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Field-Trip Guide to Subaqueous Volcaniclastic Facies in the Ancestral Cascades Arc in Southern Washington State—The Ohanapecosh Formation and Wildcat Creek Beds

Scientific Investigations Report 2017–5022–B

U.S. Department of the Interior
U.S. Geological Survey

COVER PHOTO
Photograph of the Ohanapecosh Formation at Chinook Pass (foreground), intruded by a large sill associated with the Miocene Tatoosh pluton; Mount Rainier, Washington, in the background.

Field-Trip Guide to Subaqueous Volcaniclastic Facies in the Ancestral Cascades Arc in Southern Washington State—The Ohanapecosh Formation and Wildcat Creek Beds

By Martin Jutzeler and Jocelyn McPhie

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Preface

The North American Cordillera is home to a greater diversity of volcanic provinces than any comparably sized region in the world. The interplay between changing plate-margin interactions, tectonic complexity, intra-crustal magma differentiation, and mantle melting have resulted in a wealth of volcanic landscapes. Field trips in this series visit many of these landscapes, including (1) active subduction-related arc volcanoes in the Cascade Range; (2) flood basalts of the Columbia Plateau; (3) bimodal volcanism of the Snake River Plain-Yellowstone volcanic system; (4) some of the world's largest known ignimbrites from southern Utah, central Colorado, and northern Nevada; (5) extension-related volcanism in the Rio Grande Rift and Basin and Range Province; and (6) the spectacular eastern Sierra Nevada featuring Long Valley Caldera and the iconic Bishop Tuff. Some of the field trips focus on volcanic eruptive and emplacement processes, calling attention to the fact that the western United States provides opportunities to examine a wide range of volcanological phenomena at many scales.

The 2017 Scientific Assembly of the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) in Portland, Oregon, marks the first time that the U.S. volcanological community has hosted this quadrennial meeting since 1989, when it was held in Santa Fe, New Mexico. The 1989 field-trip guides are still widely used by students and professionals alike. This new set of field guides is similarly a legacy collection that summarizes decades of advances in our understanding of magmatic and tectonic processes of volcanic western North America.

The field of volcanology has flourished since the 1989 IAVCEI meeting, and it has profited from detailed field investigations coupled with emerging new analytical methods. Mapping has been enhanced by plentiful major- and trace-element whole-rock and mineral data, technical advances in radiometric dating and collection of isotopic data, GPS (Global Positioning System) advances, and the availability of lidar (light detection and ranging) imagery. Spectacularly effective microbeam instruments, geodetic and geophysical data collection and processing, paleomagnetic determinations, and modeling capabilities have combined with mapping to provide new information and insights over the past 30 years. The collective works of the international community have made it possible to prepare wholly new guides to areas across the western United States. These comprehensive field guides are available, in large part, because of enormous contributions from many experienced geologists who have devoted entire careers to their field areas. Early career scientists are carrying forward and refining their foundational work with impressive results.

Our hope is that future generations of scientists as well as the general public will use these field guides as introductions to these fascinating areas and will be enticed toward further exploration and field-based research.

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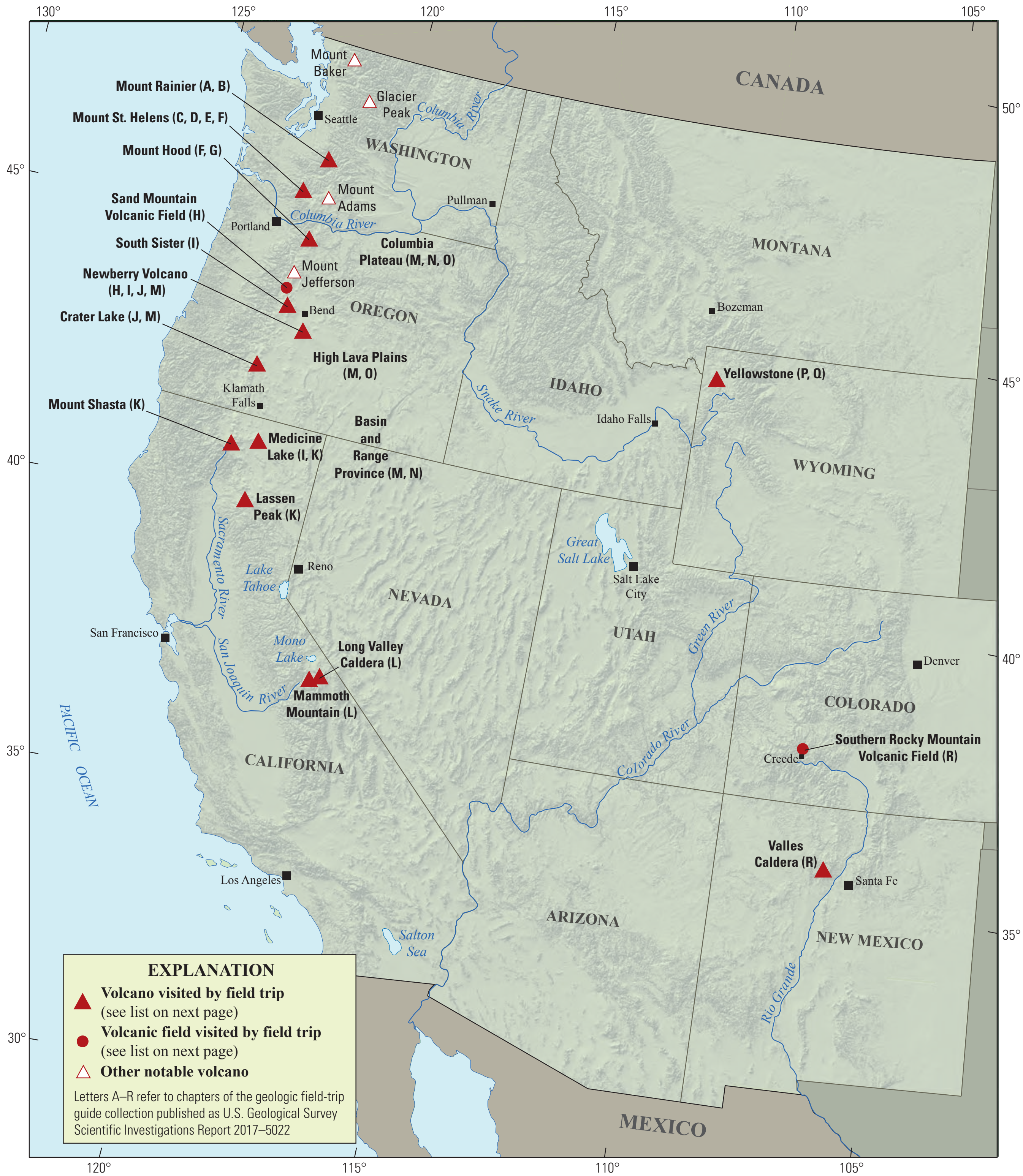
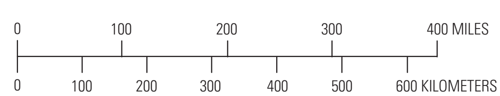
Field-trip committee, IAVCEI 2017



Map of the western United States showing volcanoes and volcanic fields visited by geologic field trips scheduled in conjunction with the 2017 meeting of the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) in Portland, Oregon, and available as chapters in U.S. Geological Survey Scientific Investigations Report 2017–5022.



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C	Field-Trip Guide for Exploring Pyroclastic Density Current Deposits from the May 18, 1980, Eruption of Mount St. Helens, Washington
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E	Field-Trip Guide to Mount St. Helens, Washington—Recent and Ancient Volcaniclastic Processes and Deposits
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Q	Field-Trip Guide to the Petrology of Quaternary Volcanism on the Yellowstone Plateau, Idaho and Wyoming
R	Field-Trip Guide to Continental Arc to Rift Volcanism of the Southern Rocky Mountains—Southern Rocky Mountain, Taos Plateau, and Jemez Volcanic Fields of Southern Colorado and Northern New Mexico

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Field-Trip Guide to Subaqueous Volcaniclastic Facies in the Ancestral Cascades Arc in Southern Washington State—The Ohanapecosh Formation and Wildcat Creek Beds

By Martin Jutzeler[1] and Jocelyn McPhie[1]

Abstract

Partly situated in the idyllic Mount Rainier National Park, this field trip visits exceptional examples of Oligocene subaqueous volcaniclastic successions in continental basins adjacent to the Ancestral Cascades arc. The >800-m-thick Ohanapecosh Formation (32–26 Ma) and the >300-m-thick Wildcat Creek (27 Ma) beds record similar sedimentation processes from various volcanic sources. Both show evidence of below-wave-base deposition, and voluminous accumulation of volcaniclastic facies from subaqueous density currents and suspension settling. Eruption-fed facies include deposits from pyroclastic flows that crossed the shoreline, from tephra fallout over water, and from probable Surtseyan eruptions, whereas re-sedimented facies comprise subaqueous density currents and debris flow deposits.

Introduction

This field trip includes study of the Ohanapecosh Formation and the Wildcat Creek beds, two Oligocene volcaniclastic successions in the Ancestral Cascades arc (fig. 1). Situated at the foot of Mount Rainier, a large part of the Ohanapecosh Formation is within the Mount Rainier National Park. This field-trip guide focuses on outcrops along White Pass, Cayuse Pass, and Chinook Pass (fig. 2). The Wildcat Creek beds, at the foot of the Cascades Range, are exposed over road outcrops and on Burnt Mountain (fig. 1).

The main publications on these successions include geologic maps at various scales (Fiske and others, 1964; Swanson, 1978; Schasse, 1987; Schuster, 2005), volcaniclastic facies interpretation (Fiske, 1963; Fiske and others, 1963; Jutzeler and others, 2014), and paleontology assessment (Strganac, 2011).

This trip highlights key examples of below-wave-base volcaniclastic facies in continental basins. The localities of the field trip record subaqueous sedimentation derived from tephra fallout over water, entrance of pyroclastic flows into water, scoria-cone building eruptions in shallow water, and re-sedimentation events. In addition, the successions are cut by multiple intrusions, most of them emplaced after diagenesis. The visited successions attest to extensive Oligocene explosive volcanism in the Ancestral Cascades arc, though with a few notable exceptions, do not include the source volcanoes.

Logistics

This guide was developed for a field trip starting and ending in Portland, Oregon. Accommodation and food supplies can be found at Packwood and Rimrock Lake. There are gas stations at Packwood and Naches. The outcrops of the Ohanapecosh Formation can be accessed in any reasonable weather; fog, intense precipitation, and cold temperatures can occur at any season. On a clear day, the view of Mount Rainier is spectacular from Chinook Pass (part 3); Burnt Mountain (part 2) has wonderful views on several Quaternary volcanoes. The weather on Burnt Mountain and in the Wildcat Creek area (part 2) is typically much drier and warmer than in the Ohanapecosh Valley.

In White Pass and on the road outcrops in the Wildcat Creek area, the traffic can be heavy, and large trucks are common. In Cayuse and Chinook Passes, the roads are narrow and drivers are easily distracted by the scenery. Reflective vests are recommended. *Cayuse and Chinook Passes are within the Mount Rainier National Park and a Scientific Research and Collecting Permit is required for any rock sampling and use of rock hammers* (https://www.nps.gov/mora/learn/nature/research.htm). Access to optional Stop 15 at Sunrise necessitates payment of a National Park fee at the gate (commonly waived if you have a research permit), and long lines at the Park entrance are common.

Geologic Setting

Ancestral Cascades Volcanism

Subduction of the Pacific plate under the North American plate began in the Paleozoic era and is still continuing today

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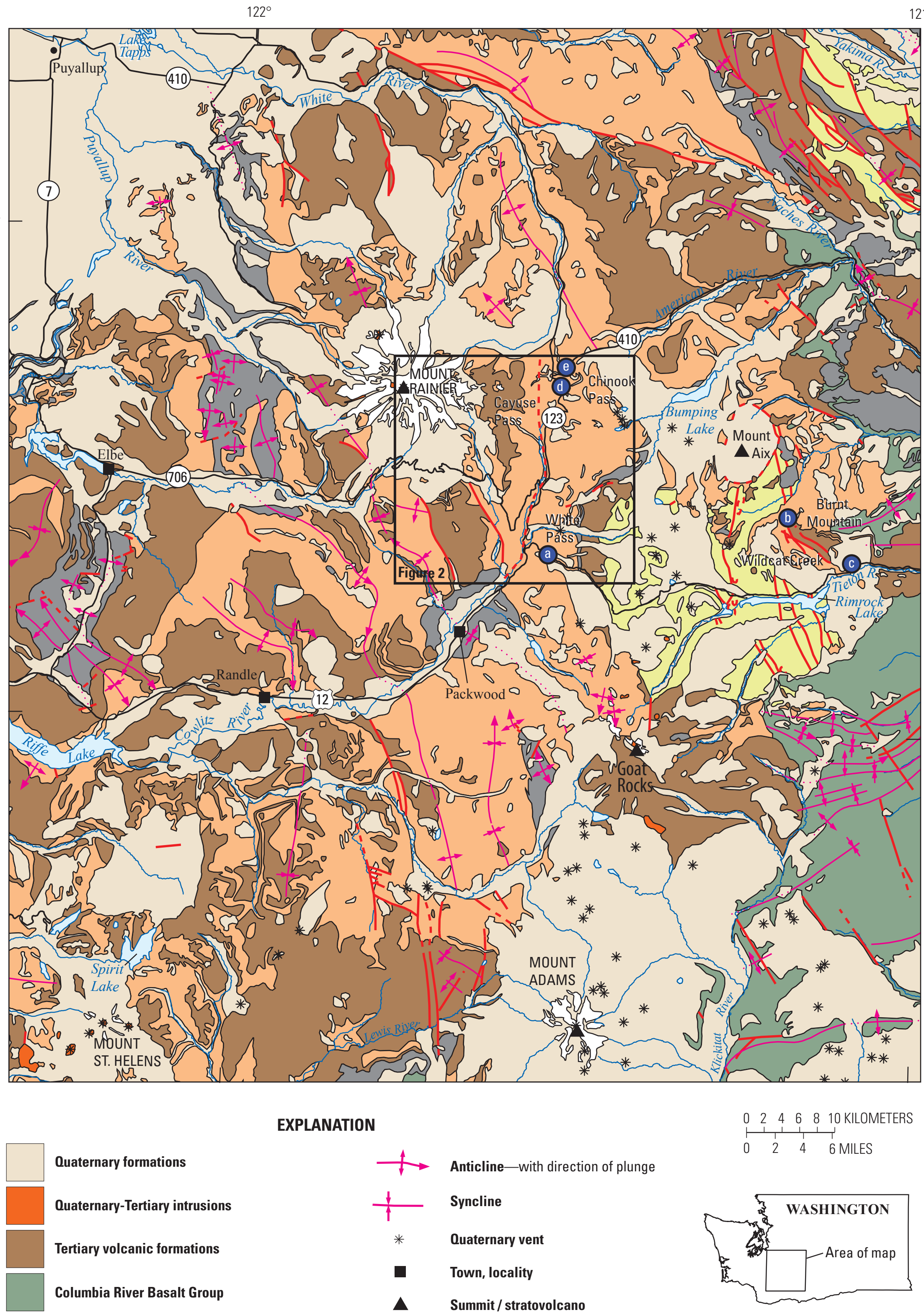


Figure 1. Geologic map of the Mount Rainier area, Washington, modified from Schuster (2005). The Ohanapecosh Formation is part of the Tertiary volcaniclastic rocks, in yellow. Letters a to e (circled) refer to the order in which major areas will be visited during the field trip. Black rectangle shows area of map in figure 2.

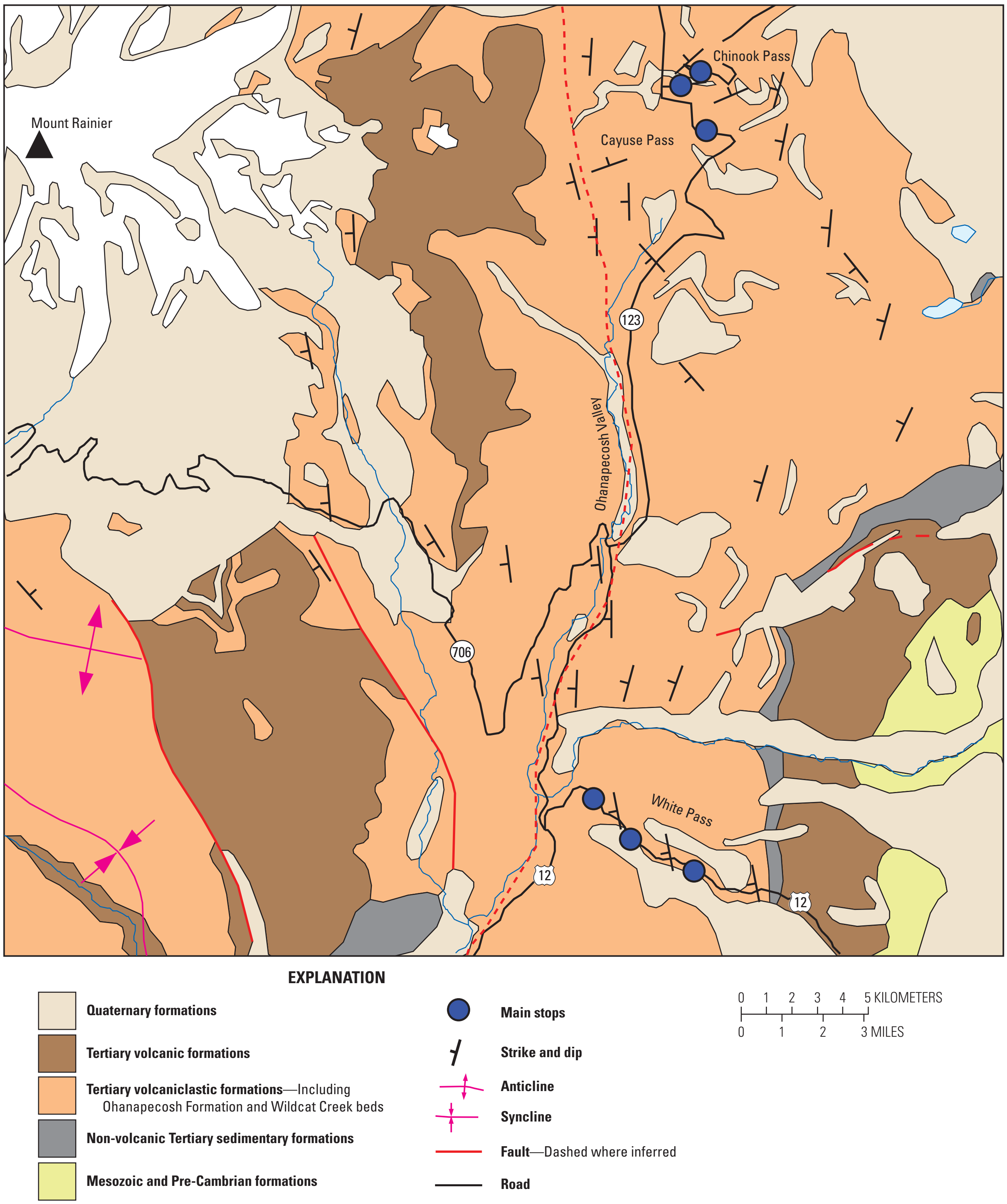


Figure 2. Local geologic map of the Ohanapecosh Formation in the Mount Rainier area, modified from Schuster (2005) and Fiske and others (1964). Location of map is shown in figure 1. Red dots are locations of main stops.

(Dickinson, 2009). During the Cenozoic, the extremely long (>1,250 km) Cascades arc developed on the Paleozoic and Mesozoic continental terranes of western North America. Clockwise rotation of the subducted Pacific plate around a pole situated in southern Washington induced compressional deformation in British Columbia, transpression in Washington, and extension in Oregon (McBirney, 1978; Wells, 1990; Wells and others, 1998; Sonder and Jones, 1999). The Cenozoic history and volcanic products of the Cascades arc have been established through an extended period of research on major geologic units, stratigraphic unconformities, sedimentation within large basins, and paleomagnetism. Uncertainties regarding the early Cenozoic history of southern Washington are partly due to loss of the geologic record by erosion in response to uplift of the northern Cascades (McBirney, 1978; Reiners and others, 2002), and burial under Quaternary volcanoes (Hildreth, 2007).

From the Eocene to the middle Oligocene, regional extension and transtension affected the northwestern part of the North American Continent, in which the Ohanapecosh Formation was deposited (Johnson, 1985; Tabor and others, 2000). In the Puget lowland, southern Washington, the inferred Puget fault is a major north-striking, dextral, transcurrent fault that offset the pre-Tertiary continental basement from Late Cretaceous to Eocene time (Johnson, 1984, 1985; Armstrong and Ward, 1991). The inferred fault coincides with a prominent gravity anomaly and is buried by upper Eocene and younger formations.

To the east of the Puget lowland, vertical middle Cretaceous north- and northwest-striking faults (Straight Creek Fault, Entiat-Leavenworth Fault) formed in response to oblique subduction of the Kula and Farallon plates beneath the North American plate as early as the Late Cretaceous. From 57 to 43 Ma (Cheney and Hayman, 2009), the faults promoted the formation of separate basins (Chuckanut Basin, Puget-Naches Basin, Chiwaukum Graben, and Swauk Basin) that have distinct sedimentary and deformation histories (Johnson, 1984, 1985). The basins (fig. 3) formed in forearc or intra-arc settings with respect to the Cascades arc. They are mainly composed of very thick (as much as >6 km) terrigenous conglomerate and sandstone, commonly of fluviatile origin. These non-marine facies are interbedded with volcaniclastic units and lavas of mostly mafic to intermediate composition. High sediment accumulation rates, extensive unconformities and abrupt changes in facies or bed thickness in these basin successions suggest a tectonically active environment in which subsidence and uplift were rapid, as in strike-slip or pull-apart basins (Johnson, 1984, 1985; Vance and others, 1987; Evans, 2010).

The Ohanapecosh Formation

The Ohanapecosh Formation, in the broad sense (*sensu lato*, per Jutzeler and others, 2014) groups broad volcaniclastic facies that are Eocene-Oligocene in age, and thought to record an early stage of volcanism in the Cascades arc (Fiske, 1963; Jutzeler and others, 2014). The formation covers an extremely wide area between the Snoqualmie area (north), the Columbia Gorge (south to Mount St. Helens and Mount Adams), Mount Rainier and Lake Tapps (west), and the Little Naches River area (east) (Jutzeler, 2012; Jutzeler and others,

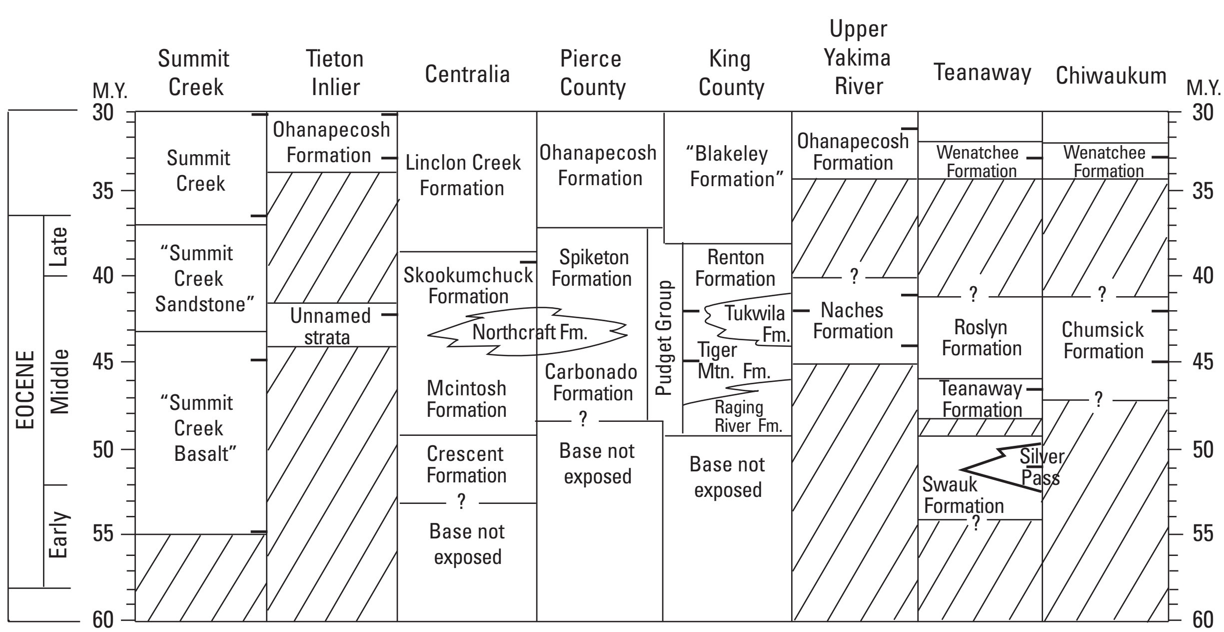


Figure 3. Diagram showing stratigraphy from Vance and others (1987) in the Mount Rainier and Tieton River area, including the broadly defined Ohanapecosh Formation. Relations are based on stratigraphy and U-Pb and fission track ages. Fm, formation.

2014, and references therein). Tabor and others (1984) and Johnson (1985) interpreted this formation to mark the end of the Eocene strike-slip faulting and magmatism of the Cascades arc in southern Washington. The Ohanapecosh Formation, in the strict sense (*sensu stricto*, per Jutzeler and others, 2014), is more than 800 m thick (Jutzeler and others, 2014), exposed across more than 400 km^2 in an area greater than 700 km^2 throughout Mount Rainier National Park and its surroundings, and is the basement upon which Mount Rainier volcano was built (Fiske, 1963; Fiske and others, 1963). Recent U/Pb analyses by Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) of zircons gave a 32–26 Ma age range (Jutzeler and others, 2014).

The contact between the Ohanapecosh Formation and the Puget Group (fig. 3) is conformable and commonly gradational (Fiske, 1963; Vance and others, 1987). In contrast, the contact with the underlying Naches Formation is uncomformable (Johnson, 1985; Vance and others, 1987; Tabor and others, 2000). The middle to late Eocene (~43–37 Ma) Summit Creek sandstone of Vance and others (1987) consists of various sandstone units conformably underlying the Ohanapecosh Formation in the studied area.

In the Mount Rainier National Park area, the Ohanapecosh Formation is overlain by the Oligocene (27–25 Ma) Stevens Ridge member, which is the lower part of the early Miocene-Oligocene Fifes Peak Formation (Fiske and others, 1963; Vance and others, 1987; P.E. Hammond, Portland State University, unpub. data, 2011). This unit is composed of multiple, quartz-bearing, rhyolitic, 5- to >100-m-thick ignimbrites. The Eocene-Miocene formations are covered by thick Quaternary volcaniclastic deposits and lavas. Major volcanoes in and around the studied area are Mount Rainier, Goat Rocks, Mount Adams, Indian Heaven and Mount St. Helens (Hildreth, 2007).

Lithofacies and Depositional Environment of the Ohanapecosh Formation

The >800-m-thick Ohanapecosh Formation records voluminous volcaniclastic sedimentation (Fiske, 1963; Jutzeler and others, 2014). Owing to widespread vegetation cover, well-exposed outcrops mostly are on road cuts and in sub-vertical cliffs. The Ohanapecosh Formation is well indurated and has a secondary mineral assemblage consistent with low-grade regional metamorphism (zeolite facies). All original volcanic glass and most original ferromagnesian and plagioclase phenocrysts have been replaced by secondary minerals. The alteration has been attributed to higher temperature and pressure associated with deep burial and contact metamorphism from intrusions, especially the Tatoosh and Snoqualmie plutons (Fiske, 1963; Tabor and others, 2000).

Most volcaniclastic beds are dominated by angular pumice clasts and fiamme (pumice clasts flattened during diagenesis) of intermediate composition. Very thick to extremely thick (1–50 m) and very thin to thick (0.001–1 m) beds are laterally continuous and have even thickness; erosion surfaces, crossbeds, and other traction structures are almost entirely absent, which strongly suggests a below-wave-base environment of deposition for most of the succession (Fiske, 1963; Jutzeler and others, 2014). Fossils of wood, leaves, and poorly preserved benthic shells (“ostracods, gastropods, and perhaps even Foraminifera” [Fiske and others, 1963]) are present, but not indicative of whether the setting was marine or lacustrine.

However, other interpretations based on crossbeds and small continental input have favored a subaerial environment of deposition, such as a fluviatile and alluvial apron in which lakes were minor, shallow, and temporary (Frizzell and others, 1984; Vance and others, 1987; Swanson, 1996; Swanson and others, 1997; Tabor and others, 2000). Such an environment of deposition was not recognized in the Ohanapecosh Formation, in the strict sense, by Jutzeler and others (2014). Moreover, such facies can be explained as deposition in below-wave-base channels.

Volcanic Influences on the Ohanapecosh Formation

Sections through the Ohanapecosh Formation in the Chinook Pass and Cayuse Pass area (fig. 4) are mostly composed of extremely thick, graded, matrix-supported, pumice-and-fiamme-rich beds that commonly include a coarse basal breccia comprising sub-rounded dense clasts (table 1). The abundance of angular pumice clasts and extreme thickness suggest that this facies was generated by magmatic volatile-driven explosive eruptions, and the sub-rounded dense clasts were probably rounded within or above wave base. Thus, these beds are interpreted to have been deposited in a below-wave-base setting by subaerial pyroclastic flows that crossed the shoreline, and transformed into eruption-fed, water-supported volcaniclastic density currents (Jutzeler and others, 2014). A reversely to normally graded pumice breccia facies that contains sub-rounded pumice clasts, wood, and accretionary lapilli is interpreted to have formed by settling from pumice rafts, and is also related to subaerial explosive eruptions (Jutzeler and others, 2014). Sections in the White Pass area (fig. 4) chiefly contain graded or massive volcanic breccia and massive volcanic breccia that suggest deposition from subaqueous high-concentration density currents and subaqueous debris flows (Jutzeler and others, 2014). The abundance of angular pumice clasts suggests minor reworking above wave base. Very thin to thick interbeds of fine sandstone to mudstone are interpreted to be derived from subaqueous and subaerial sources, and to have mostly been deposited from low density turbidity currents and suspension. The presence of vesicular basalt and basaltic scoria breccia with rare accretionary lapilli indicate the presence of small intra-basinal pyroclastic cones that may have been partly subaerial (Jutzeler and others, 2014).

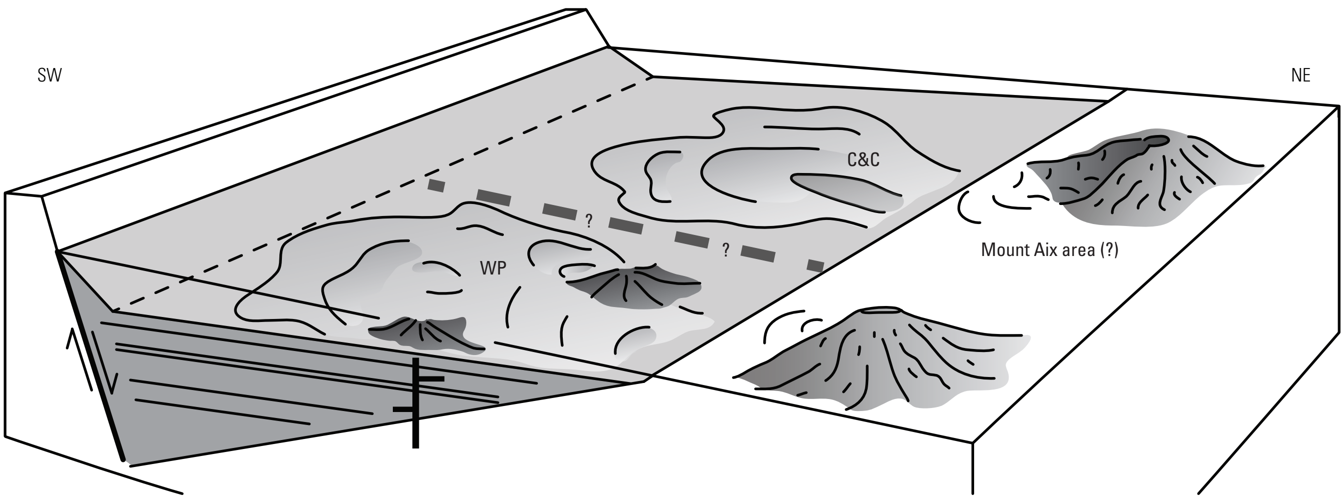


Figure 4. Block diagram showing reconstruction of the Ohanapecosh basin. Active subaerial andesitic volcanoes (possibly in the Mount Aix area) supplied most of the volcaniclastic facies preserved in the Ohanapecosh Formation. The depositional setting for most facies was subaqueous and below wave base. Local intrabasinal scoria cones and basaltic intrusions are present. C&C, Cayuse and Chinook Passes; WP, White Pass. Modified from Jutzeler and others (2014).

The Wildcat Creek Beds

The Oligocene volcaniclastic Wildcat Creek beds, which are more than 300 m thick, were mapped by Swanson (1978) to the northeast of Rimrock Lake in south-central Washington, at the foot of the Cascades Range (fig. 1). These beds record explosive Ancestral Cascades volcanism during the Oligocene, and are considered a part of the Ohanapecosh Formation, in the broad sense (Swanson, 1965, 1978; Vance and others, 1987; Hammond, 2005; Strganac, 2011; P.E. Hammond, Portland State University, unpub. data, 2011). The Wildcat Creek beds were first described by Swanson (1965, 1978) as mostly andesitic to dacitic, more than 350 m thick, and forming a well-bedded volcaniclastic sequence, tilted in a homocline dipping 20–30 degrees northeastward (Swanson, 1965). In outcrops nearby those visited during this field trip, the plagioclase in the upper part of the Wildcat Creek beds have been Ar/Ar dated at 26.97±0.30 Ma, 27.02±0.22 Ma, and 27.16±0.19 Ma (Strganac, 2011; P.E. Hammond, Portland State University, unpub. data, 2011). To the east of Mount Aix, beds possibly equivalent to the Wildcat Creek beds have been dated by Ar/Ar on plagioclase at 29.15±0.4 Ma (early Oligocene [Hammond, 2005]). Previous fission track ages on zircon in successions apparently belonging to the Wildcat Creek beds gave 30 Ma (Schreiber, 1981) and 34–32 Ma (Vance and others, 1987).

The Cenozoic rocks in the Tieton River area unconformably overlie the Jurassic to Cretaceous metasedimentary units forming the Tieton inlier (Swanson, 1965, 1966, 1978; Vance and others, 1987). The base of the Wildcat Creek beds is not exposed. Swanson (1978) inferred the Wildcat Creek beds to conformably overlie the Eocene "sandstone of Spencer Creek," and to be a lateral equivalent of the "tuff of Milk Creek." Both of these successions are exposed about 4 km southeast of Rimrock Lake and overlie an unnamed, more than 100-m-thick "welded tuff" (Swanson, 1978) dated at about 42 Ma (Vance and others, 1987). The "sandstone of Spencer Creek" contains lithic conglomerate and volcanic sandstone interbedded with thick red and purple clay units. The "tuff of Milk Creek" is a thick succession of clayey red and purple units with minor volcaniclastic beds. To the northwest of Rimrock Lake, the Wildcat Creek beds unconformably overlie Eocene quartzose sandstone (Vance and others, 1987). Other outcrops attributed to the Wildcat Creek beds were recognized to the east of Mount Aix (Hammond, 2005). The Wildcat Creek beds are overlain by the 24.6±2.4 Ma Burnt Mountain tuff (Miocene Fifes Peak Formation) of Vance and others (1987); the contact is slightly discordant. The Wildcat Creek beds are intersected by several small faults, and intruded by numerous dikes related to early Miocene volcanism (Swanson, 1966).

Swanson (1965) proposed three informal units, the >20-m-thick lower Wildcat Creek beds, a 20-m-thick pumice lapilli-tuff, here renamed more descriptively as blue tube pumice breccia, and the >260-m-thick upper Wildcat Creek beds. Strganac (2011) separated the upper Wildcat Creek beds into a lower unit A and upper unit B. The Wildcat Creek beds contain abundant pumice, scoria, glass shards, and dense clasts; accretionary lapilli are abundant in a few beds. Originally glassy components have completely devitrified and have been replaced by celadonite, zeolites (heulandite, mordenite) and clay minerals (Montmorillonite group) (Swanson, 1965). Original porosity has been filled by silica, carbonates, and zeolites.

Thirty-four disarticulated fossils of terrestrial (nonmarine) mammals were discovered within unit B of the upper Wildcat Creek beds (Strganac, 2011). The fossils represent a biogeographic extension of the middle John Day fauna in Oregon (Grant, 1941; Strganac, 2011). Essentially based on "slickensides, orange mottling, and low chroma color" present in the poorly exposed lower Wildcat Creek beds, Strganac (2011) inferred a subaerial environment of deposition, and extended this interpretation to the entire Wildcat Creek beds succession. On the basis of one gnawed fossil and the disarticulated condition of the fossils, Strganac (2011) concluded that the carcasses were exposed before burial. These hypotheses are strongly in contrast to the early hypothesis of Swanson (1965), who proposed, on the basis of the very good lateral continuity and grading of the depositional units, that at least the upper Wildcat Creek beds were deposited in a quiet, subaqueous environment. Such an interpretation is consistent with the inferred subaqueous depositional setting of the Ohanapecosh Formation, in the strict sense (Fiske, 1963; Fiske and others, 1963; Jutzeler and others, 2014). Moreover, Swanson (1965) suggested the terrestrial fossils were fed to the basin through rivers, and then transported by subaqueous density currents to their final resting place. Current research based on extensive lithostratigraphic analysis confirms Swanson's hypothesis.

Lithofacies and Depositional Environment of the Wildcat Creek Beds

The Wildcat Creek beds are exposed in multiple localities north to Rimrock Lake (fig. 1). The exposures chiefly consist of smooth, steep slopes and cliffs having lateral extents of a few hundred meters. The differential erosion between thick sequences of soft beds and thin ledge-forming units emphasizes the overall good lateral continuity of the beds. The beds are chiefly brown to beige in color, although green, white, dark yellow, and purple beds also are present, depending on clast componentry and (or) contact metamorphism from nearby intrusions and dikes. Green-altered pumice clasts are the dominant type of clast; purple and brown dense clasts and brown scoria are sub-dominant clast types, and accretionary lapilli are very common in some fine-grained beds. The matrix is chiefly made of devitrified glass shards and crystal fragments.

The Wildcat Creek beds consist exclusively of volcaniclastic facies, all of them being laterally continuous over large distances. Current research shows that single beds can be followed for >8 km laterally without any change in facies. There are four main volcaniclastic facies, the most abundant being matrix-supported volcanic breccia, in which <1–40 percent of volcanic granules to pebbles (pumice, dense clasts, and (or) scoria) are dispersed in a mud matrix. This facies consists of medium to extremely thick beds that are chiefly non-graded, but may include a concentration of pumice clasts at the top. Framework-supported volcanic breccia forms as thin to very thin beds that are non-graded or normally graded and shows very good sorting by clast size and clast density. Beds can be exclusively made of scoria or pumice that are pebbles to granules in size, or consist of a mixture of pumice, scoria, dense clasts, and (or) crystals.

This facies is found as standalone beds, or grades into matrix-supported volcanic breccia by progressive increase of the matrix content upwards. There are a few beds of polymictic pumice-dense clast breccia. This facies shows strong similarities in alteration color, grain size, and fabric to the massive volcanic breccia beds in the White Pass section of the Ohanapecosh Formation, in the strict sense (for example, Stops 1 and 2). An extremely thick bed of blue tube pumice breccia is present in the middle of the succession. It is matrix supported, reversely graded, and as thick as 13 m, and its large blue-green, rounded tube-pumice clasts are highly distinctive. This bed is used as a stratigraphic marker in the field. All these facies are interpreted as products of subaerial eruptions. The framework-supported volcanic breccia beds were interpreted as deposits from pyroclastic fall onto water (Swanson, 1965), however the high concentration of pumice clasts may also be from the result of density sorting in density currents. All other facies are interpreted as deposited by subaqueous density currents derived from subaerial explosive eruptions or mass wasting from non-identified vents.

Field-Trip Stops

Ohanapecosh Formation Along White Pass—Part 1

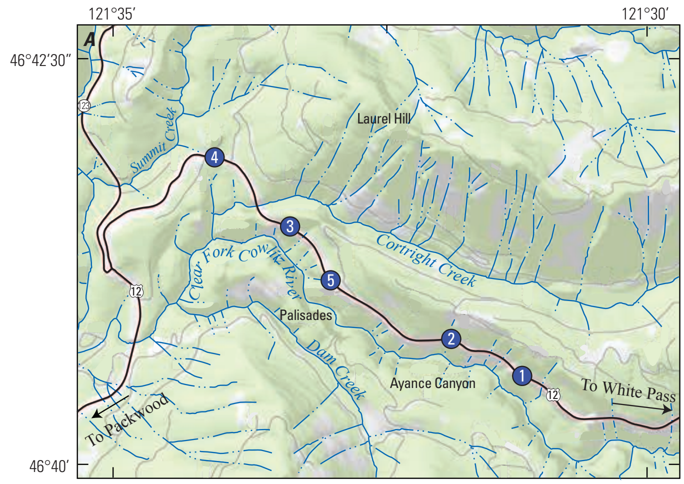
The field-trip itinerary starts at Packwood and ends at Rimrock Lake, crossing through White Pass. It is intended to look at the outcrops of the Ohanapecosh Formation from the base to the top of stratigraphy and end with two lookouts.

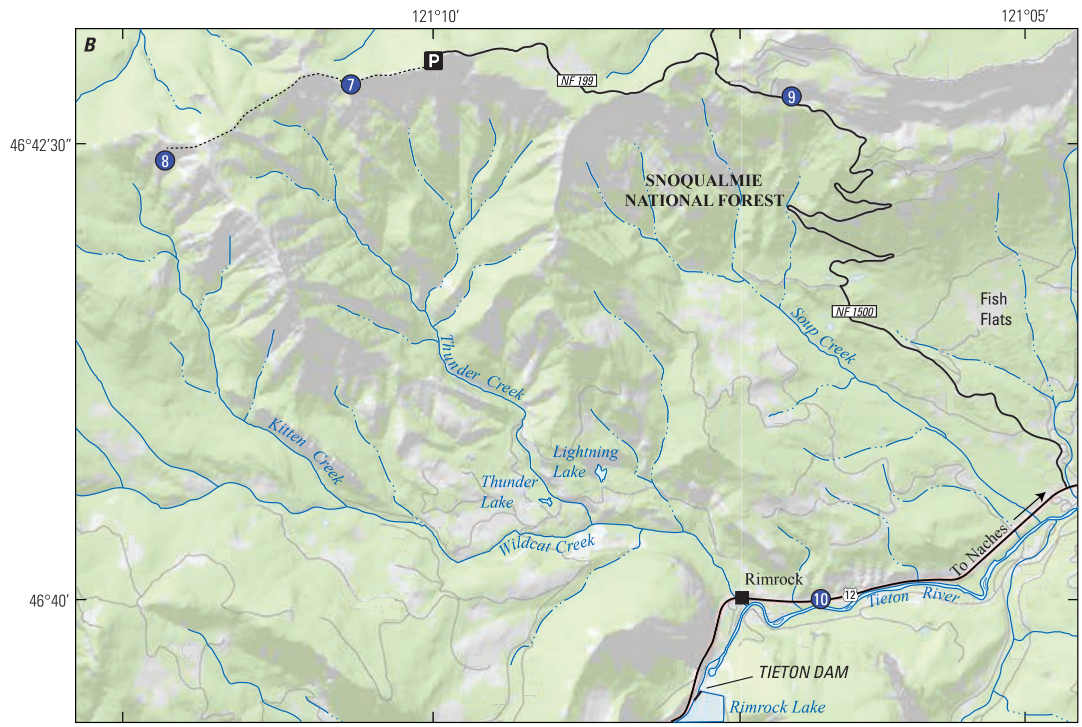
The >850-m-thick White Pass section (fig. 5a) consists of very thick to extremely thick and very thin to thick, dark green volcaniclastic facies (figs. 6, 7; table 1). The exposed stratigraphy along White Pass dips at 45° towards the west overall, and the younging direction is down-road. Many Miocene silicic dikes cut through the stratigraphy. The lower part of the White Pass section is dominated by graded or massive volcanic breccia, fine mafic sandstone, and massive volcanic breccia (fig. 6). The middle part of the White Pass section is dominated by massive volcanic breccia, basaltic scoria breccia, vesicular basalt, and fine sandstone and mudstone (fig. 6).

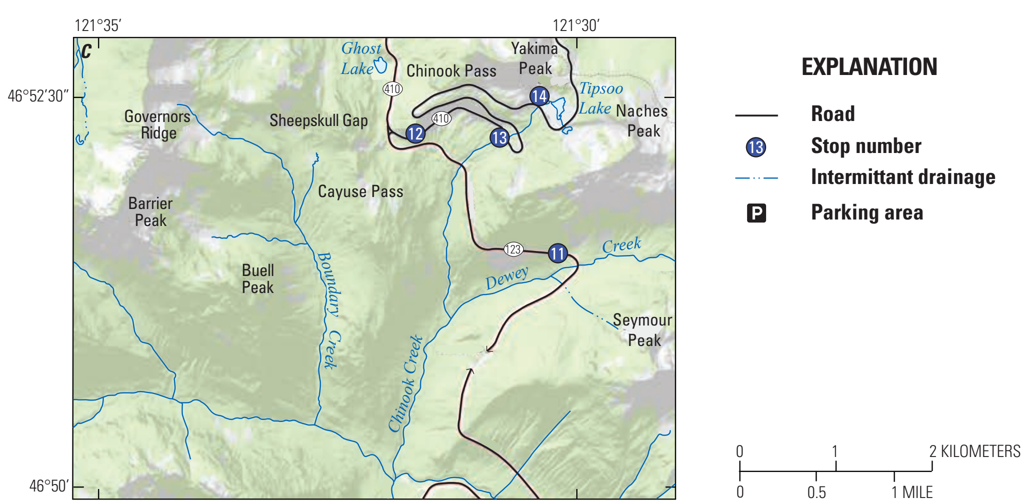
Stop 1 (lat 46°40′34″ N., long 121°31′26″ W.): From Packwood, drive north, then east on U.S. Highway 12 for 11.3 mi, climbing White Pass. Stop at the parking site to the right. The first continuous stratigraphy of the Ohanapecosh Formation starts 100 m up the road (east).

This outcrop shows the lowermost continuous beds of the Ohanapecosh Formation on this section. The contact with the underlying sandstone of Summit Creek is covered. Green-altered pumice and fiamme-rich beds of graded or massive volcanic breccia and massive volcanic breccia are present (figs. 6, 8*B*), and unit 5 was dated at 31.9±1.4 Ma (U/Pb on zircons by LA-ICP-MS; Jutzeler and others, 2014). Walk 300 m west down the road to find similar stratigraphy in addition to laterally continuous thin beds of fine sandstone

Figure 5. Topographic maps showing field-trip stops (blue hexagons). *A*, Part 1 along White Pass (Stop 6 is east of the map area). *B*, Part 2, Wildcat Creek beds. *C*, Part 3 at Cayuse Pass and Chinook Pass (optional Stop 15 is north of the map area). Base map from USGS topographic maps.







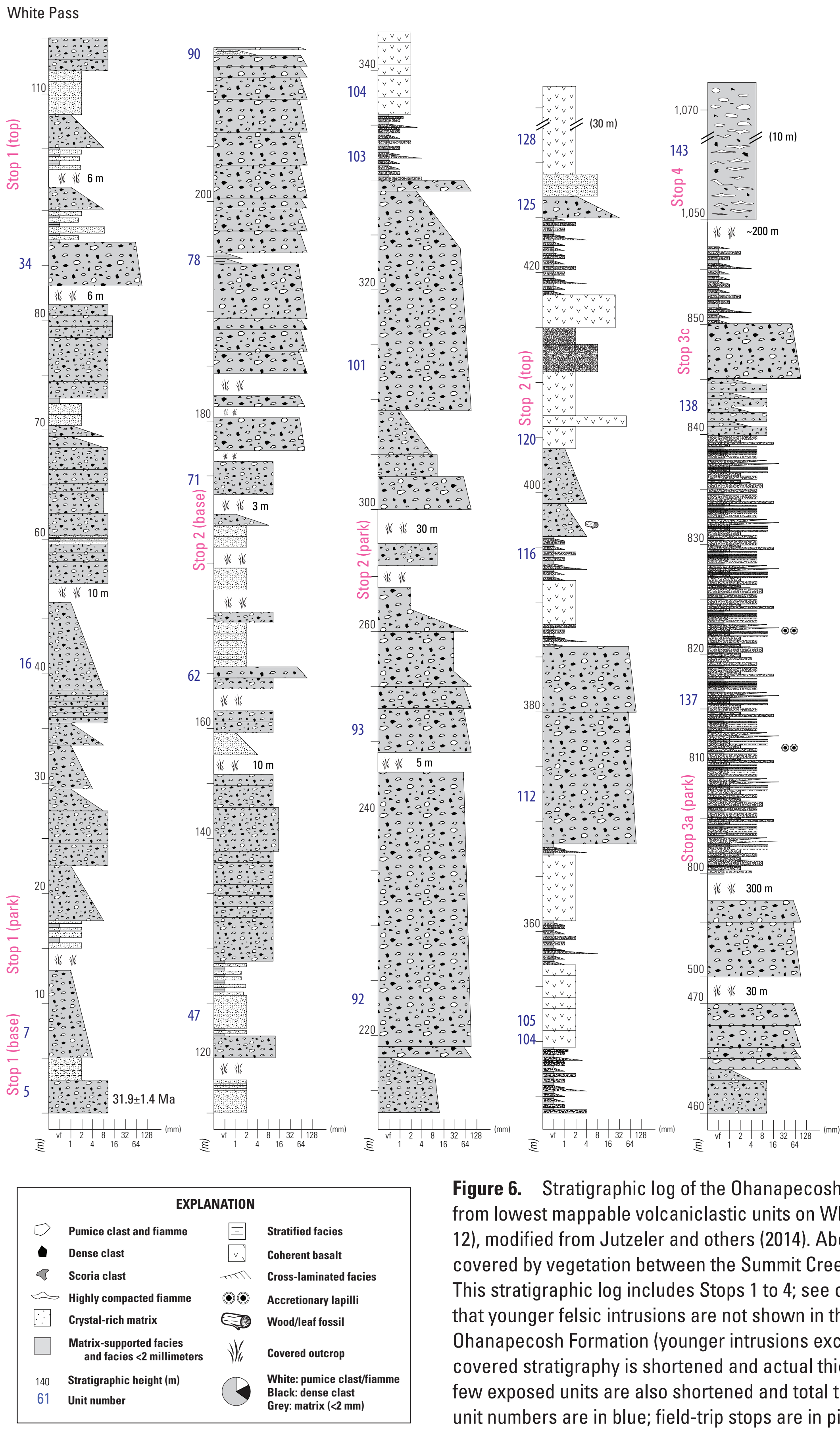


Figure 6. Stratigraphic log of the Ohanapecosh Formation at White Pass, from lowest mappable volcaniclastic units on White Pass (U.S. Highway 12), modified from Jutzeler and others (2014). About 500 m of stratigraphy is covered by vegetation between the Summit Creek sandstone and this log. This stratigraphic log includes Stops 1 to 4; see coordinates in main text. Note that younger felsic intrusions are not shown in the logs. Thicknesses of the Ohanapecosh Formation (younger intrusions excluded) are in black italic; covered stratigraphy is shortened and actual thicknesses are noted in black; a few exposed units are also shortened and total thicknesses are in parentheses; unit numbers are in blue; field-trip stops are in pink.

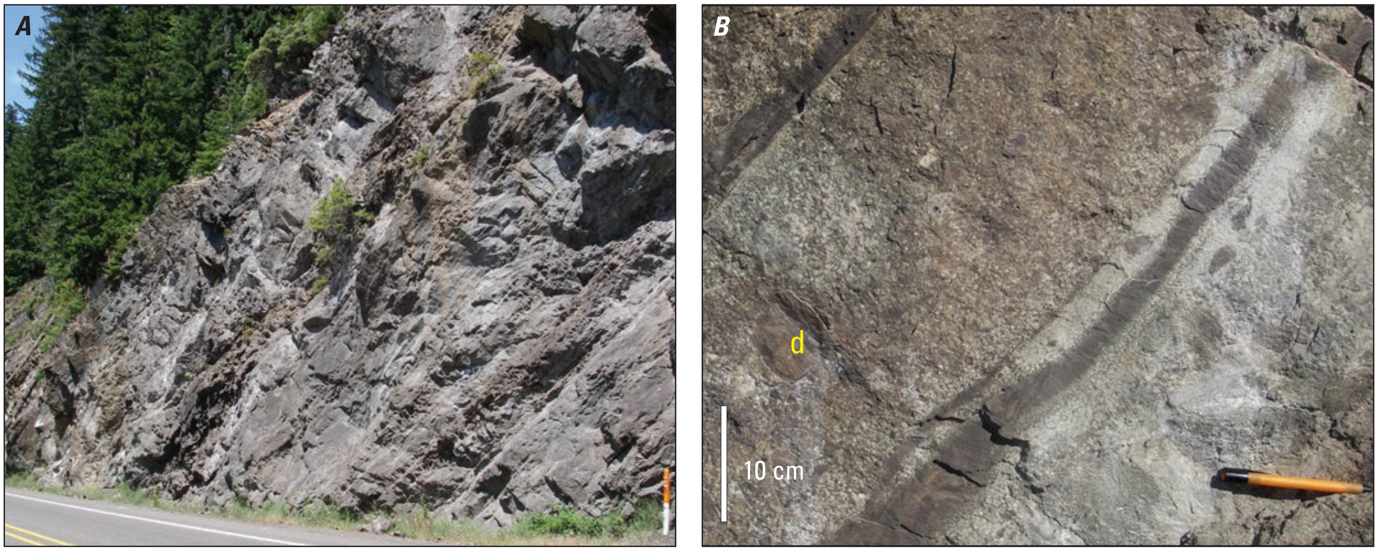


Figure 7. (Above) Photographs of the White Pass section. *A*, Road cut in the White Pass area (Stop 2). *B*, Fine sandstone and mudstone (unit 78) interbedded with graded or massive volcanic breccia and dense clast (d).

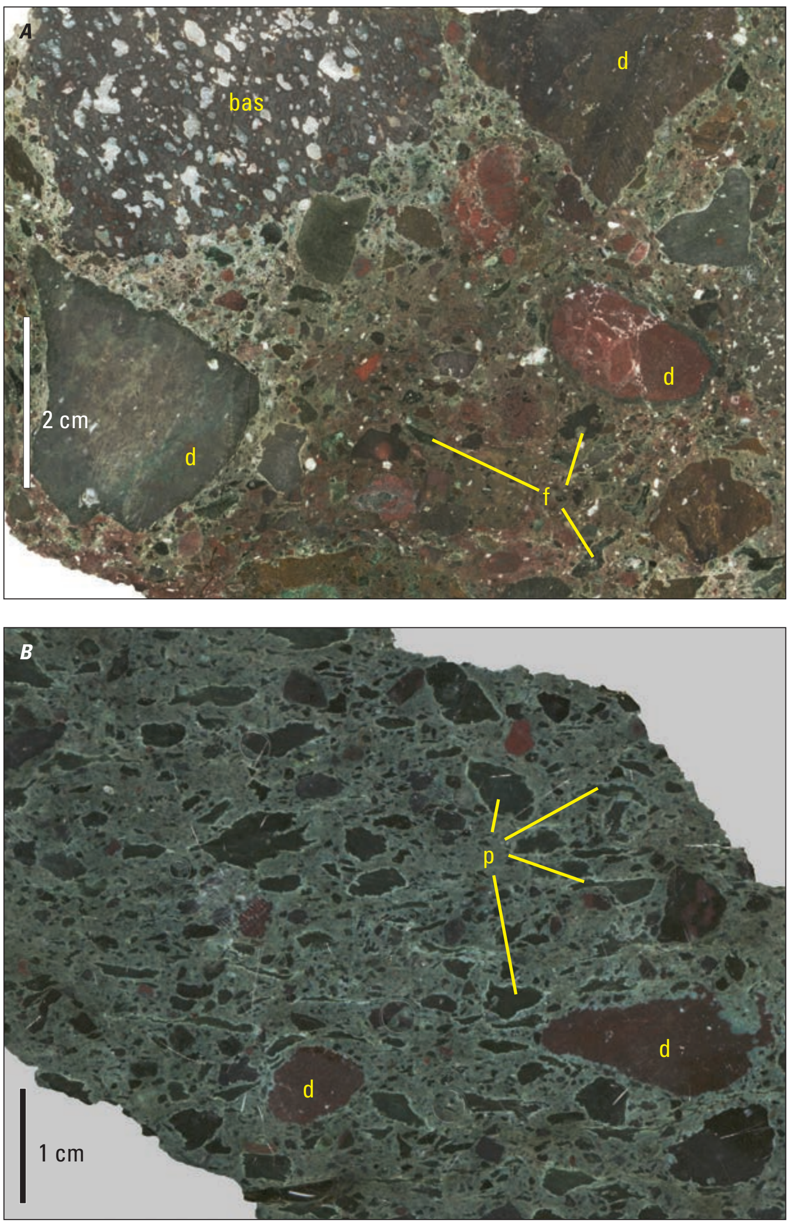


Figure 8. (Left) Magnified images of slabs of the upper White Pass section (Stops 1 and 2). *A*, Coarse volcanic breccia (unit 62), with fine pumice clasts and fiamme (f, black), dense clasts (d, red, dark green, brown), and vesicular basalt clast (bas). *B*, Graded or massive volcanic breccia (unit 5) at the base of the Ohanapecosh Formation (Stop 1), with dark green fiamme and pumice clasts (p) and red dense clasts (d) in a pale green matrix.

Table 1. Most common facies in the Ohanapecosh Formation, modified from Jutzeler and others (2014).

Name	Occurrence	Thickness	Facies description
Normally graded fiamme–dense clast breccia	Cayuse Pass, unit 40	>15 m	This facies is represented by unit 40 at Cayuse Pass, which consists of a >20-m-thick tabular bed laterally continuous over >400 m. The basal sub-facies consists of 3 m of clast-supported, normally graded polymictic breccia, mostly composed of a variety of coarse, dense, angular to sub-rounded volcanic clasts, dominated by dark aphyric dense clasts. The size of the dense clasts gradually decreases upward, and rare sub-rounded outsized clasts occur. The other components are abundant feldspar crystal fragments, black moderately porphyritic fiamme and pumice clasts, and matrix. The middle sub-facies (10 m thick) is matrix-supported, normally graded breccia. The volume of dense clasts decreases, whereas fiamme become abundant. The upper sub-facies is normally graded, matrix-supported breccia and occupies the upper third (6–7 m) of the unit.
Normally graded dense clast–fiamme breccia	Cayuse Pass, unit 42	>20 m	This facies is >20 m thick, tabular, and laterally continuous for >400 m. It is very similar to facies 1, but rounded dense clasts are coarser and more abundant in this facies. The lower sub-facies is <10 m thick. The angular to sub-rounded dense volcanic clasts (dominated by a green aphyric type) are normally graded. Fiamme are relatively abundant; the matrix includes feldspar crystal fragments and dense clasts. The upper sub-facies is matrix-rich.
Normally graded fiamme breccia	Chinook Pass, unit 57	>20 m	This facies is poorly preserved, in tabular, 20-m-thick beds with two gradational sub-facies of similar thickness. The basal sub-facies is clast supported in pale- to-dark green fiamme and pumice clasts, feldspar crystal fragments, and minor sub-rounded dense clasts. The upper sub-facies show similar componentry but finer grained.
Reversely graded fiamme breccia	Chinook Pass, units 59 and 61	>40 m	This facies consists of tabular, 40- to 50-m-thick beds. The basal sub-facies contains pale- to-dark green fiamme and pumice clasts, feldspar crystal fragments, dense clasts, and matrix. The fiamme and pumice clast sizes increase upwards and feldspar crystal fragments become more abundant. The upper 10 m of the unit shows a drastic increase in fiamme and pumice clast sizes. Few dense clasts are found throughout the whole bed.
Reversely to normally graded pumice breccia	Chinook Pass, unit 60	2.5 m	Beds of this facies are laterally extensive for >100 m. The main part of the facies consists of fine pumice breccia chiefly composed of pale yellow to pale brown sub-rounded pumice clasts, with minor fiamme and rare feldspar crystals fragments, and unbroken and broken, rim-type accretionary lapilli. The mudstone at the top of the units contains wood fragments. The grading of the pumice breccia is laterally continuous over tens of meters, but mudstone interlayers vary in thickness laterally and commonly disappear locally. Unit 60a is poorly preserved and its base is covered by vegetation. The base of unit 60b overlies unit 60a with 20 cm of smooth erosional relief over 3 m laterally. In units 60b and 60c, there are six main beds that are reversely to normally graded and range from clast supported to matrix supported. Most units are interrupted with tens of laminae or very thin beds of mudstone.
Graded or massive volcanic breccia	White Pass	1–15 m, max 15 m	This facies is made of very thick beds that can be clast supported or matrix supported, and dominated by fiamme or dense clasts. The average grain size decreases upwards, or shows no change. The components are green to dark gray fiamme and pumice clasts, very angular dense clasts, feldspar crystal fragments, and matrix combined. The dense clasts are a mixture of red and dark-gray clasts of probable mafic and intermediate composition.
Massive volcanic breccia	White Pass	1–5 m, max 25 m	This facies shows slight coarse-tail normal grading in the size of dense clasts. Clasts are angular to sub-rounded. Dense clasts, pumice clasts and fiamme, and feldspar crystal fragments together are dominant over matrix. Fiamme are green to dark gray.
Fine sandstone and mudstone	Everywhere	1 mm–1 m	Laterally extensive, very thin to thick beds of fine sandstone and mudstone facies are present throughout the Ohanapecosh Formation. The beds are laterally continuous and uniform in thickness; very rare centimeter-scours and centimeter-wavelength cross-laminations occur. The beds commonly occur in meter-thick groups separating groups of very thick to extremely thick beds. Beds can be dark gray, purple, or pale gray and most beds are probably composed exclusively of volcanic components. Crystal fragments are common. Wood fragments are present in some beds.
Basalt scoria breccia	White Pass, unit 137	<1 m	This facies occurs in thin to thick, normally graded beds, and is composed of very angular scoria clasts. The scoria clasts are red to dark brown, and contain ovoid to highly contorted vesicles. The abundance of feldspar microlites is variable. Beds are matrix or clast supported. In a cliff close to White Pass (unit 137), the gently undulating beds occur in a 70–100-m-thick succession that is discordant to the regional strike. The orientation of beds in the section defines an upward arch, defining a scoria cone structure. This succession includes scattered <2-m-long impact sags with clasts within. A few beds contain accretionary lapilli.
Vesicular basalt	White Pass	0.3 m–3 m	The basalt has sharp contacts and is conformable with bedding. Coherent vesicular basalt contains ellipsoidal vesicles filled by zeolites.

and mudstone (unit 35). Other thin beds of fine sandstone and mudstone can be seen down the road (around unit 40).

Stop 2 (lat 46°40′44″ N., long 121°31′57 W”): Drive west on U.S. Highway 12, back towards Packwood, for 0.5 mi and park on the right-hand side of the road.

This locality is around unit 97. Walk up the road (east) for 100 m from the parking site to find an extremely thick, very coarse, dense, clast-rich unit (unit 92) overlying thin beds, some of them containing organic matter (units 65, 78, 90). Return to the parking site, then walk down the road (west) for 200 m to find multiple outcrops that show units 100–120 (figs. 6, 7), chiefly made of vesicular basalt, massive volcanic breccia, and mafic scoria breccia. Amygdales in vesicular basalt are zeolite-filled. Wood chips are present in unit 117 (fig. 6).

Stop 3a (lat 46°41′21″ N., long 121°33′16″ W.): Continue west along U.S. Highway 12 for 1.4 mi and park on the left-hand side of the road. The main outcrop is the roadcut and adjacent cliff.

This outcrop exposes basaltic scoria breccia (fig. 9). The road cut and adjacent cliff in the forest consist of hundreds of gently undulating, thin to thick beds (unit 137). The section represents a dissected scoria cone, possibly of Surtseyan origin. Accretionary lapilli are present in a few fine-grained intervals in the road cut and in the cliff. The top of the cliff cannot be easily accessed through the forest.

Stop 3b: Walk 50 m east up the road from the parking site then down 150 m in the forest towards the canyon, up to a cliff edge above a shear drop. The cliff is collapsing in part, and extreme caution should be taken.

From the lookout, a beautiful cliff of basaltic scoria breccia is visible across the canyon (fig. 9). Note the up-arching beds forming the scoria cone succession and the bomb sags. A few basaltic dikes crosscut the stratigraphy. Down the valley, thick beds of the Ohanapecosh Formation overlie this scoria cone.

Stop 3c: Walk back to the parking site, then walk down the road (west) for 200 m.

The volcanic breccias and fine sandstone and mudstone facies of the Ohanapecosh Formation are present here (units 138, 139). These are the last continuous beds of the Ohanapecosh Formation of this section.

Stop 4 (lat 46°41′45″ N., long 121°33′53”W.): Continue west along U.S. Highway 12 for 0.7 mi and park on the left-hand side of the road.

This outcrop is part of the overlying Stevens Ridge Formation. One bed (unit 143) is red-oxidized and comprises very elongated red and white fiamme at its base; it may represent a welded ignimbrite. Other beds in the area are quartz-rich, and match the facies characteristics of the Stevens Ridge Formation. Similar beds are found on top of Backbone Ridge, the hill on the other side of the Ohanapecosh Valley, and Jutzeler and others (2014) inferred a north-south-striking fault along the Ohanapecosh Valley.

Stop 5 (lat 46°41′02″ N., long 121°32′58″ W.): Turn back (east) and drive up White Pass for 1.2 mi. Turn right at the view point (Palisades).

Look out over the Quaternary Palisades columnar jointed dacite lava.

Stop 6 (lat 46°37′54″ N., long 121°26′53″ W.): Continue east up White Pass for 6.6 mi to the lookout area on the right.

Look out towards Mount Rainier.

Continue climbing White Pass and drive east towards Rimrock Lake (12 mi).

Wildcat Creek Beds—Part 2

The Oligocene Wildcat Creek beds are exposed across multiple outcrops North of Rimrock Lake. Most sections are in lowland topography, owing to the relative softness of the beds in comparison to intrusions and lavas. This field trip includes two iconic sections where the beds are relatively easily reached and well exposed (figs. 10–12). The Wildcat Creek area contains several well-exposed localities, but steep scree slopes and cliffs make their access more difficult and risky. Moreover, floods in late 2015 cut the main road into the Wildcat Creek Valley, considerably increasing the walking distance to some outcrops. Additional sections through well-exposed stratigraphy can be found at lat 46°40′25″ N., long 121°08′42″ W. (lower Wildcat Creek beds); lat 46°40′29″ N., long 121°07′45″ W. (unit B of the upper Wildcat Creek beds); and lat 46°40′45″ N., long 121°10′10″ W. (blue tube pumice breccia and unit A of the upper Wildcat Creek beds), amongst others.

The section at Burnt Mountain (Stop 8) exposes most of the stratigraphy of the Wildcat Creek beds, starting from the blue tube pumice breccia. Bare rock exposures allow tracking of single units for several hundreds of meters laterally. All four facies are exposed in the visited section (fig. 10). The U.S. Highway 12 road cut section starts from the upper part of the blue tube pumice breccia and exposes part of the upper Wildcat Creek beds (fig. 11). Both sections show very similar facies, and Stop 8 could be used as a single stop for this part in case of bad weather.

Stop 7 (lat 46°42′52″ N., long 121°10′08″ W.): From Rimrock Lake, drive east on U.S. Highway 12 towards Yakima. After the dam, Rimrock Grocery Store is on the right. From there, continue east for 2.4 mi. Turn left onto Bethell Ridge Road (U.S. Forest Service Road 1500), and drive 6.9 mi north to the top of the ridge, staying on U.S. Forest Service Road 1500, which is the best maintained road. Turn left (west) off U.S. Forest Service Road 1500 towards Cash Prairie (U.S. Forest Service Road 199) and drive 2.0 mi to the end of the road (lat 46°42′58″ N., long 121°09′48″ W.). This is the start of Wilderness Trail 1141 (Ironstone Mountain). Free registration on site is mandatory. Walk west along the crest trail for 0.6 km.

Look out over Mount Rainier, Mount Adams, and Mount Hood (north to south). The brown-yellow outcrops belong to the Oligocene rhyolite tuff of Burnt Mountain.

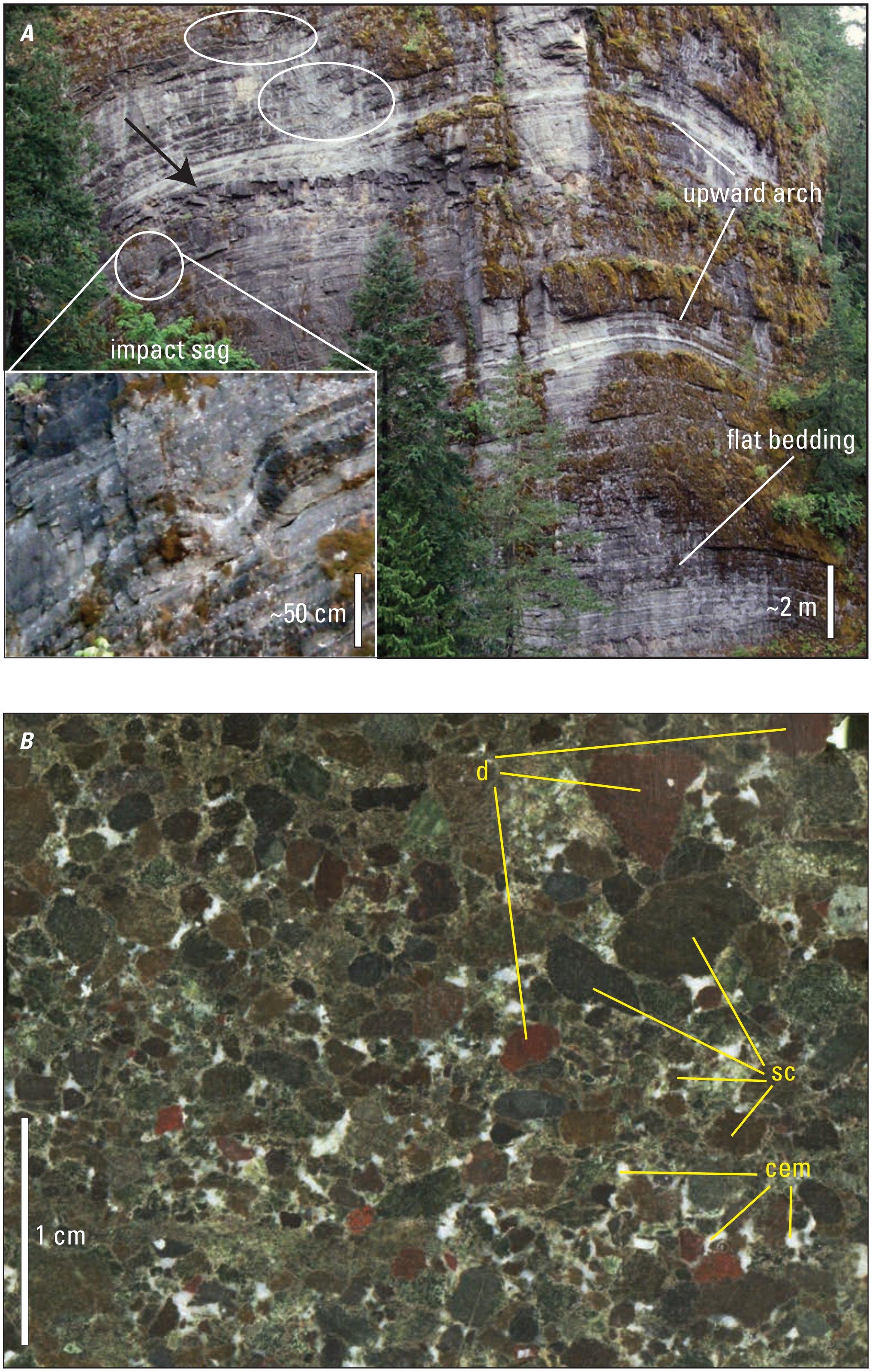


Figure 9. Photographs of the lower White Pass section with basaltic scoria breccia (Stops 3 and 3b). *A*, Upward-arching beds of basaltic scoria breccia, interpreted to be primary dip. White circles show interpreted impact sags, arrow shows mafic dike. Inset gives a detailed view of an interpreted impact sag. *B*, Magnified image of a slab of basaltic scoria breccia with dark gray and red-oxidized mafic scoria clasts (sc) and dense clasts (d) in pale green matrix and white zeolite cement (cem).

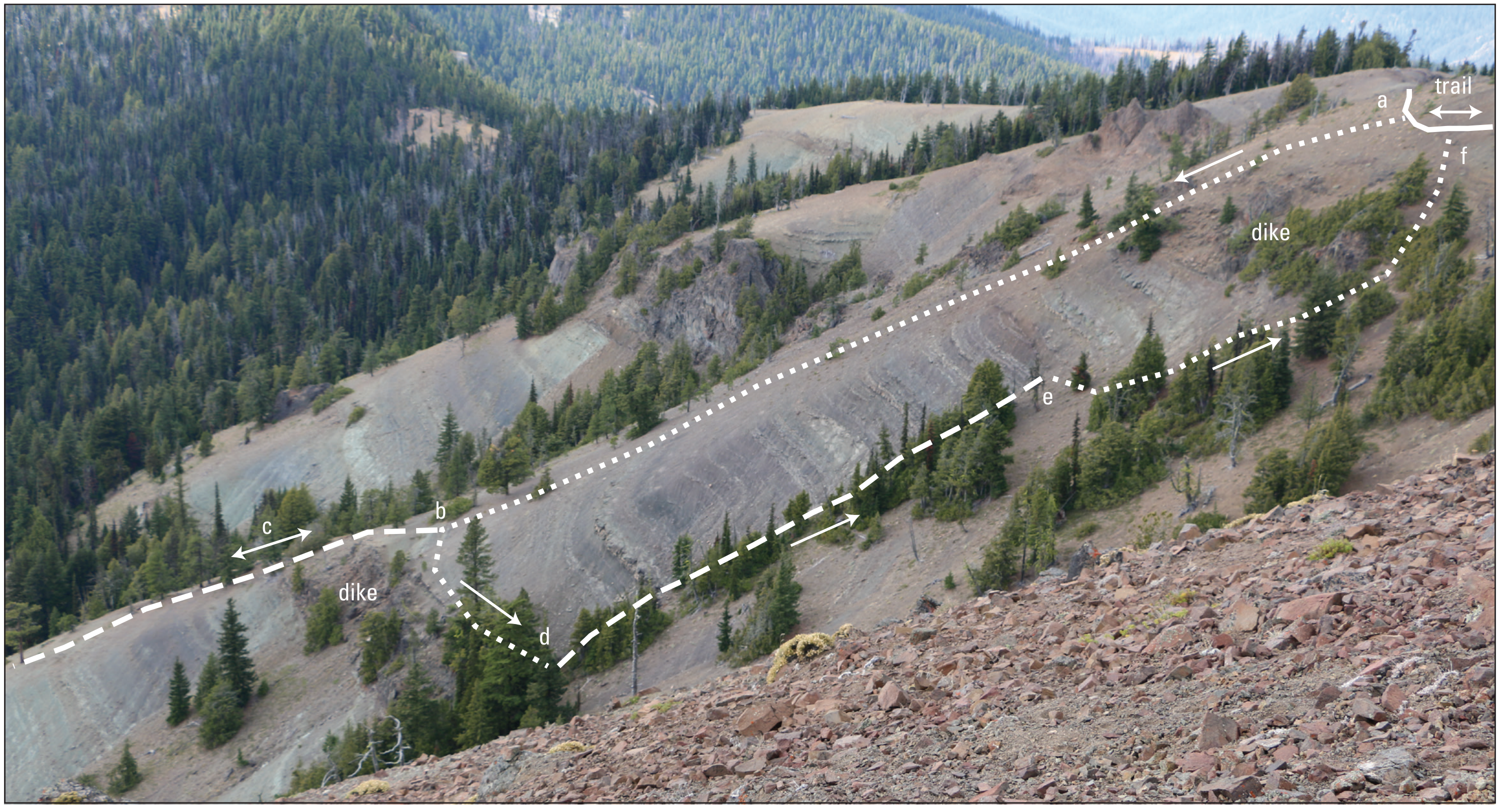


Figure 10. Photograph showing overview of the outcrops of Burnt Mountain (Stop 8). The view is towards the northwest, and the summit is to the right of the photo. Solid line shows the trail, dotted lines show access routes, and dashed lines show stratigraphy. Points a–f are detailed in the explanation of Stop 8.

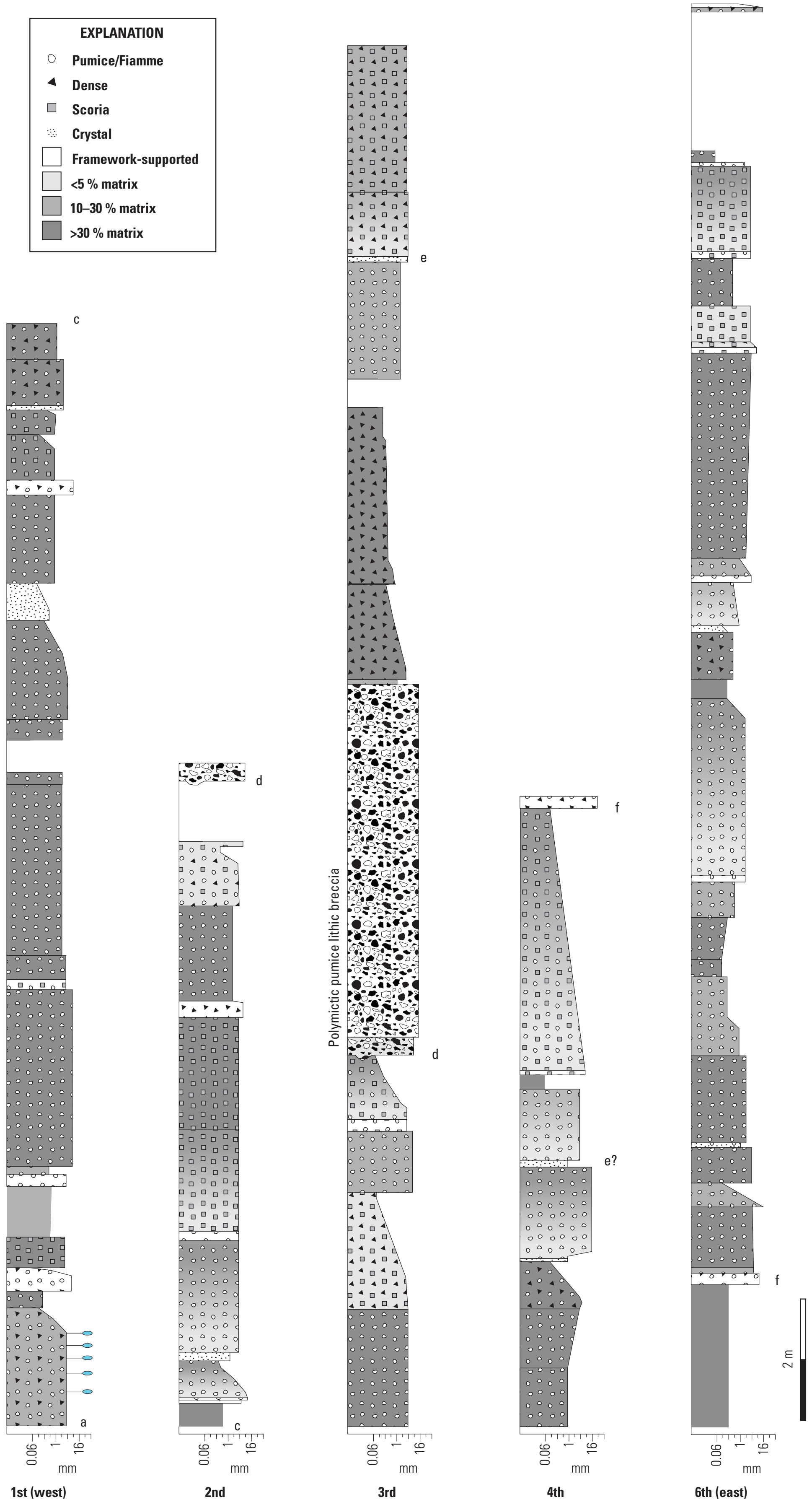


Figure 11. Stratigraphic log of the U.S. Highway 12 outcrop east to Wildcat Creek. The Wildcat Creek beds are continuously exposed across six outcrops (first, second, and so on) along the road, starting from Stop 10. Letters refer to key stratigraphy levels to evaluate outcrop continuity.

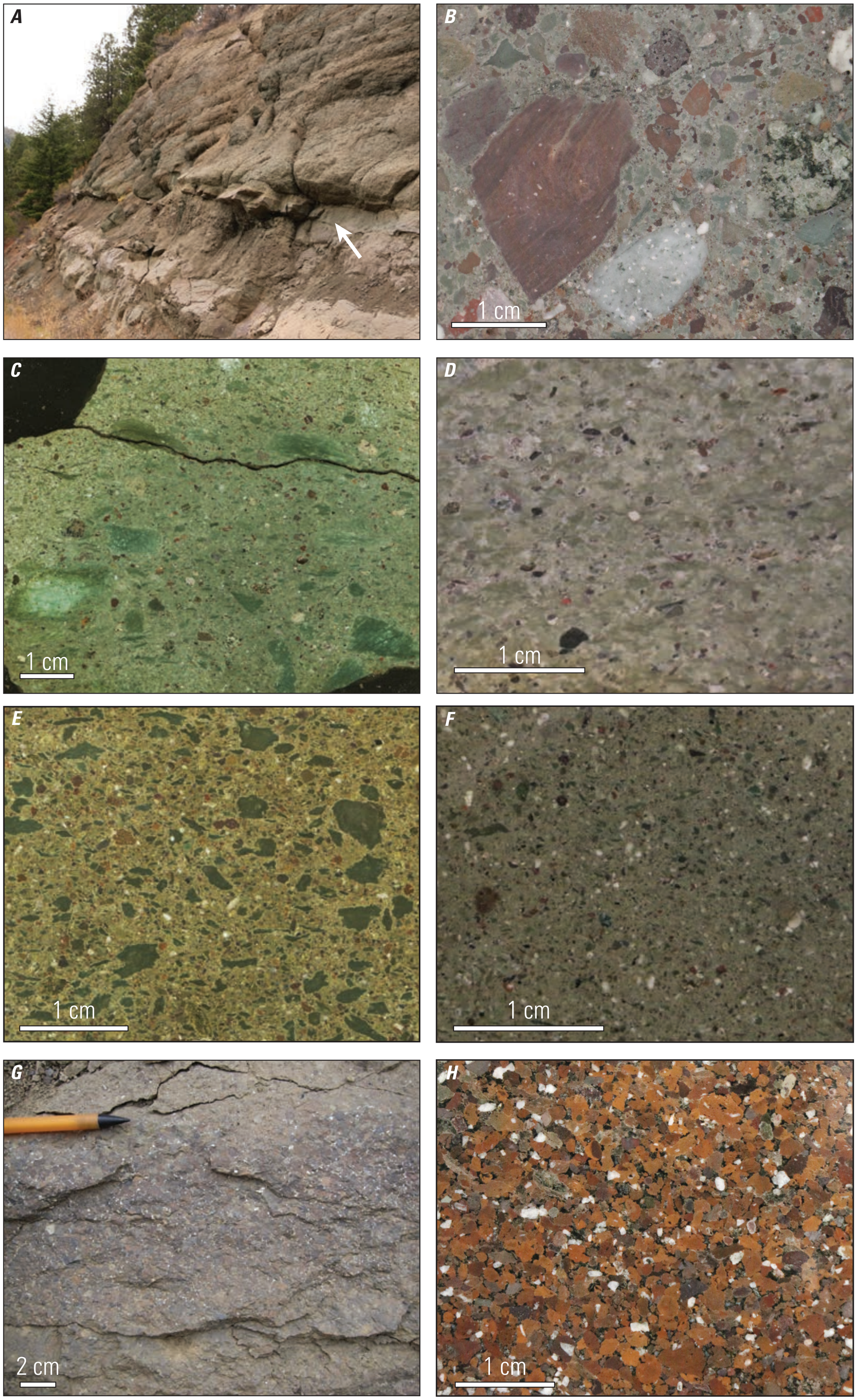


Figure 12. Photographs showing outcrops and rocks of the Oligocene Wildcat Creek beds. *A*, Outcrop of the Wildcat Creek beds at Stop 10. The extremely thick polymictic pumice-dense clast breccia starts at the white arrow. *B*, Polymictic pumice-dense clast breccia. The extreme diversity of angular dense volcanic clasts supported in green matrix makes it easily recognizable. *C*, Blue tube pumice breccia with abundant tube pumice clasts (green) and minor, much finer dense clasts (red, black, white) and crystals. *D*, Framework-supported volcanic breccia chiefly composed of fiamme (green) with minor dense clasts (black, brown, white) and crystals. *E*, Matrix-supported volcanic breccia with abundant angular pumice clasts (green) and subordinate dense clasts and scoria (red, brown). *F*, Matrix-supported volcanic breccia with fine angular pumice clasts (green), dense clasts (purple, brown), and crystal fragments (white). *G*, Outcrop of framework-supported volcanic breccia dominated by scoria clasts (brown). The bed ends at the pencil. White color is cement between scoria clasts. *H*, Framework-supported volcanic breccia dominated by sub-angular scoria clasts (brown, orange). Crystals (white) occur as fragments or in scoria clasts; fiamme (middle-top left) are rare.

Stop 8 (lat 46°42′15″ N., long 121°12′11″ W.): Continue on the ridge trail for about 2 km, going west then southwest up to Burnt Mountain (lat 46°42′24″ N., long 121°11′46″ W.), where the track crosses the crest and goes down and westwards. From the summit, walk down the trail for 400 m (to point a on figure 10) (lat 46°42′25.3″ N., long 121°12′05.6″ W.). Referring to figure 10, leave the trail and walk south down the scree slope (to b). Continue down and view stratigraphy as you walk down and back up the same path (c). Arriving back at b, walk east, just above the dike, until reaching the line of trees (d). Stratigraphy can be viewed walking up the little dry creek adjacent to the line of trees (d to e). Rejoin the trail, walking up in the scree slightly towards the east to avoid dikes (f).

The Wildcat Creek beds are beautifully exposed on Burnt Mountain, and cut by only a few dikes and intrusions (fig. 10). A few sub-vertical faults, commonly found in dried rivulets, displace the stratigraphy over a few tens of meters. The blue tube pumice breccia crops out in the creek less than 100 m down in the forest. The lower 50-m-thick unit of polymictic pumice-dense clast breccia crops out 50 m up in the slope. This facies is made of two beds: a 20–30-cm-thick matrix-supported lower bed, overlain by a 12-m-thick bed that grades from clast-supported at the base to matrix-supported at its top. This well-exposed, easily identifiable unit contains dense clasts as large as 30 cm in diameter. Many instances of matrix-supported volcanic breccia and framework-supported volcanic breccia are interbedded through the stratigraphy. Accretionary lapilli are found in large groups in a very fine-grained unit near the top of the section.

Stop 9 (lat 46°42′40″ N., long 121°07′00″ W.): Walk north then east back to the top of Burnt Mountain and follow the trail (northeast then east) to Cash Prairie. Drive back to U.S. Forest Service Road 1500, turn right, and drive 0.7 mi back (south) towards Rimrock Lake.

The exposed lavas belong to the Grouse Creek lava, which is part of the Miocene Grande Ronde Basalt (Columbia River Basalt Group).

Stop 10 (lat 46°39′57″ N., long 121°06′31″ W.): Drive south to U.S. Highway 12, and turn right (west) towards White Pass and Rimrock Lake. Drive 1.6 mi and park in the parking site on the right-hand side of the road. The stratigraphic section starts here and goes 1 km eastwards, through six main outcrops.

This section exposes very similar facies to Stop 8. The outcrop at the parking site (outcrop 1) consists of the top of the blue tube pumice breccia bed in which large pebbles of blue-green tube pumice are nicely exposed. Farther east, outcrops 2, 3, 4, and 6 show well-exposed, continuous stratigraphy that is easily accessible. The polymictic pumice-dense clast breccia facies is best exposed at outcrop 3, and shows the same features as at Burnt Mountain (Stop 8), despite the two sections being 8 km apart. At outcrop 4 and below unit f, there is a superb example of a scoria-rich bed grading from framework-supported volcanic breccia into matrix-supported volcanic breccia.

To return to Packwood, take U.S. Highway 12 for 35 mi, driving westwards through White Pass.

Ohanapecosh Formation at Cayuse Pass and Chinook Pass—Part 3

The >350-m-thick volcaniclastic sequence exposed at Cayuse Pass and Chinook Pass overall dips at 20° towards the north-northwest, and the younging direction is up-road (figs. 13–18; table 1). The base of the sequence is the Cayuse Pass section, which comprises multiple very thin to thick beds, overlain by a succession of extremely thick graded beds. The >200–m-thick Chinook Pass section overlies the Cayuse Pass section above a couple of hundred meters of hidden stratigraphy. The Chinook Pass section is composed of very thin to thick beds that are overlain by numerous extremely thick (>30 m) beds. The section is cut by a very thick silicic sill associated with the Miocene Tatoosh pluton (see cover photo) that oxidized and indurated the adjacent Ohanapecosh Formation.

Stop 11 (lat 46°52′20″ N., long 121°31′09″ W.): From Packwood, follow U.S. Highway 12 north for 7.6 mi. Turn left (west) on State Route 123, enter the Mount Rainier National Park and start climbing Cayuse Pass. At 22.3 mi from Packwood (1.1 mi from the little tunnel), park in the parking site on the left. The main outcrops are farther up (west), along 600 m of road cuts. To follow stratigraphy, it is best to visit the outcrops walking downhill (east).

The base of the Cayuse Pass section is below the road and accessible with difficulty; however some beds are partly exposed along the road. It is chiefly made of graded or massive volcanic breccia and fine sandstone and mudstone. The upper part of the section forms the main road cut, and is fully accessible. It consists of three extremely thick (>20 m), tabular beds that are laterally continuous for 400 m (figs. 13, 14). Normally graded fiamme–dense clast breccia (unit 40; figs. 6, 14) is overlain by normally graded dense clast–fiamme breccia (units 42 and 43; figs. 6, 14*B*). The facies grades upwards from a coarse, dense, clast-supported base to fiamme-rich middle and ends with a matrix-supported top.

Stop 12 (lat 46°51′59″ N., long 121°32′11″ W.): Continue north on State Route 123 and turn right on State Route 410 (Chinook Pass). Follow State Route 410 for 150 m and park in the parking site on the side of the road. The main outcrops start here and continue east for 500 m along the road.

The lower part of the Chinook Pass section comprises fine, dense clast volcanic breccia and fine sandstone and mudstone, from which large pieces of dark silicified wood have been recovered (figs. 15, 16). It is overlain by extremely thick beds of normally graded fiamme breccia (unit 57) and the base of a reversely graded fiamme breccia (unit 59). The road cut ends in a large silicic sill (cover photo).

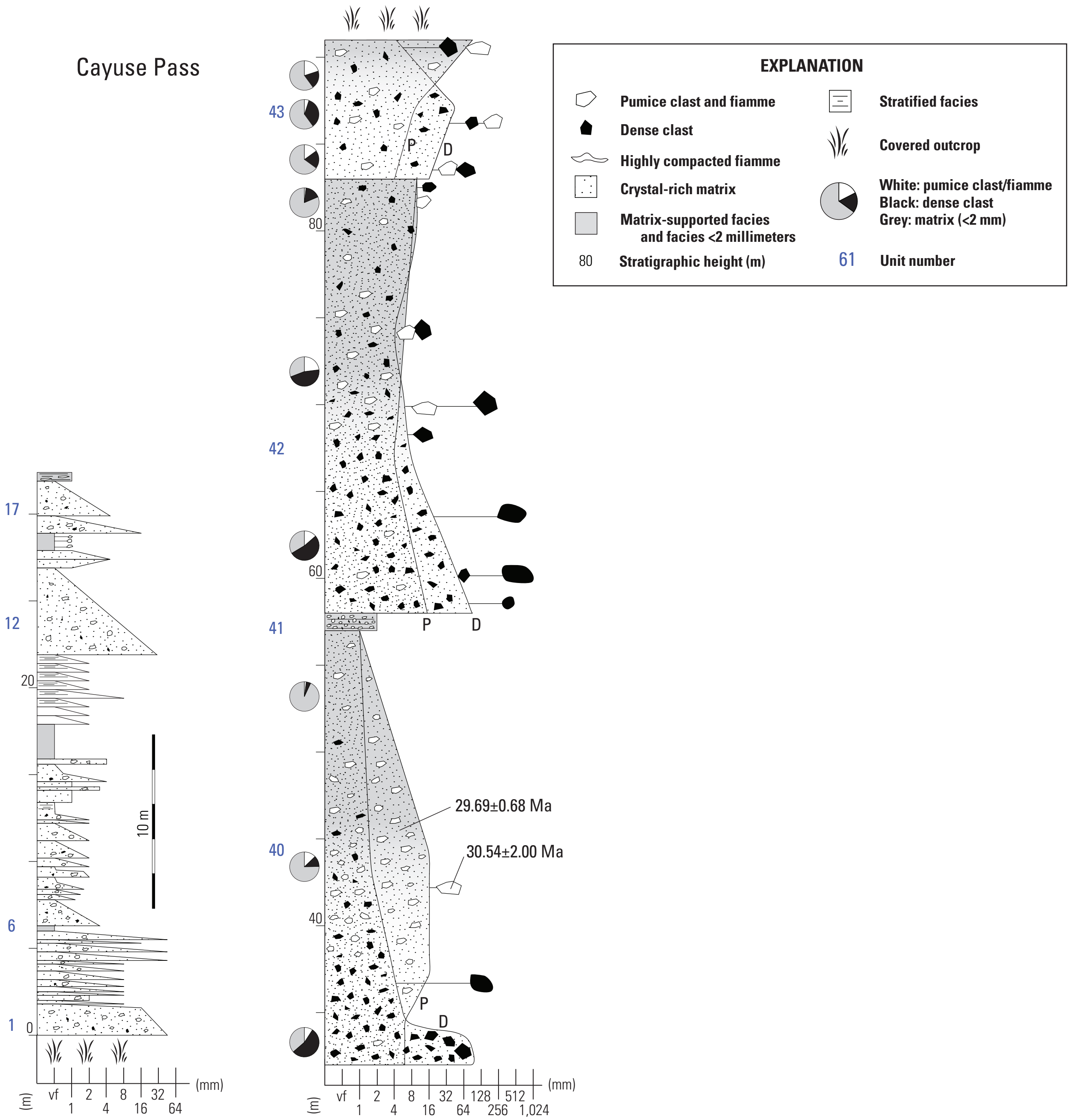


Figure 13. Stratigraphic log of the Ohanapecosh Formation at Cayuse Pass (Stop 11); modified from Jutzeler and others (2014). Pumice clasts and fiamme (P) and dense clasts (D) are present.

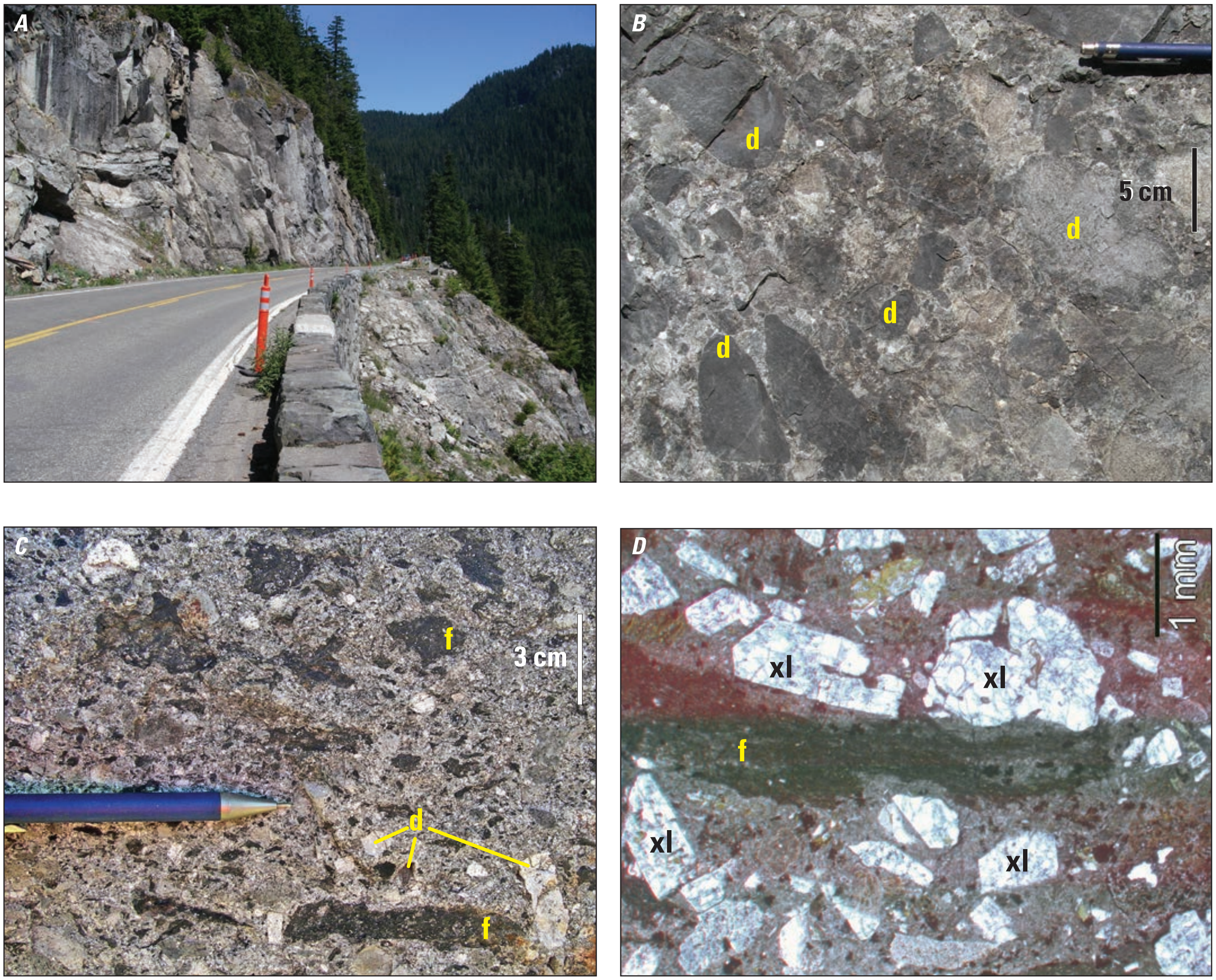


Figure 14. Photographs of the Cayuse Pass section (Stop 11). A, Outcrop of the Ohanapecosh Formation at Cayuse Pass. Most thin beds (see fig. 13) are beneath the road, whereas very thick beds are in the road cut. B, Base of normally graded dense clast–fiamme breccia (unit 42) with sub-rounded dark gray and brown dense clasts (d) in a gray matrix. C, Middle facies of normally graded fiamme–dense clast breccia (unit 40) with fiamme (f, black) and dense clasts (d, white and gray) in a gray matrix. D, Fiamme (f), broken feldspar crystals (xl), and matrix in the middle of normally graded fiamme–dense clast breccia in the Cayuse Pass section (unit 40).

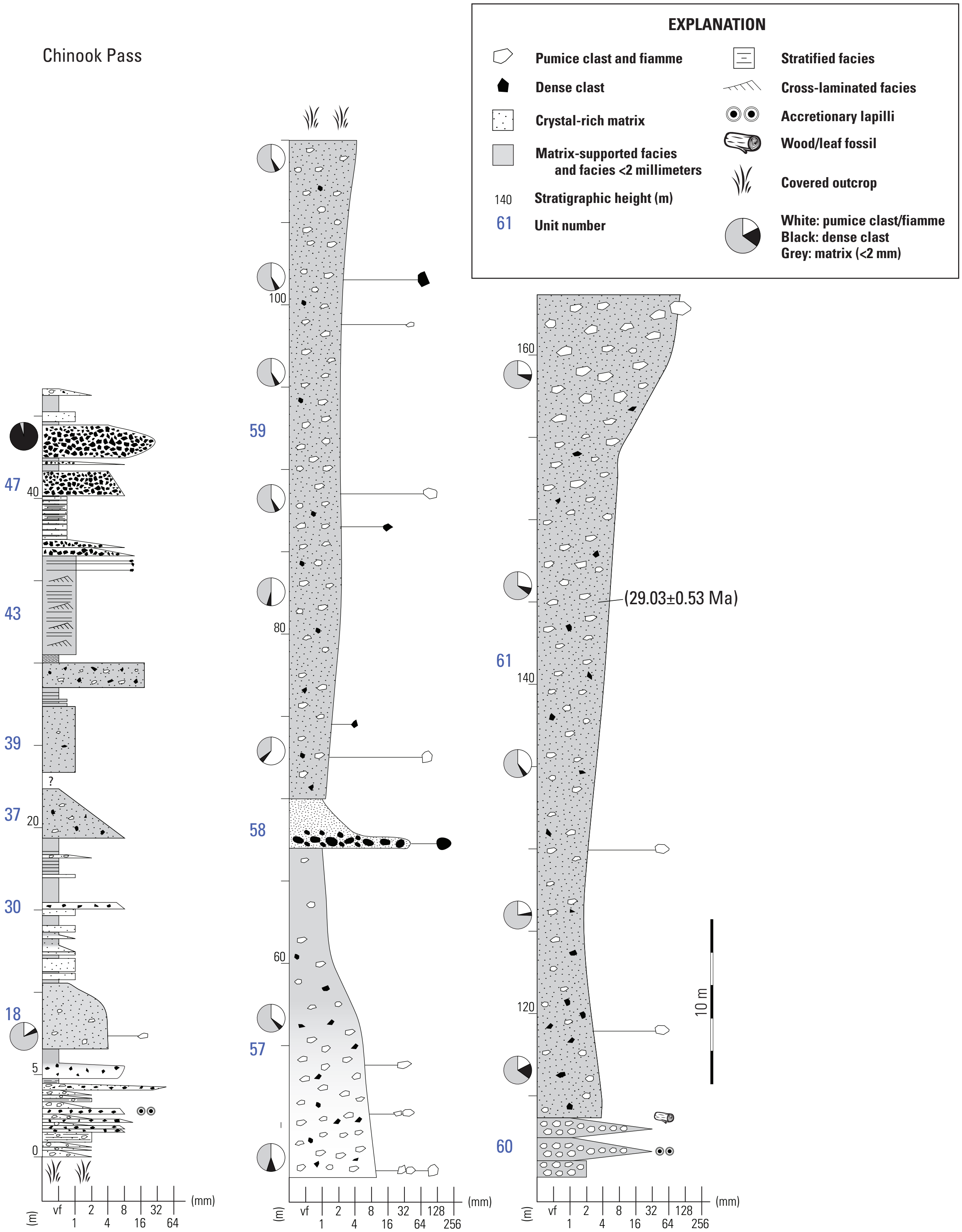


Figure 15. Stratigraphic log of the Ohanapecosh Formation at Chinook Pass (Stops 12 and 13); modified from Jutzeler and others (2014). See figure 17 for detailed log of unit 60. Date in parentheses is uncertain as it is based on age from a single zircon.

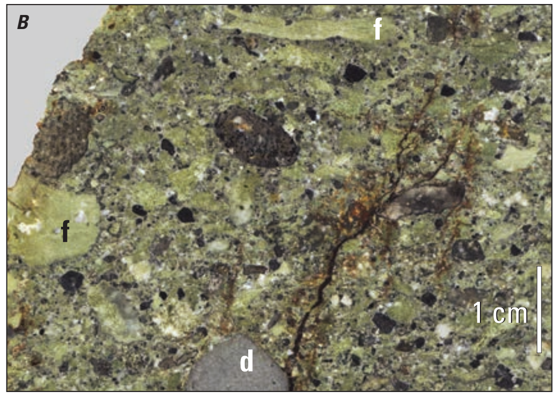


Figure 16. Photographs of the base of the Chinook Pass section (Stop 12). *A*, Abundant thin beds in the lowermost part of the section. *B*, Base of Normally graded fiamme breccia with abundant fiamme (f, pale green), minor dense clasts (d, gray and black) in matrix.

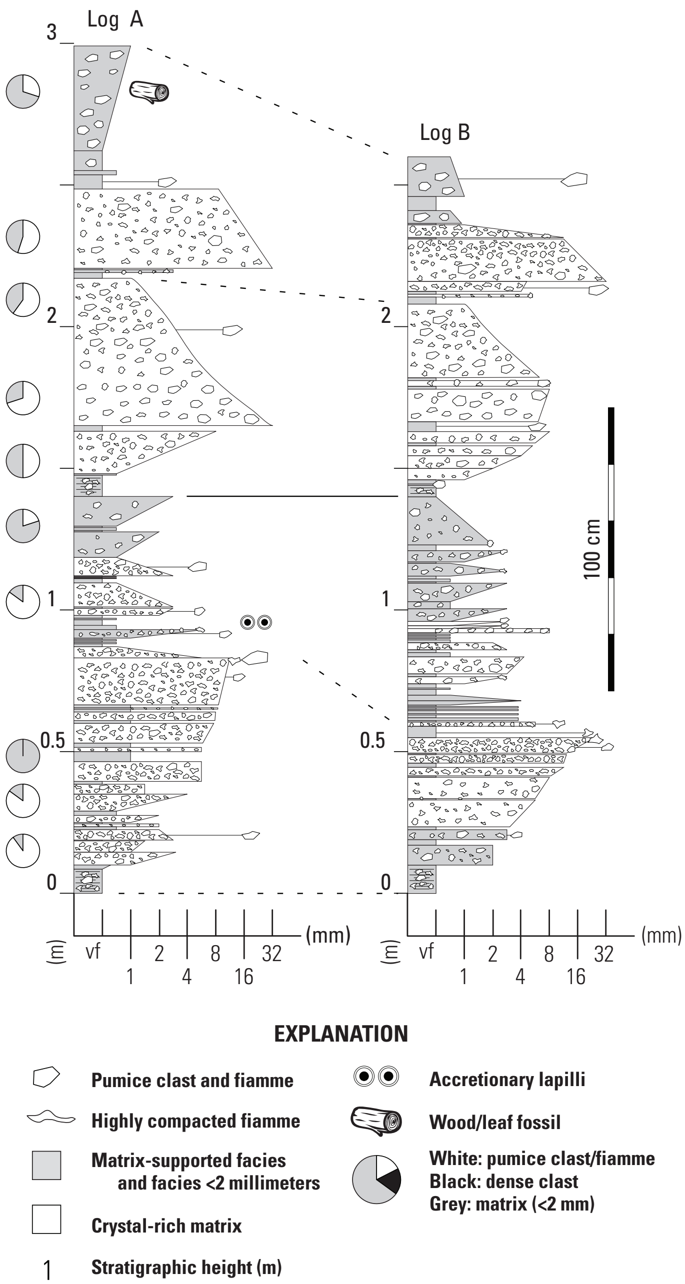


Figure 17. Detailed stratigraphic logs of laterally continuous unit 60 in the Chinook Pass section (Stop 13); modified from Jutzeler and others (2014). Log A is >80 m to the east of log B. Lines show main parts of the two sections that can be traced in the field.

Figure 18. Photographs of the Chinook Pass section (Stop 13). *A*, Laterally continuous beds of reversely to normally graded pumice breccia (unit 60) and reversely graded fiamme breccia (unit 61) at Chinook Pass; top of unit 61 is not seen. *B*, Reversely to normally graded pumice breccia (unit 60). The reverse grading in pumice clasts (p) is interrupted by dark bands of mudstone (m). *C*, Fiamme and pumice clasts (f, dark green), rare dense clasts (d, white and pale green), and free broken feldspar crystals (xl, white) in a green matrix of the reversely graded fiamme breccia (unit 61). *D*, Reddened top of the reversely graded fiamme breccia (unit 61), adjacent to Miocene Tatoosh sill, with large fiamme (f, red) and dense clasts (d, pale green) in red-purple matrix.

Stop 13 (lat 46°52′10″ N., long 121°31′58″ W.): Option 1 (multiple cars)—continue climbing Chinook Pass for 0.8 mi to the parking site to the right (lat 46°52′07″ N., long 121°31′44″ W.), then walk up (east then west through a bend) the road for 1 km to reach the outcrops that continue for a farther 500 m westwards. Option 2 (single car)—continue climbing Chinook Pass for 1.8 mi, then stop at the small parking site to the left (lat 46°52′05″ N., long 121°32′13″ W.); outcrops are down the road (east) for 500 m.

The upper part of the Chinook Pass section starts with a very interesting succession made of three thick units of reversely graded to normally graded pumice breccia (unit 60; fig. 17) that are laterally continuous for 100 m. These units comprise tens of pumice-rich beds interbedded with mudstone. The pumice-rich beds are continuously graded in grain size, but segmented by intervals of mudstone. Pumice clasts are sub-rounded; rare accretionary lapilli and wood are present. On the basis of their content and grading, these units have been interpreted as pumice raft deposits (Jutzeler and others, 2014). These units are directly overlain by a ~50-m-thick, tabular, reversely graded fiamme breccia (unit 61) (fig. 18) which forms the main road cut.

Stop 14: Continue climbing Chinook Pass for 0.9 mi (or 1.8 mi from the earlier parking site) and stop at Tipsoo Lake parking lot.

This rest area has an excellent view of Mount Rainier.

Stop 15 (optional): Turn right (west) on State Route 410 and return to the junction with State Route 123. Turn right and follow State Route 410 north, towards Sunrise, for 3.5 mi. Turn left (west) on White River Road, continuing towards Sunrise. Drive 15.3 mi to the Sunrise Visitor Center.

Take a short walk on the Wonderland Trail (or another trail) for a magnificent view of Mount Rainier.

Return to Packwood: Drive back down White River Road towards the junction with State Route 410. Turn right (south) on State Route 410 and continue for 3.5 mi. At the pass, turn right (south) on State Route 123 towards Packwood. After 16.3 miles, turn right at the junction with U.S. Highway 12 and continue to Packwood (7.6 mi).

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