overlie the Paradise lahar. The lahar deposit is about 245 m above the valley floor of the Paradise River at this location. Downstream at Longmire the lahar was more than 70 m deep and is 1.2 m thick where it overlies layer 0. It has only 1 percent clay at the latter location; however, clay content of the deposit varies widely, from 1 to 6 percent (Scott and others, 1992). The low ratio of deposit thickness to flow depth, >270 m here, combined with the wide variation in clay content, suggest that the Paradise lahar may have been catastrophically ejected.

The age of the Paradise lahar previously was thought to be bracketed by layer O and tephra layer D from Mount Rainier (about 6,000 yr old) (Crandell, 1971). Scott and others (1992), however, found wood from near this site that was dated at 4,625 ± 250 yr B.P., wood that yields an age of 4,955 ± 585 yr B.P. from slightly above layer Oat the Longmire location, and wood that has an age of 4,730 ± 320 yr B.P. from a correlative lahar deposit downstream of National. The apparent discrepancy of these three younger ages indicates that the Paradise Lahar is younger than originally thought and could be related to the same episode of volcanism that produced the Osceola Mudflow. Alternatively, it could indicate that another cohesive lahar occurs stratigraphically above the Paradise lahar but below tephra layer Y n.

The central part of the Tatoosh Range looms to the south. The contact between the bedded rocks of the Stevens Ridge Formation to the west and the Tatoosh pluton to the east is located between Lane Peak and Pinnacle Peak.

Historic Paradise

Of all the areas constructed inside Mount Rainier National Park, the Paradise Lodge and surroundings was the first road paved all the way to the destination. The Carbon River entrance was paved to the mining town of Carbonado, and beyond that it was 12 miles of graveled road maintained by Pierce County going to the Carbon River entrance. The Sunrise entrance, approaching from the White River valley, was a blend of paved and gravel surfaced roadway which designated the Mather T. Memorial Parkway but still nominally a highway. Considering the standard vehicle in 1932 and the standard method of road construction, it is safe to assume that maximum operating speeds for the traveling public were rarely achieved.

Hired methods of traveling to Paradise ranged from services offered by the Northern Pacific; Chicago, Milwaukee, St. Paul & Pacific; and the Great Northern Railroads or by the Rainier National Park Company's automobile stage departing daily out of Seattle and Tacoma. The stages would depart Tacoma and Seattle offices early in the morning to bring visitors to the Paradise Inn for luncheon, outdoor excursions or even lodging in the grand building itself. In addition to transportation, the Railroads and Rainier National Park Co. offered packaged tours including motoring throughout the Park, guided climbs to the summit of the volcano or other natural wonders such as glaciers, ice caves and sublime features. An all-expenses trip on the Wonderland Trail guided by a concessionaire while taking in the entire 145 mile trail in horse-mounted leisure.

For those who didn't have up to 12 days to circle the mountain there was golfing located a short distance from the Paradise Inn. Opened in 1931 the nine hole golf course was billed as the most scenic in America. Named Paradise Golf Course after the nearby Paradise Valley, the course at that time claimed to be the highest in America at 5,500 feet above sea level. It measured a respectable 2,349 yards with four Par 3, four Par 4, and one Par 5 hole. The first tee was 300 feet above the landing area. Every hole was downhill, and when nine holes were completed, a car transported the players back to the first tee if a full 18 holes of play had been purchased. The rarefied air, the scenic beauty, and the favorable topography were all designed, as one line put it, "... to make profane golfers contemplative, and the contemplative golfers better men." For all the potential and high praise for the view, the golf course permanently closed only after being open for 2 months.

Paradise Inn located just above the golf course was finished with weathered cedar logs rising to an impressive structure in the lobby, with great stone chimneys and fireplaces at each end with comfortable lounging chairs. Adding to the glamour offered in such a regal place was a ladies beauty shop offering hair styling and treatments, and for the gentlemen a barber shop offering shaves, cuts and massage. Only the barber shop offered a sunburn treatment option but that does not imply that only gentlemen climbed upon Mount Rainer.

Climbing services offered in the summer season ranged from full equipment kit rental to individual items offered at rates. Guide services were also offered, sometimes as a package deal or for the truly well-off a personal guide could be acquired for $25.00 ($533 adjusted for inflation). The guide service was based in an auditorium building located next to the Inn, and in it could be found information to help the

GOLF COURSE

The 9-hole golf course, one of the most scenic in America, is located a short distance from Paradise Inn. Every green and tee offers a striking mountain scene and is also a test of golfing skill.

9-hole play	$1.00
18-hole play	1.50
All-day play	2.00
Annual tickets	35.00
Rental of 5 clubs and bag, 18-hole play or less	.50
Rental of 5 clubs and bag, all-day play	1.00
Caddy service for each 18 holes or fraction thereof	1.00
Prereservation fee	1.00

Players are transported free from last hole near Marmot Point back to No. 1 tee.

Equipment on sale in caddy house at standard prices. Light refreshments also on sale.

Beauty-shop price schedule

Water wave	$1.00
Marcel	1.00
Marcel and bob curl	1.25
Round curl	.50
Plain shampoo	$0.75 and 1.00
Hot-oil shampoo	1.50
Tonic rub	.50
Plain facial massage	1.00
Facial massage with pack	1.50
Eyebrow arch	.50
Manicure	.50
Henna pack	1.50 and 3.00
Hair bleach	1.00 and 1.50
Egyptian rinse	.25
Golden glint rinse	.25
Lemon rinse	.25
Blueing rinse	.25

BARBER-SHOP PRICE SCHEDULE

Shaving	$0.25
Hair cutting	.65
Hair bobbing	.75
Hair singeing	.25
Beard trimming	.50
Shampoo, plain	.50
Shampoo, special	.75
Witch-hazel steam	.25
Combination massage	.75
Boncilla massage	1.00
Head massage	.25
Tonics	.25
Sunburn treatment	.50

PARADISE LODGE—YEAR ROUND

Paradise Lodge is located near Paradise Inn and operated separately. It is intended to care for visitors desiring moderately priced accommodations. Rooms with and without bath and housekeeping cabins are offered here. Meals are served cafeteria style. There are shower baths and a laundry for the use of patrons.

Paradise Lodge has 35 bedrooms and 275 modern housekeeping cabins adjacent thereto. Rooms are equipped with electric light, hot and cold running water, and are heated and completely furnished.

Each cabin is provided with a double bed, springs, mattress, pillows, cookstove, table, benches, sink, cold running water, and electric lights.

1 person in room with bath, per day	$5.00
Each additional person, per day	3.00
1 person in room, without bath, per day	3.00
Each additional person, per day	2.00

A 10-per-cent discount is allowed on room rental for a stay of a week or longer.

intrepid climbers prepare. Moving-picture and stereopticon talks were given in the 200-seat auditorium for the purpose of illustrating the hiking and saddle trips on the glaciers and to other interesting regions in the park. For the intrepid adventurer intent on achieving the summit several suggestions were put forward in the guide's auditorium talks. Generally speaking, Mount Rainier is not Prospective clients were admonished to have moderation in diet and avoid heavy foods such as fried eggs, fried potatoes, hot cakes or heavy pastry. Potential clients were also suggested to, if possible, abstain from coffee and tobacco.

Outside of the services offered by the Rainier National Park Company, the rest of the park was administered by the National Park Service who provided the rules and regulation for the general public in published circulars. The following are excerpts from the General Regulations, 1932 edition, and highlight some of the questionable and hilarious activities once tolerated by the general public. Thankfully many of these regulations have change drastically:

- **Preservation of natural features and curiosities** – The destruction, injury, defacement or disturbance in any way of the public buildings, signs, equipment or other property, or the trees, flowers, vegetation, rocks, minerals, animal or bird, or other life is prohibited: Provided, That flowers may be gathered in small quantities when, in the judgement of the Superintendent, their removal will not impair the beauty of the park. Before any flowers are picked permit must be secured from this officer.

- **Camping** – Permanent camp sites have been set apart for visitors touring the park, and no camping is permitted outside the specially designated sites. Campers shall not wash clothing or cooking utensils or pollute in any other manner the waters of the park. Bathing in any of the streams near the regularly traveled thoroughfares in the park is not permitted without suitable bathing clothes.

- **Hunting** – The park is a sanctuary for wild life of every sort. This act by its terms applies to all lands within the park whether in public or private ownership. Molesting, teasing, or touching the animals is prohibited. Persons feedings bears do so at their own risk and peril.

- **Travel** – Saddle horses, pack trains, and horse-drawn vehicles have right of way over motor-propelled vehicles at all times.
    - On sidehill grades throughout the park motor-driven vehicles shall take the outer edge o the road when meeting or passing vehicles of any kind drawn by animals; likewise freight, baggage and heavy camping outfits shall take the outer side of the hill.
    - All vehicles shall be equipped with lights for night travel. At least one light must be carried on the left front side of all horse-drawn vehicles in a position such as to be visible from both front and rear.
    - Speed is limited to 15 miles per hour on grades and sharp curves. On straight open stretches the speed may be increased to 30 miles per hour.
    - Automobiles while in motion shall be not less than 150 feet apart, except for the purpose of passing, which is permissible only on comparatively level stretches of road or slight grades.

Geology of Paradise:

Numerous large boulders in the Paradise lahar deposit lie on the ground surface in this area. The lahar deposit and various tephra layers are visible in exposures at the parking area and along the trails that weave through the alpine meadows.

A trail in the alpine meadows at Paradise Park. Boulders and clayey yellowish-orange sediments exposed in trail cuts are deposits of the Paradise lahar (~5,600 cal yr B.P.). Nisqually Glacier is above the hiker and Cowlitz Glacier is to the upper right. Wilson Glacier behind the trees to the left is tributary to the Nisqually River. Kautz Glacier is in the upper left corner of the photo. View is to the north-northwest.

HIKES FROM PARADISE

Here are some rules and hiking etiquette to follow when hiking in Mount Rainier National Park:

- Stay on designated trails. Do not cut switchbacks or trample fragile alpine meadows and wildflower fields.
- Leave no trace. Pack out all trash and belongings. Do not disturb plants, rocks, signs, or other natural features.
- Maximum group size of 12.
- Yield to uphill hikers when on narrow trails. Stand to side to allow safe passage.
- Keep voices and noise down to avoid disturbing wildlife. Observe animals respectfully from a distance. Do not approach, feed, or touch wildlife including marmots and mountain goats.

By following park rules and practicing responsible hiking habits, we can keep Mount Rainier National Park beautiful for all to enjoy. Be aware and tread lightly!

Suggested Hikes	Distance	Elevation Gain	Time Expected	Challenge	Local Geologist Guide
Myrtle Falls	0.9 miles	200 feet	20-45 mins	Easy	Abby Hanson
Avalanche Lily and Waterfall Trail	1.2 miles	270 feet	25-50 minutes	Easy	Becca Goughnour
Nisqually Vista	1.8 miles	400 feet	35 mins-1 hour	Easy	Marc Fish
Alta Vista	1.8 miles	600 feet	45 mins-1 hour	Moderate	Todd Hansen / Mike Mulhern
Moraine Trail	2.5 miles	700 feet	1-2 hours	Moderate	Katelyn Card
Glacier Vista	2.5 miles	940 feet	1-2 hours	Moderate	Cody Chaussee
Moraine and Vistas	3.7 miles	1,200 feet	1.5-2.5 hours	Strenuous	Gabe Taylor
Golden Gate-Skyline	3.9 miles	1,150 feet	1.5-2.5 hours	Strenuous	Stephen Newman
Panorama Point	4.0 miles	1,450 feet	1.5-2.5 hours	Strenuous	Jenny DiGiulio

Myrtle Falls

Challenge: Easy

Distance: 0.9 miles

Elevation: 200 feet

Estimated Hike Time: 20-45 mins

Suitable for wheelchairs with help, and strollers.

Myrtle Falls is a stunning 60-foot waterfall along the Edith Creek drainage. Approaching the falls, the rush of cascading waters can be heard long before the view opens up. The two-tiered falls showcase Edith Creek plunging over a moss-draped cliff of andesite.

From the overlook perch, the upper tier drops about 25 feet into a punchbowl before flowing over the lower 35-foot cascade.

Though powerful in spring runoff, Myrtle Falls maintains a year-round beauty enhanced by its secluded setting. Myrtle Falls is an easily accessible yet hidden gem within the majestic landscape of Mount Rainier National Park.


5961ft
Alta Vista
Myrtle Falls
Skyline Trail
Paradise Inn
Tatoosh Cafe
Nisqually Vista


5,700 ft
5,650 ft
5,600 ft
5,550 ft
5,500 ft
5,450 ft
0.0 mi
0.1 mi
0.2 mi
0.3 mi
0.4 mi
0.5 mi
0.6 mi
0.7 mi
0.8 mi
0.9 mi

Avalanche Lily and Waterfall Trails

Challenge: Easy

Distance: 1.2 miles

Elevation: 270 feet

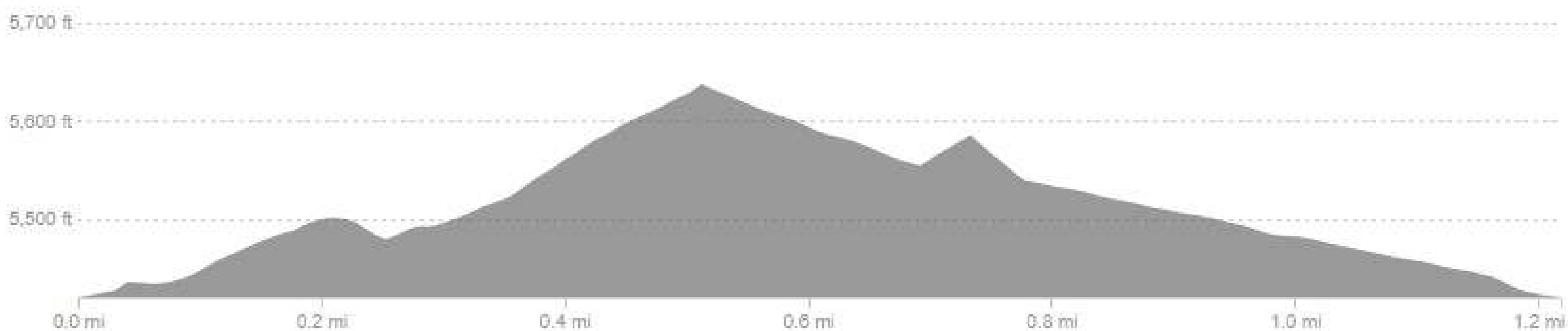
Estimated Hike Time: 25-50 minutes

This short but spectacular loop hike from Paradise encapsulates alpine ecology - wildflowers, ancient forest, and glacial meltwaters flowing in the shadow of Mount Rainier's iconic peak.

Starting at the Paradise complex, the trail heads uphill into meadows bursting with colorful wildflowers in July and August. Avalanche lilies carpet the mountainsides.

The forest opens occasionally to reveal Rainier's domed summit before returning to the flower-filled meadows of the Paradise loop.


5961ft
Alta Vista
Myrtle Falls
Skyline Trail
Nisqually Vista
Tatoosh Cafe
Paradise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Nisqually Vista

Challenge: Easy

Distance: 1.8 miles

Elevation: 400 feet

Estimated Hike Time: 35 mins – 1 hour

This short hike along an asphalt trail to Nisqually Vista provides an excellent view of the glacier's terminus. The asphalt trail has a loop and includes a few spectacular overlooks down into the canyon of the Nisqually River.

From the overlooks, you can see the Little Ice Age moraines and trimlines, the contact of Mount Rainier andesite with the underlying basement granodiorite, the various layers of Mount Rainier lavas and fragmental deposits exposed at the upper end of Rampart Ridge across the valley, and of course the Nisqually glacier.


Nisqually Vista
Paradise Inn
Tatoosh Cafe


5,500 ft
5,400 ft
5,300 ft
0.0 mi
0.2 mi
0.4 mi
0.6 mi
0.8 mi
1.0 mi
1.2 mi
1.4 mi
1.6 mi

Glacier Vista

Challenge: Moderate

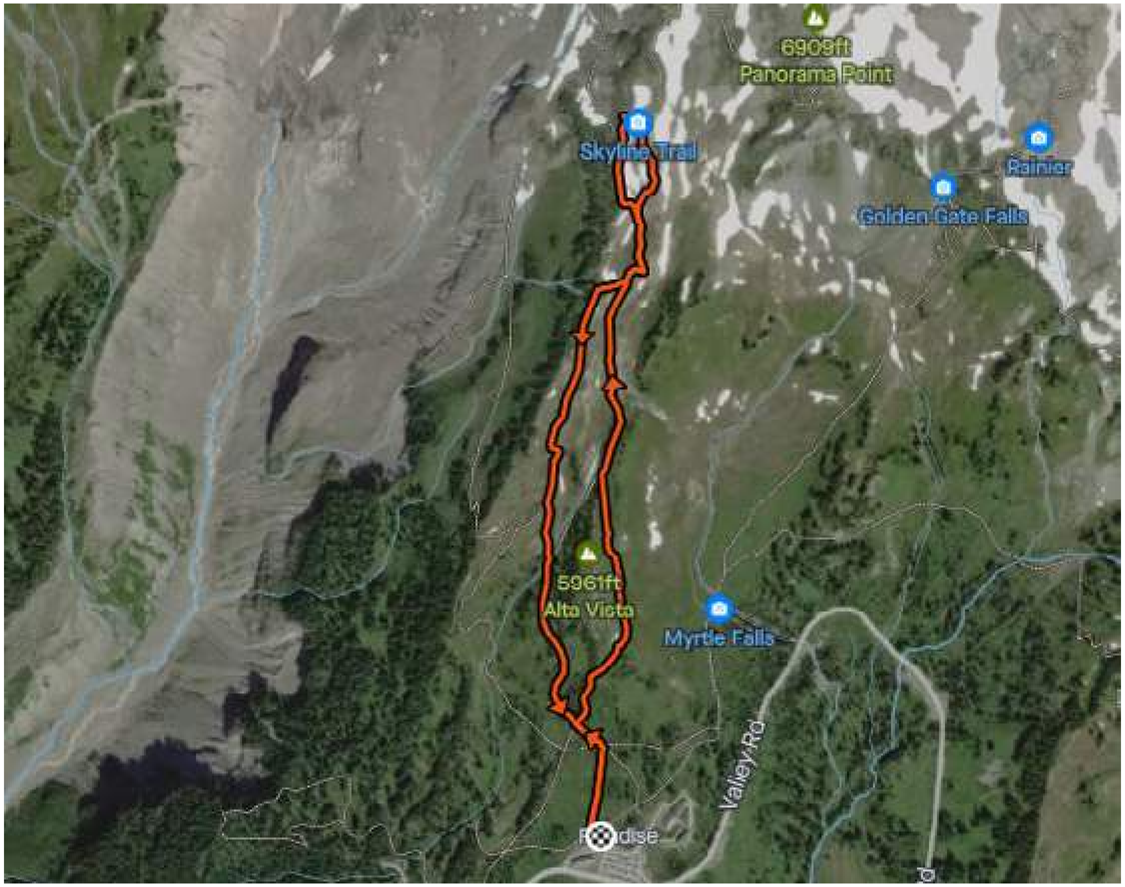
Distance: 2.5 miles

Elevation: 940 feet

Estimated Hike Time: 1-2 hours

The Glacier Vista hike provides a spectacular view of the Nisqually and Wilson Glaciers, glacial moraines, and upper Rampart Ridge.

Starting in the meadows of Paradise, the trail ascends through subalpine firs and mountain hemlocks, crossing several avalanche tracks which expose volcanic bedrock. As the trail switchbacks upward, views open up to Rainier's summit and the massive icefall of the Nisqually Glacier. Reaching Glacier Vista, Rainier's volcanic peaks and ridges surround you. The stacked layers of lava and ash that tier the mountainside are more evident here. Signs mark where the glacier terminus once reached before receding over the past century. This hike showcases Mount Rainier as an active geologic landscape. Dynamic glacial and volcanic forces sculpted its slopes and continue reshaping them today.


6909ft
Panorama Point
Skyline Trail
Rainier
Golden Gate Falls
5961ft
Alta Vista
Myrtle Falls
Valley Rd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5,800 ft
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1.4 mi
1.6 mi
1.8 mi
2.0 mi
2.2 mi
2.4 mi

Alta Vista

Challenge: Moderate

Distance: 1.8 miles

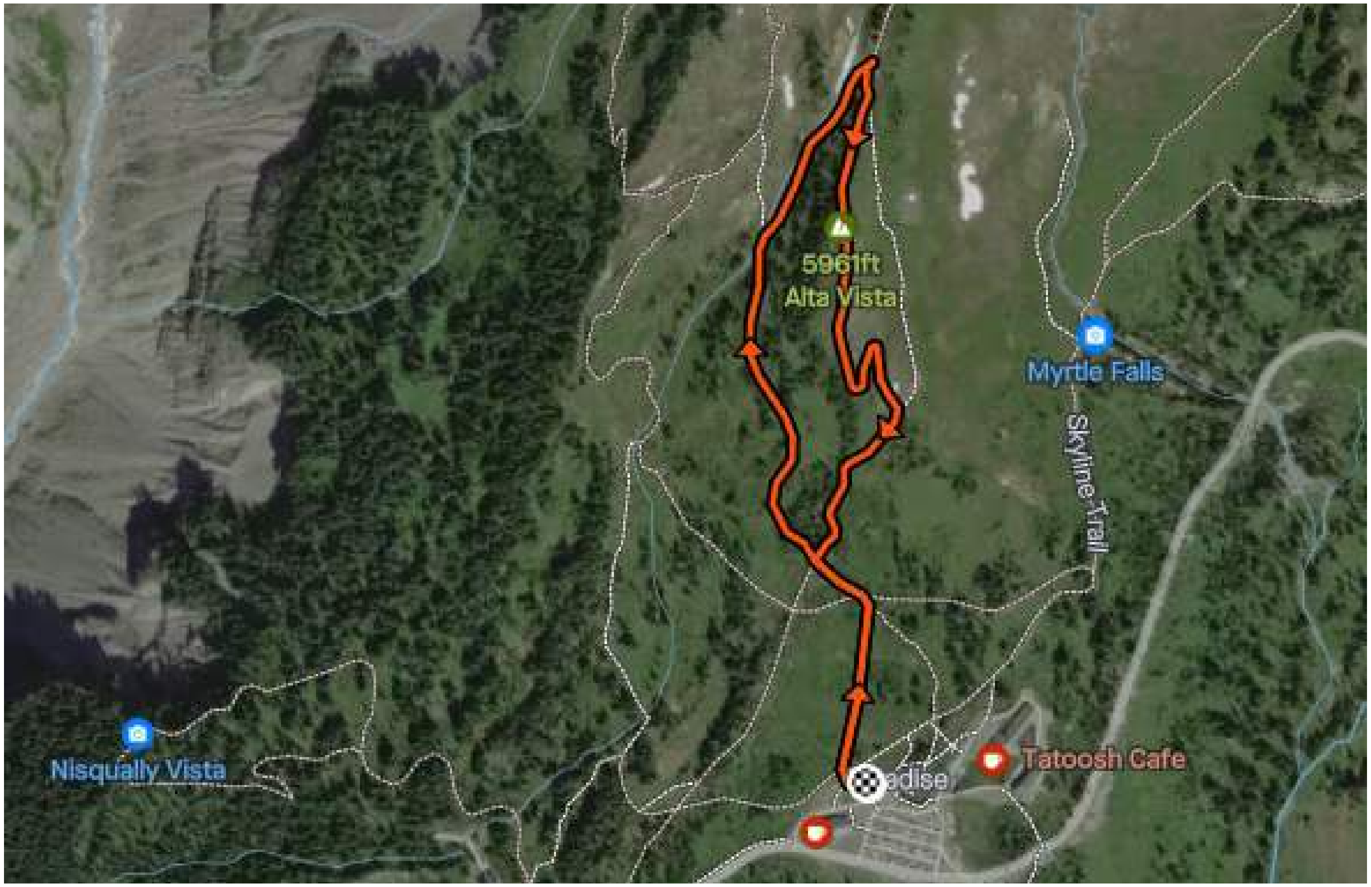
Elevation: 600 feet

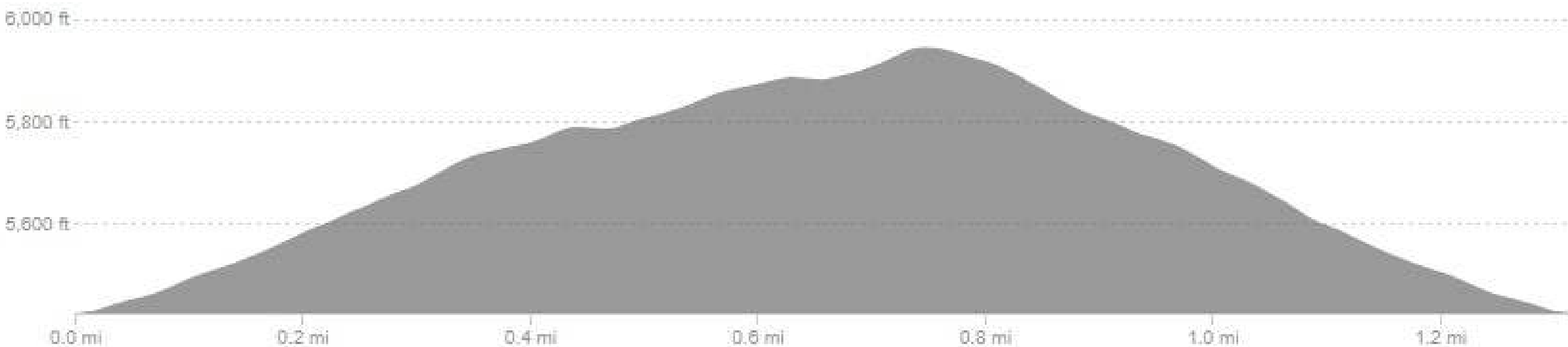
Estimated Hike Time: 45 mins – 1 hour

The hike from Paradise to Alta Vista (5.5 miles roundtrip with 1,400 feet elevation gain) rewards hikers with stunning wildflower meadows and panoramic views of Mount Rainier's snowy volcanic peak.

Setting out from the Paradise complex, the trail passes through subalpine forest with spectacular views of the Tatoosh Range to the south. Ascending via long switchbacks, the trees thin to reveal the expansive glacier-carved basins surrounding Mount Rainier's summit.

The trail traverses avalanche slopes dotted with tenacious trees and crosses burbling Edith Creek over a rustic log bridge. After a steady uphill climb, the path crests a rise unveiling 360-degree mountain views from the rocky overlooks at Alta Vista. Looking north over the Paradise meadows, the imposing volcanic cone of Mount Rainier towers above its surrounding ridges and glacial valleys.


5961ft
Alta Vista
Myrtle Falls
Skyline Trail
Nisqually Vista
Tatoosh Cafe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1.2 mi

Moraine Trail

Challenge: Moderate

Distance: 2.5 miles

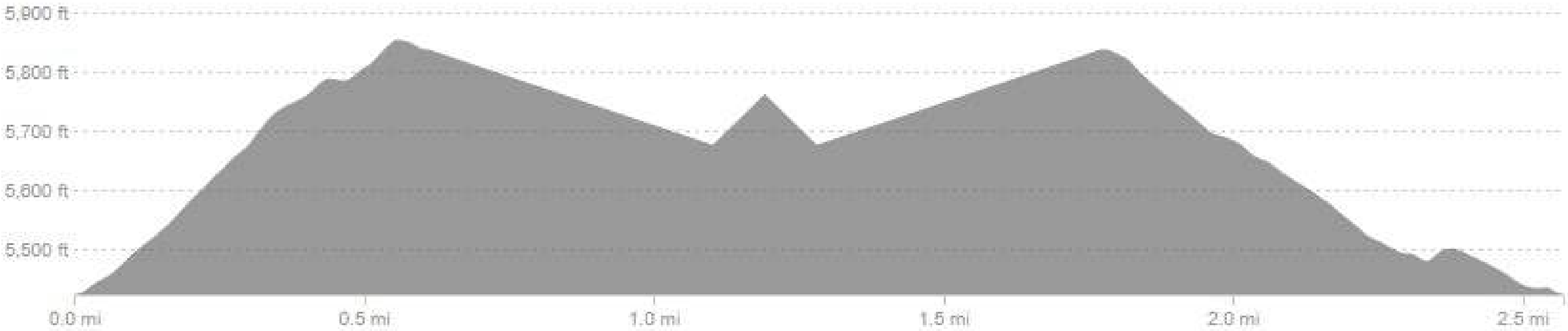
Elevation: 700 feet

Estimated Hike Time: 1-2 hours

The hike from Paradise to the end of the Moraine Trail follows the edge of a glacial moraine, providing stunning views of the retreating Nisqually Glacier.

The trail ends at the left lateral moraine that was created during the Little Ice Age and offers a close-up view of the terminal area of the Nisqually Glacier. The ice caves in this area, once a favorite destination of glacier aficionados, are no longer safe and have been closed.


Skyline Trail
Rainier
Golden Gate Falls
5961ft
Alta Vista
Myrtle Falls
Valley Rd
Rd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2.5 mi

Moraine and Vistas

Challenge: Strenuous

Distance: 3.7 miles

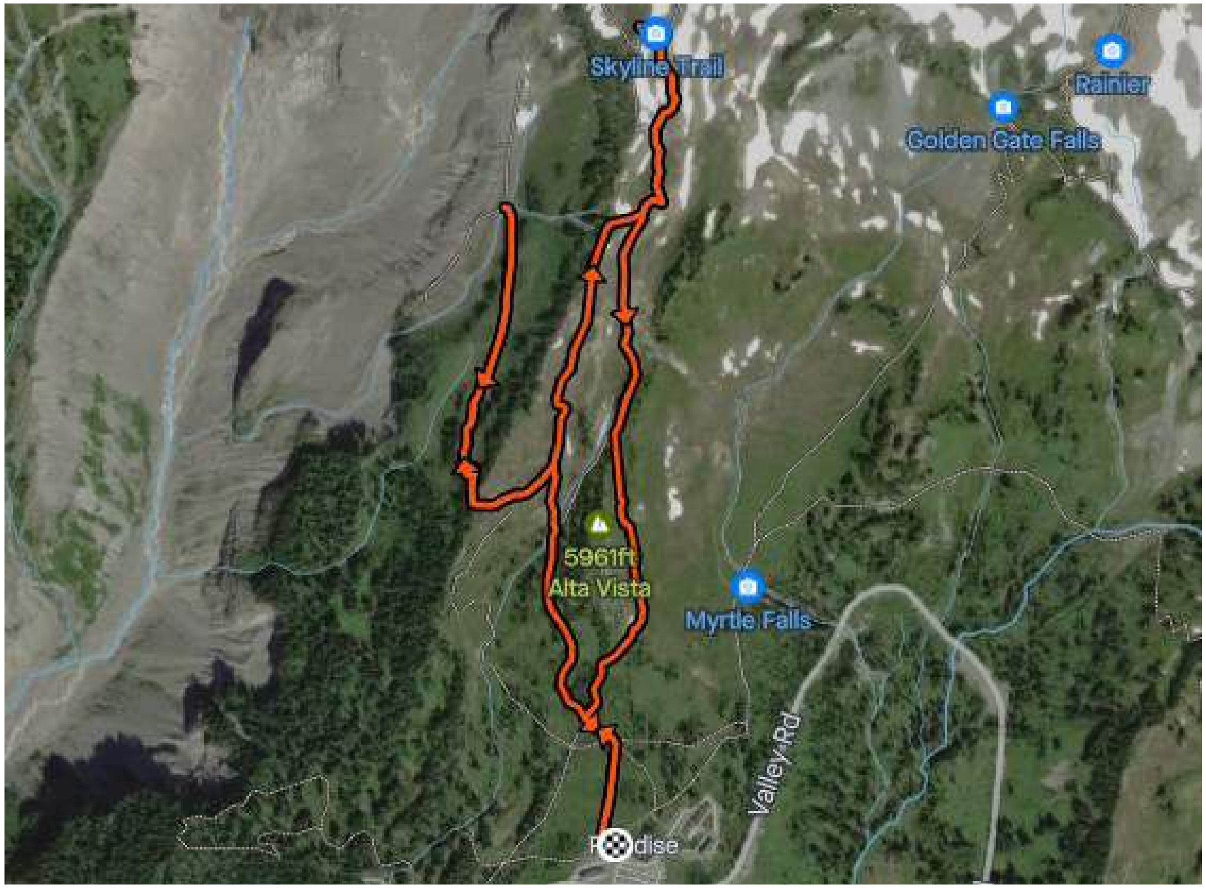
Elevation: 1,200 feet

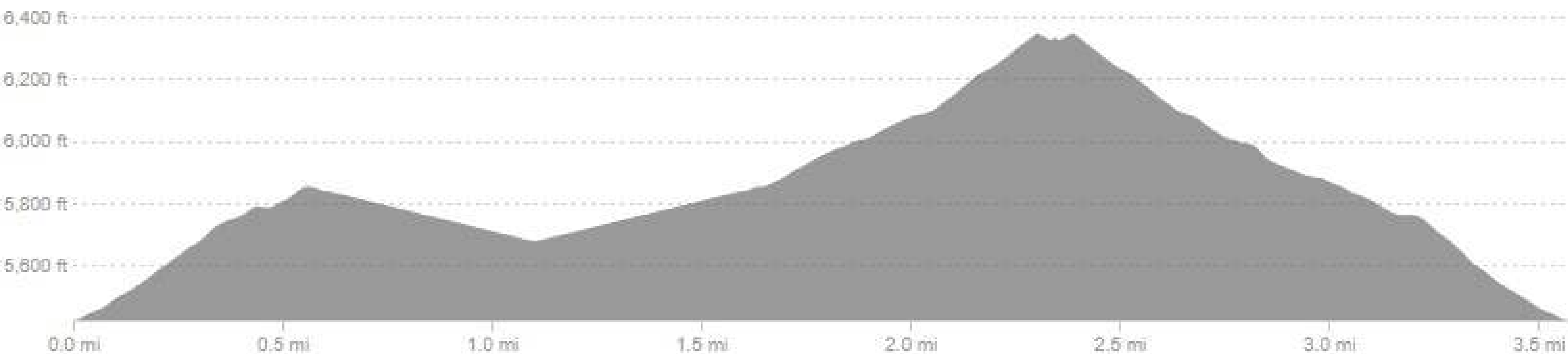
Estimated Hike Time: 1.5-2 hours

This strenuous hike from Paradise begins by hiking up to the Moraine Trail and following it as far as the lateral moraine that flanks the Nisqually River Valley, downslope of the glacial front. We will not hike the entire moraine trail (that's another hike – see Moraine Trail hike). We will turn around at the moraine and then hike up to Glacier Vista, where the trail overlooks the valley carved out by the Nisqually Glacier.

From this lofty vantage, the full expanse of the Nisqually Glacier unfolds, bounded by the towering mass of Mount Rainier. After taking in the views, the trail descends back into mountain hemlock forest toward Paradise. Stopping at the Alta Vista lookout reveals a 360-degree panorama of Mount Rainier, Paradise, and the Tatoosh Range to the south.

The hike ends with a return descent through wildflower meadows back to the Paradise complex, completing a strenuous but unforgettable alpine loop showcasing glaciers, iconic vistas, and the unique beauty of Mount Rainier National Park.


Skyline Trail
Rainier
Golden Gate Falls
5961ft
Alta Vista
Myrtle Falls
Valley Rd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3.5 mi

Panorama Point

Challenge: Strenuous

Distance: 4.0 miles

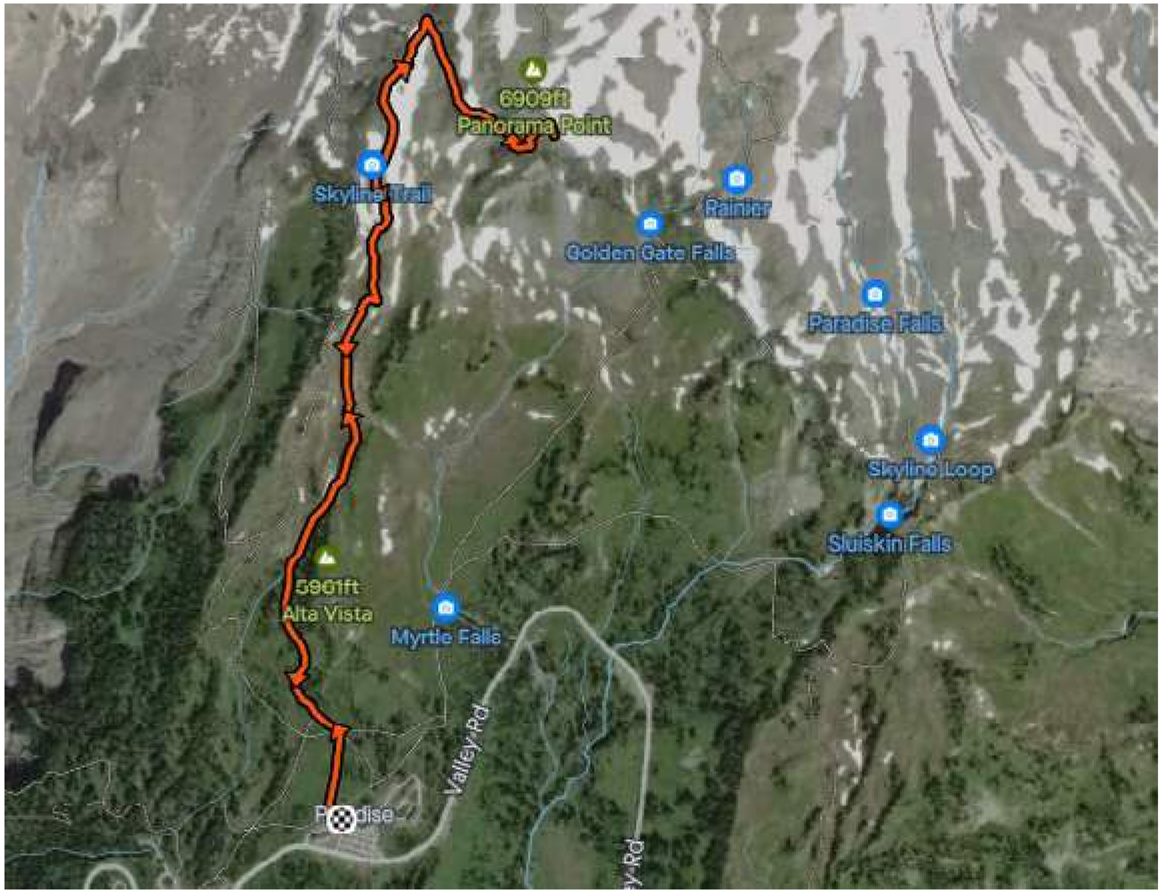
Elevation: 1,450 feet

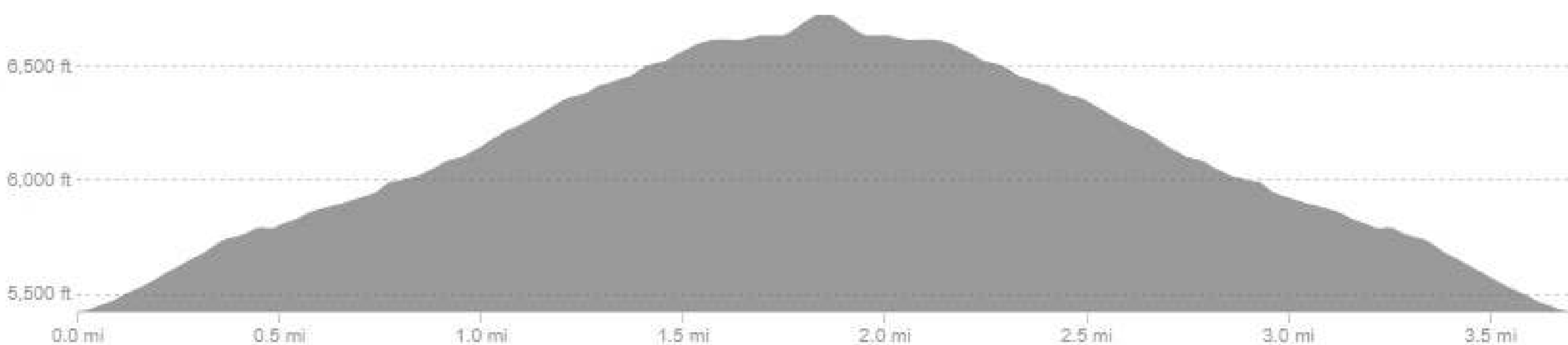
Estimated Hike Time: 1.5-2.5 hours

The hike from Paradise up to Panorama Point offers gorgeous subalpine scenery and sweeping views of Mount Rainier and the surrounding ranges.

The path switchbacks up past Alta Vista and Glacier Vista, through subalpine meadows where Mount Rainier lilies bloom in July amidst craggy outcroppings. Looking south, the Tatoosh Range is in view, and on a clear day you may see other Cascades stratovolcanoes to the south, the nearest being Mt Adams and Mt St Helens.

As you near Panorama Point, the forest opens up, unveiling panoramic vistas across the glaciated basins surrounding Mount Rainier's icy summit. Views of the Nisqually Glacier are abundant as you pass by Glacier Vista on the way up to Panorama Point. From this breathtaking overlook, Mount Rainier towers high above the surrounding landscape and provides a fantastic view of the Cascade Range to the south.


6909ft
Panorama Point
Skyline Trail
Rainier
Golden Gate Falls
Paradise Falls
Skyline Loop
Sluiskin Falls
5961ft
Alta Vista
Myrtle Falls
Valley Rd


6,500 ft
6,000 ft
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0.0 mi
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3.5 mi

Golden Gate to Skyline

Challenge: Strenuous

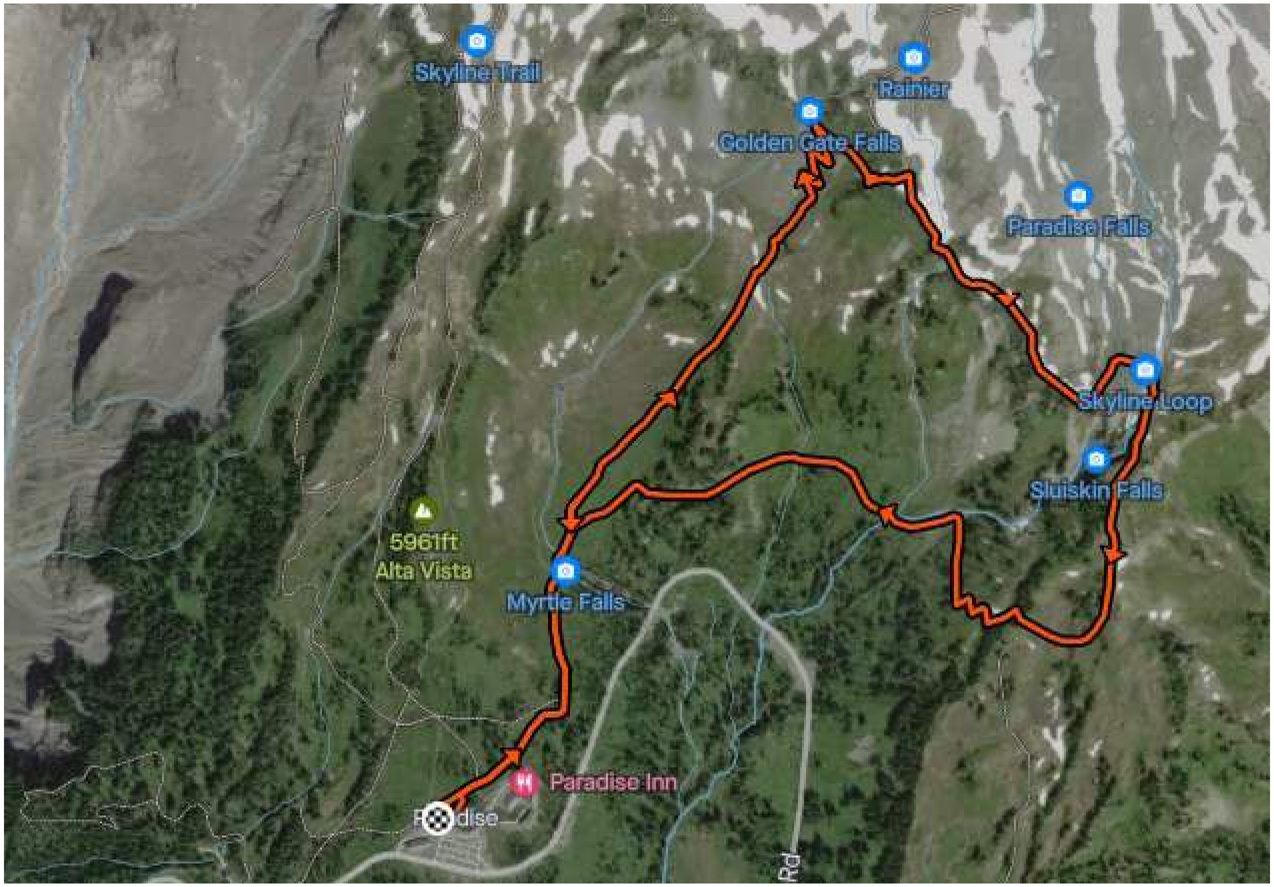
Distance: 3.9 miles

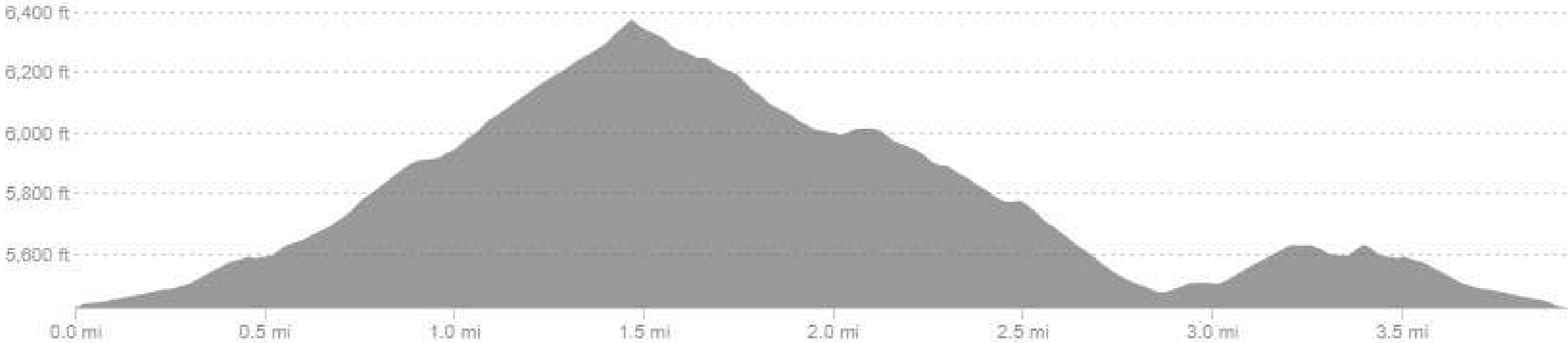
Elevation: 1,150 feet

Estimated Hike Time: 1.5 hours – 2 hours

This scenic loop hike features grand views and waterfalls! The hike begins at the Paradise complex, ascending through wildflower meadows on the Skyline Trail with panoramic views of Mount Rainier's snowy summit.

At the high point of the Skyline Loop, the trail passes beneath meadows dotted with rainbow-colored mountain heather before steeply switchbacking down into forest. Soon the rush of plunging waters leads to an overlook of billowing Suiskin Falls. Continuing on the Skyline Loop, Golden Gate Falls comes into view, a long cascading ribbon of water spilling down a mossy cliff into fern-filled forests below. After taking in both waterfalls, the trail climbs out of the valleys, crossing Edith Creek on log bridges. The loop closes by winding down to the top of feathery, two-tiered Myrtle Falls, surrounded by towering fir and cedar trees. From Myrtle Falls, it is an easy half mile walk back down to Paradise.


Skyline Trail
Rainier
Golden Gate Falls
Paradise Falls
Skyline Loop
Sluiskin Falls
5961ft
Alta Vista
Myrtle Falls
Paradise Inn
Rd


6,400 ft
6,200 ft
6,000 ft
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3.0 mi
3.5 mi

SR 7 SPIDER EXCAVATOR DEMONSTRATION

The WSDOT Geotechnical Office conducted an emergency response on April 10, 2023, following a rockfall event that occurred on SR 7, in the vicinity of MP 23.7. The rockfall event was reported by the Washington State Patrol around 1:30 AM on Monday morning and resulted in a 13-hour highway closure. Rockfall debris was cleared from the roadway and the catchment area, but no upslope mitigation was conducted, until now!

This rock slope is located on the east side of Alder Canyon, mid-way up a slope that extends from the Nisqually River up to the top of an adjacent ridge. The unstable highway cut is about 150 feet long and approximately 50 feet high with an overall slope orientation of 70 degrees. The brow of the highway cut is oversteepened.

The rock mass consists of Miocene-Oligocene aged intrusive andesite deposits overlain by colluvium and saprolite. The formation has persistent joints with orientations dipping adversely towards the highway forming planar and wedge features.

This slope was previously scaled in the summer of 2019. After the slope scaling was complete, a concrete barrier was placed along the edge of pavement to contain the smaller rockfall that continued to ravel from the slope. The ditch at this location is less than 2 feet wide and is unable to contain larger rockfall.

We will observe a demonstration of the capabilities of a modern walking or “spider” excavator. The spider excavator will perform limited access work along the top of an existing highway cut slope on SR 7, between La Grande and Alder. The demonstration will begin with the spider excavator accessing the slope at a location to the south of the cut. The spider excavator will position itself on the backslope above the highway cut and remove overhanging and oversteepened residual soil and reshape the top of the slope.

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