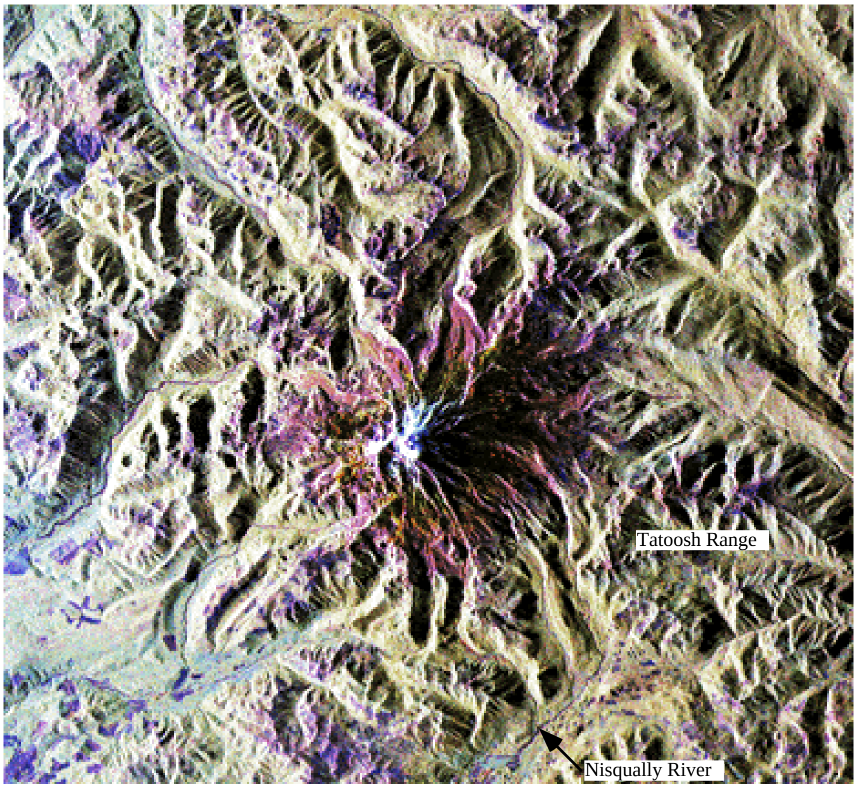
Field Trip Guide to Mt. Rainier
Geology and Art
Fall, 2004

This field trip guide contains two parts, a review of the geologic history of Mt. Rainier and the present geologic hazards associated. The geologic history section is written in a very technical manner and there may be several terms that you are not familiar with yet, but read through it. The geologic history and hazards will be clarified in the field.



This is a radar image (SIR-C) of the Mt. Rainier region acquired from the space shuttle Endeavour on 10/1/94. This image can be found in false color on the www at : www.uni-sb.de/philfak/fb6/fr66/tpw/rem_sens/radar/mtrainie.gif

Geologic History

Volcanism has dominated Cascade Range for the past 40 million years and eruptions continue to this day, a product of subduction of the Pacific Plate beneath the North American continental plate (Vance and Naeser, 1977; McBirney and others, 1974; Hammond and others, 1977; Duncan and Kulm, 1989; Evart and Swanson, 1994). The rocks exposed in this region can be divided into the following four groups:

(1) pre-Tertiary units,
(2) Western Cascade volcanic and sedimentary strata,
(3) lava flows of the Miocene Columbia River Basalt group and associated sedimentary and volcanic rocks, and
(4) Late Cenozoic volcanics of the High Cascades

Mt. Rainier National Park is dominated by groups (2) and (4), Western Cascade volcanic and sedimentary strata and Late Cenozoic volcanics of the High Cascades.

The continental crust below the arc of volcanoes in the southern Washington Cascades is complex and poorly understood but appears to consist of complex accretionary structures formed during Late Mesozoic and Early Tertiary plate convergence between an oceanic plate to the west and the North American continental crust (Stanley et al., 1990). Gravity and aeromagnetic data suggests that oceanic basement (Siletzia terrane) extends at shallow depths beneath the volcanic arc as far east as Mount St. Helens (Finn, 1990).

During the Middle Eocene (55 to 43 Ma) rivers drained a granitic highland to the east and northeast, they flowed westward across a subdued landscape and deposited sediment into two large marine basins, creating the Cowlitz Formation and Puget Group (a group is a number of associated formations). Sediments were deposited over the basaltic Crescent Terrane during the later part of this interval. Clastic sediments and coal were deposited in flood plains, swamps, deltas and coastal lagoons (Buckovic, 1979; Armentrout and Suek, 1985; Vance et al., 1987; Heller et al., 1987). These Eocene coal deposits have been exploited all along the western Cascade foothills and towns such as Black Diamond, Carbonado, and Centralia grew up around the coal mines. Eastern correlative fluvial and lacustrine units include the Naches, Roslyn, and Chumstick Formations (Tabor et al., 1984; Vance et al., 1987; Walsh et al., 1987). A volcanic arc (Challis volcanics) was active several hundred kilometers to the east in eastern Washington and Idaho, later it migrated westward (Pringle, 1993).

In the Late Eocene (42 to 36 Ma) volcanic activity initiated in the Cascade region. The westward relocation of the volcanic arc may have been a consequence of the accretion of the Crescent Terrane (now the Washington Coastal Range and Olympic Mountains.) and the development of a new subduction zone further to the west or, more likely, a shift in the tectonic regime replaced a diffusely distributed extensional magmatic arc (of the Challis episode) with a more focused compressional arc (Heller et al., 1987; Evarts and Swanson, 1994). Throughout most of the western Washington these isolated volcanoes produced silica-rich eruptive products including rhyolites and pyroclastics but to the west, in the present location of Mount St. Helens, shield volcanoes erupted basaltic and andesitic lavas that became interbedded with fluvial deposits (Northcraft Fm.) (Gard 1968; Vine, 1969; Phillips et al., 1989; Pringle, 1993). The Rainier region was part of a broad, low-lying coastal plain that extended along the site of the present day Cascades. Much of this lowland was submerged beneath large lakes or embayments of the sea (Fiske and others, 1964).

The middle Tertiary volcanic rocks (Western Cascade Group from the lithologically similar Western Cascade volcanic rocks of Oregon) are deformed, intruded, hydrothermally altered and metamorphosed regionally to zeolite facies (Peck and others, 1964; Grant, 1969; Wise, 1961; Fiske and others, 1963; Hartman, 1973). The rocks are calc-alkaline and consist of pyroxene andesite, basalt, rhyodacite, dacite and rhyolite in the form of lava flows, laharic breccias, ash-flow tuffs and volcanic rocks. The volcanic sources of these rocks (stratovolcanoes) are not well defined (Hammond and others, 1977). In the Mount Rainier-Tieton River region these are represented by the Ohanapecosh (Late Eocene - Early Oligocene), Stevens Ridge (Oligocene - Early Miocene) and Fifes Peak (Early Miocene) Formations. All of these units are exposed in Mt. Rainier National Park.

The Ohanapecosh Formation is the oldest formation exposed in Mt. Rainier National Park. This unit is widely exposed in southern Washington between the Columbia River Gorge and Snoqualmie Pass and represents the first volcanic expression of the Tertiary Western Cascade magmatic arc in southern Washington and marks the end of the Eocene tectonic regime in the Pacific Northwest (Vance, 1982). The facies have been interpreted as debris flows and turbidites generated by subaqueous eruptions (Fiske and others, 1963) but evidence, such as the lack of pillow basalts, accumulations of pumice and accretionary lapilli, carbonized wood and nonmarine vertebrate fossils suggest a terrestrial source, if not subaerial deposition (Vance and others, 1987; Fiske and others, 1963). Vents of the volcanoes which produced the Ohanapecosh Fm. are found throughout the park region. The Ohanapecosh Fm. is suggested to have been folded, regionally altered (zeolite facies), uplifted, and deeply eroded prior to the deposition of the Stevens Ridge rocks (Fiske and others, 1963) but recent mapping cast doubts on the existence of the unconformity at the top of the Ohanapecosh (Smith, 1993; Evarts et al., 1993). Fission-track data indicate that the Ohanapecosh Fm. spans the age range of at least 36 to 28 Ma (Late Eocene - Early Oligocene).

The Fifes Peak Formation overlays the Ohanapecosh Formation in the White Pass-Tieton River region but an intermediate unit, the Stevens Ridge Formation, has been identified in the park to the north (Fiske and others, 1963). The Stevens Ridge Fm. attains a thickness of up to 1,000 m and consists mainly of massive welded pyroclastic flows. The "ash" is now devitrified and altered. Age data and lateral correlations indicate that the Stevens Ridge unit differs significantly in stratigraphic position, lithology, and age with the type Stevens Ridge and, thus, can not be physically correlated. The Stevens Ridge Fm., which is a silicic pyroclastic unit, is probably laterally discontinuous and lithologically equivalent to many units within the Fifes Peak Fm. and not unique to a single stratigraphic interval in the Washington Cascades outside of the park region (Vance and others, 1987). The Stevens Ridge Fm. was deposited during the Oligocene or Miocene (Fiske and others, 1964).

The long interval of subsidence which allowed the Ohanapecosh Fm. to accumulate ended by 27 Ma with an episode of folding, uplift and erosion. The Fifes Peak activity was initiated by violent, large-volume eruptions of silicic pyroclastics from a number of vents, at least one of which was a major caldera (Fiske and others, 1963; Vance and others, 1987). Fifes Peak volcanism lasted from 25.5 to at least 22 Ma (late Oligocene), ceasing prior to extrusion of the Columbia River Basalts (16 Ma). The Fifes Peak Fm. consists of lava flows, subordinate mudflows, and minor quantities of tuffaceous clastic rocks (Fiske and others, 1963). The lavas are predominantly olivine basalts and basaltic andesite, but they also include a little rhyolite (Fiske and others, 1963). The upper part of this unit is generally eroded in the Mt. Rainier region but dikes that fed the eruptions are common. Sills of the Fife Peak Fm. occur commonly along the contact between the Ohanapecosh and Stevens Ridge Fms.

There was a gentle deformational (folding, uplift and erosion) event prior to the emplacement of the Late Miocene Tatoosh Pluton. This created gentle northwest-trending folds. The folding occurred largely between 21 and 12 Ma (Vance et al., 1987). The emplacement of the pluton was accompanied by the injection of a variety of satellitic stocks, sills, and dikes. In several places magma reached the surface initiating violent eruptions (The Palisades). The Tatoosh Range represents the eroded roots of a volcanic complex (Fiske et al., 1963).

In the Middle Miocene (14 to 3 Ma) there was a decrease in the amount of volcanism in the Cascades, or evidence of the magmatism may have been subsequently eroded. During this interval the region was being actively uplifted, gentle folding may have continued into the late Miocene (10 Ma) (Pringle, 1993). Several interesting events occurred in the Middle Miocene:

- (a) the decline of volcanic activity
- (b) change in petrology of the magmatic arc
- (c) shift from regional subsidence to uplift of the Cascade Range
- (d) folding of Tertiary strata
- (e) eruption of the Columbia River Basalts

These events could be linked to a change in the tectonic regime of the Pacific Northwest at about 17 Ma, perhaps driven by initial activity of the Yellowstone plume (Brandon and Goles, 1988; Pringle et al., 1994).

Erosion of the unroofed Tatoosh pluton occurred prior to the development of the Rainier (Ta-co-man: "snow-covered mountain") volcano, probably in early Pleistocene time (Fiske and others, 1963). The first evidence of proto-Mount Rainier, referred to as the Lily Creek Fm., consists of a thick sequence of volcaniclastic debris that has been dated between 2.9 and 0.84 Ma (Easterbrook et al., 1981; Smith, 1987, Pringle et al., 1994). Early inter-canyon lava flows (pyroxene andesite) leveled the topography, filling the dissected surface of the Tertiary basement and produced a base for the present volcano (Rampart Ridge). Despite rapid erosion by streams and glaciers, the lava, mudflows, and thin pyroclastic deposits built a cone that was about 300 m higher than the present volcano. The summit either collapsed or was eroded and a subsequent small cone formed which culminates in Columbia Crest along the SE edge of the old summit rim. During the growth of this cone a pumice sheet was deposited, the age of the youngest deposit (600 - 500 years) records the last activity of the mountain (Fiske and others, 1963; Mullineaux, 1974). An estimated 140 km^3 of lava has been erupted from Mount Rainier in the past 1 my (Sherrod and Smith, 1989).

Geologic Hazards

Rainier has the potential to be the most dangerous volcano in the Cascade Range because of the large (and increasing) population living along its lowland drainage. More than 100,000 people live on young volcanic mudflows that have flowed down the various drainage systems, away from the volcano, in the past 10,000 years. Because of the tremendous hazards associated with this volcano, Mt. Rainier was designated as a Decade Volcano study area by the National Research Council in 1994. The mountain's high relief and volume of ice and snow on the cone ($4.4x10^9$ m^3) have the potential to generate enormous lahars and debris flow (especially during eruption) (Driedger and Kennard, 1986; Pringle et al., 1994). Six or seven such flows have occurred since the Mount Mazama ash of 6,845 ybp including the Osceola, Round Pass, and Electon Mudflows (Bacon, 1983). Mudflow hazard is enhanced by the mountains steep, glacially carved slopes, hydrothermally altered core, active hydrothermal system, bedding dipping downslope, and frequency of tectonic and magmatic pulses. Recent efforts have been made to map hydrothermally altered materials using remotely sensed data and field mapping (Crowley and Zimbelman, 1997).

Postglacial deposits at Mt. Rainier are dominated by lahars (more than 60 have been identified) and they have been interpreted as eruption induced, particularly the Paradise Lahar and Osceola Mudflow (Crandell, 1971; Dragovich et al., in press). The 5,600 ka Osceola Mudflow had a volume of more than 4 km^3, inundating at least 485 km^2, and flowing more than 110 km to the Puget Sound. The Electron Mudflow has been dated at 530 ybp and appears to have been induced by a failure of part of the western slope and incorporated 0.26km^3 of material (Scott et al., 1992). The Kautz lahar of 1947 moved 0.4 km^3 of debris several miles downstream and redeposited it in a huge fan that temporarily blocked the Nisqually River.

Glacial outburst floods are frequent events. Floods from South Tahoma Glacier have repeatedly scoured Tahoma Creek during the past 30 years. These floods are usually associated with seasonally extremely weather (warm or wet conditions) (Walder and Driedger, 1994). Similar events have occurred in Kautz Creek and the Nisqually River (Driedger and Fountain, 1989).

The hydrothermal system on Mount Rainier suggests a substantial heat emission along a narrow, central zone which creates snow-free areas at the summit crater (Moxham et al., 1965; Frank, 1985). The hydrothermal system alters (argillization and silicification) and weakens the rock. Four Quaternary hydrothermal systems have been identified on Mt. Rainier:

(a) Summit craters (temperatures 76° - 86° C)
(b) Upper flank (max. temperature 60° C)
(c) Lower flank (max. temperature 9° - 24° C)
(d) Longmire Springs (max. temperature 25° C)

All sets of springs could be derived from similar acidic sulfate-chlorite waters that originate in a central hydrothermal system. Cooling of the water during flow away from the system toward lower elevation could be caused by dilution with meteoric water (Pringle et al., 1994).

Approximately 30 small earthquakes occur under Mt. Rainier annually, making it the most seismically active volcano in the Cascade Range after Mt. St. Helens (Malone and Swanson, 1986). These events may trigger slope failure and lahars. An important north-northwest-trending zone of seismicity is the Western Rainier seismic zone (National Resource Council, 1994; Goter, 1994).

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Geologic Time Scale

Eon	Era	Period	Epoch	Time (millions of years)
Phanerozoic	Cenozoic	Quaternary	Holocene	0 - 0.01
			Pleistocene	0.01 - 1.8
		Tertiary	Pliocene	1.8 - 5.3
			Miocene	5.3 - 23.8
			Oligocene	23.8 – 33.7
			Eocene	33.7 – 54.8
			Paleocene	54.8 - 65
	Mesozoic	Cretaceous		65 - 144
		Jurassic		144 - 206
		Triassic		206 - 248
	Paleozoic	Permian		248 - 290
		Pennsylvanian		290 - 323
		Mississippian		323 - 354
		Devonian		354 - 417
		Silurian		417 - 443
		Ordovician		443 - 490
		Cambrian		490 - 542
Proterozoic				543 - 2500
Archean				2500 - 3800
Hadean				3800 - 4500

Time Scale from Geological Society of America (1999) http://www.geosociety.org/science/timescale/timescl.pdf