LEG F: EASTERN APPROACH

Yakima to Cayuse Pass via U.S. Highway 12 and State Route 410

by Wendy J. Gerstel, Paul E. Hammond, Newell P. Campbell, and Patrick T. Pringle*

This 66-mi (108 km) route takes you from the western fringes of the Columbia Basin to the Cascade Range at Chinook and Cayuse Passes, climbing about 3700 ft (1288 m) in 46 mi (74 km) (Fig. F-1). You will follow the valleys of the Naches and American Rivers for most of the trip, and en route you will have the opportunity to see the interior plumbing of a number of dissected Miocene volcanoes. The more ambitious traveler may want to explore roads and trails in Wenatchee National Forest for a more intimate look at these volcanic remnants. Some of these volcanoes may have exceeded Mount Rainier in height and circumference. The Fifes Peaks* and Bumping Lake volcanoes of Miocene age were certainly highly explosive because they produced welded tuffs and expelled such great quantities of magma that the volcanoes collapsed to form calderas.

The Yakima area is a starting point for many geological excursions; however, there isn't space here to describe them all. Those who want to delve deeper can start with Campbell (1998). (See also Norman and others, 2004, along with other sources in "Further Reading", p. 102.) Through the eastern part of this leg, you will pass young lava flows of the Tieton Andesite (Pleistocene) and the Columbia River Basalt Group (Miocene). The Tieton Andesite, best viewed along U.S. Highway (US) 12 at milepost (MP) 199 or about 1 to 2 mi (1.6–3.2 km) west of its junction with State Route (SR) 410, offers dramatic examples of columnar jointing. Visit this locale during the late afternoon for some great photo opportunities!

As you enter and travel the steep-walled reach of the Naches River valley, you parallel the west flank of the largest anticline of the Yakima Fold Belt. (See "The Yakima Fold and Thrust Belt", p. 17). This fold, known as Cleman Mountain, hosts one of the largest landslides along the route, the Sanford Pasture landslide. The landslide extends for about 5 or 6 highway miles (6–10 km) and is best seen from the air because of its scale. This and other huge landslides in the area likely failed along weak layers where fine sediments, including ash, are interbedded with the Columbia River basalt flows. Strong ground motion during past earthquakes could have contributed to movement of some of the landslides. Some portions of these slides are still moving, as indicated by recently tilted trees and cracked and buckled ground.

What formed the curious stone stripes, the strands or branch-shaped arrays of rocks that drape the hillsides in some places along this route and are surrounded by grassy and, locally, scrubby vegetation? Geologists lump these features in a category called 'patterned ground'. The formation of these features, although something of a geologic curiosity, is probably due to frost action in concert with gravity. Depending on the sizes of rocks, elevation, and physiographic factors such as south-facing vs. north-facing slope, and whether the bottom of the talus is deep in its gulley, these stripes can create a cool, shaded, moist microclimate that provides habitat for squirrels, lizards, some frogs, and even a few slug species. Look for greener grass around the stripe edges locally. In the autumn, the dark basalt rocks of the stone stripes provide a stark color and textural contrast to the surrounding golden grassy slopes.

As you approach Chinook Pass, the American River valley with its classic U shape lies to the south. This carved valley is a product of several episodes of alpine glaciation whose source was an ice cap centered at Mount Rainier. Smaller glaciers that fed into this larger ice stream created hanging valleys, many of which host beautiful waterfalls.

This route also takes you through a dacitic intrusive body and past unconsolidated deposits such as glacial till and outwash. Trails throughout the area offer endless opportunities to look at the geology in more detail, with grand and secluded views. Leg O (p. 163) is a short side trip along Bumping Lake Road that features landslides, old mining cabins, volcanic peaks, and glaciated valleys, as well as thick deposits of welded tuff that are locally intruded by dikes.

Note: Because this leg is run from east to west, the map route runs from right to left on each panel. Signed mileposts for the first 16 mi (26 km) refer to US 12, but refer to SR 410 for the remainder of the leg to Cayuse Pass. The highway is sometimes closed in winter, so it is wise to check on road conditions before traveling. Road status can be checked at the Washington State Dept. of Transportation website or by phone. (See "Websites and Phone Numbers", p. 176.)

Distances along the route are given in miles, followed by kilometers in italics. If you take any side trips, you'll have to keep track of and add those miles to all the remaining mileages in the leg. Having a pencil and paper handy, and even a calculator will be helpful.

Mileage

0.0 *0.0* This leg begins at the parking lot for the Yakima Greenway at the North 16th Avenue exit off US 12. It is about 1 mi (1.6 km) west of the junction of US 12 and Interstate 82. Cliffs to the north of the highway are composed of the Grande Ronde Basalt of the Columbia River Basalt Group (see Fig. 20, p. 25). Slightly west of the Park and Ride, the Yakima River exits a gorge gradually cut through Yakima Ridge over the millions of years it was being folded or uplifted. Folded rocks and evidence of the faulting that accompanied the folding are exposed within the gorge. The sloped bench above the river is planed on the base of the Vantage interbed; the Vantage sediments overlie the Grande Ronde Basalt. This interbed represents sedimentation dur-

* A discrepancy between the name of the Fifes Peak Formation and the landform, Fifes Peaks, is probably the result of a typo. The Fifes Peak Andesite was originally named by Warren (1933), who, although he didn't designate a type section, said that "Fifes Peak, in the northern part of the quadrangle" is one of the most prominent vents. The landform after which Warren was naming the formation is labeled "Fifes Peaks" on the Mount Aix quadrangle map. However, Warren evidently left out the 's'. In his map of the Tieton River, Don Swanson (1978) revised the age of rock unit and called it "Fifes Peak Formation". Although he clearly recognized that the geographic feature is called Fifes Peaks, Swanson did not comment on the discrepancy.

* See "Contributors", p. ii, for affiliation.

ing a hiatus in lava extrusion. In this unit, plant fossils such as *Ginkgo* leaves can be found. Grande Ronde N_2 flows are below the Vantage interbed. The Frenchman Springs (lower) Member of the Wanapum Basalt is above the N_2 sequence and the Vantage interbed. The Eckler Mountain Member is missing here, either because the flow never reached this area or it was eroded away before the Frenchman Springs flows arrived. The Saddle Mountains Basalt is exposed on the skyline (Reidel and Campbell, 1989).

These Grande Ronde flows are termed 'N' because they have normal magnetic polarity. The crystals or grains of magnetite and other iron-rich minerals in each of these flows are oriented with the Earth's magnetic field of the time of their eruption, just like a compass needle; they would have normal polarity if the flow were emplaced today because they would align with the north magnetic pole. Flows labeled 'R' have reversed magnetic polarity because the Earth's magnetic poles were reversed during that time. That is, a compass needle during 'R' times would align with today's south magnetic pole. The numbers associated with the N or R flows indicate the sequence of their eruption, '1' being erupted before '2'. (See the "Paleomagnetism" sidebar on p. 104.)

Lavas of the Columbia River Basalt Group make up the hillside on the right (north). Some of these flow units were formerly known as the 'Yakima Basalt'; however, geologists discovered that this unit consisted of several distinct flows of the Grande Ronde Basalt (Swanson and others, 1979). Even though these basalts may look the same from a distance, geologists distinguish them on the basis of their geochemistry and texture.

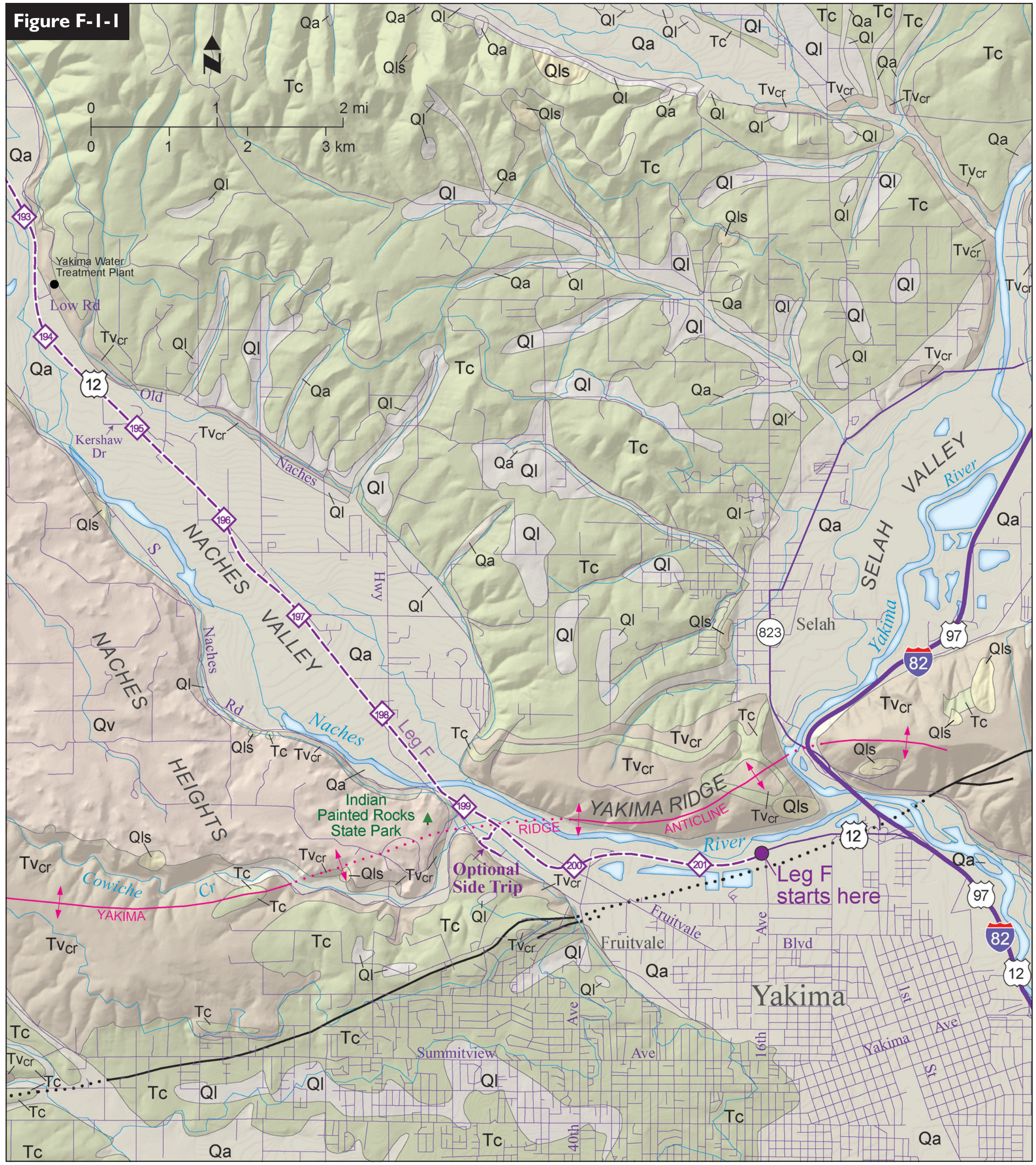


Figure F-1. Geologic map for Leg F (seven consecutive panels). The geology was adapted from 1:100,000- and 1:500,000-scale digital versions of Schasse (1987b), Walsh (1986), and Schuster (2005) and has been draped over a shaded relief image generated from 10-m elevation data. The leg maps were constructed using source-map data whose scale is smaller than the leg map scale, thus minor exposures may not appear on leg maps. The numbers in diamonds indicate mileposts. The map explanation is on the inside back cover. *Note:* Because this leg is run from east to west, the map route runs from right to left on each panel.

Figure F-2. A restored pictograph on a column of Tieton Andesite. The pictograph is about 1 ft (30.5 cm) wide. This site is now closed.

Paleomagnetism—Volcanoes as Tape Recorders

by Patrick T. Pringle and Katherine M. Reed

Geophysicists study paleomagnetism, the natural magnetization in rocks, to determine the history of the Earth's magnetic field. Atoms in magnetite or other iron- rich minerals crystallizing from molten magma or lava orient themselves with the Earth's magnetic field, just like a compass needle. When the rock solidifies, this magnetic orientation is preserved and can be detected with a sensitive instrument called a magnetometer. Under the right conditions, this magnetic alignment can also occur in sediments. Changes in the Earth's magnetic field can, therefore, be interpreted from the magnetic orientations recorded in rocks and compared with the orientation of the present magnetic field.

In 1929, a Japanese geophysicist named Motonari Matuyama published the results of his research on changes in the magnetic field. He had noticed that the magnetism of rocks generally pointed either north (like today's magnetic field) or south. Although his theory was controversial and not accepted for many years, eventually a history of the Earth's magnetic reversals was compiled with the help of advances in the radiometric dating of rocks.

During World War II, the military developed technology for studying the sea floor. The results of that work and the instruments for those studies became available to other scientists in the 1950s for increasingly detailed studies of topography, gravity, seismicity, heat flow, and paleomagnetism. Geophysicists on research ships that were towing magnetometers discovered a pattern of multiple magnetic stripes, each 12 to 18 mi (20–30 km) wide, across the sea floor. The stripes seemed to be parallel to and symmetrical across midocean ridges (see Fig. 7, p. 9).

Meanwhile, other geophysicists were compiling data about apparently anomalous magnetic orientations in rocks worldwide. These deviations made it appear that the Earth's magnetic poles had gradually changed position. Plots of these pole positions that show this apparent movement of the magnetic poles are called 'polar wandering curves', although changing pole positions largely record the movements of tectonic plates. This work shows that Earth's magnetic field has remained normal or reversed for as little as 100,000 years to as much as several million years.

Geomagnetic polarity reversals occur when the Earth's magnetic field reverses, or flips, from one near- axial position to the other, for example from north to south. Figure 20 (p. 25) shows that the Columbia River Grande Ronde Basalt flows termed 'N' have normal magnetic polarity. The crystals or grains of magnetite and other iron-rich minerals in each of these flows are oriented with the Earth's magnetic field of the time of their eruption; they would have normal polarity if the flow were emplaced today because they would align with the north magnetic pole. Flows labeled 'R' have reversed magnetic polarity because the Earth's magnetic poles were reversed during that time. That is, a compass needle during "R" times would align with the south magnetic pole. The numbers associated with the N or R flows indicate the sequence of their eruption, '1' being erupted before '2'. Geomagnetic excursions (denoted as 'E') occur when the Earth's magnetic field drifts dramatically from a near axial position without a complete reversal, and geomagnetic polarity transitions ('T') record orientations of the geomagnetic field that are intermediate between complete reversals.

Geologists studying volcanic rocks in particular have combined the use of paleomagnetism with dating, chemistry and mineralogy, and stratigraphic studies to map distinctive rock units and correlate them with like units over broad areas, as well as to reconstruct the history of rotation of rock units (Beeson and others, 1979; Wells and others, 1998). As noted in Part I of this book ("Lahars, Tephra, and Buried Forests", p. 34), geologists have used secular variation, the drift of the magnetic field over a few centuries, to estimate the age of rocks that were erupted from Mount Rainier within the past few thousand years. ■

1.0 1.6 Near the 40th Street exit, you travel diagonally through the core of the west-southwest-trending Yakima Ridge anticline, a fold that arches the lava beds. The houses on the hillside to the northeast sit on the Wanapum Basalt.

1.5 2.4 MP 200. For about a mile here are some of the famous orchards and vineyards that provide revenue for the Yakima Valley. Agricultural products from here are shipped worldwide. The temperature and general climate of this area help foster a robust agricultural output that includes fruits, wine, and hops. A mere 7 in. (18 cm) of annual rainfall here necessitates irrigation of the orchards. Water demands are intense in the Yakima River valley: more than 97 percent of surface water is used for irrigation (Solley and others, 1998), and as much as 60 percent of the groundwater goes for irrigation (Vaccaro and Sumioka, 2006).

2.6 4.2 **OPTIONAL SIDE TRIP:** MP 199. You can see the terminus of the Tieton Andesite flow by turning south onto Ackley Road for 0.1 mi (0.16 km) and then right on Powerhouse Road for about 100 yd (100 m). The Tieton Andesite flow is the largest lava flow from the Pliocene and Pleistocene Goat Rocks volcano. (See Leg H, p. 132, mile 29.5.) Swallows have taken advantage of fracture pockets in the entablature here to build nests.

On the lava columns are restored pictographs originally painted by some of this area's indigenous peoples (Fig. F-2). However, public access is now closed to protect the pictographs. An informational resource about the art is "Petroglyphs of Central Washington" by Cain (1950). There is no water or restroom at the site.

The Tieton Andesite is noteworthy because it is thought to be the world's longest andesite flow, more than 49 mi (79 km) from source to terminus (Swanson, 1990). Andesite flows are generally too viscous to flow far from their source. The unusual length of the Tieton flow is attributed to its having been confined to a pre-existing stream channel, the ancestral Tieton River canyon. Notice that it now forms a ridge. The deposits that originally confined the flow have since been partially eroded away, and the resulting landscape is described as having 'reversed topography'. Swanson and others (1989) dated the flow to 1 Ma and noted that it was reversely magnetized. Hammond recently dated the flow to 1.64 Ma using Ar-Ar methods.

As you leave this site, you pass through the north limb of the Yakima Ridge anticline, through which the Naches River has cut a notch. *Remember to compensate for mileage along the side trip.*

2.8 4.5 Cross the Naches River. The plateau area to the south dotted with houses is underlain by the

Tieton Andesite flow and is known as Naches Heights. This reach of the Naches River is a good apple-growing area because of the well-drained alluvial soils and moderate climate. Notice that the lava flows dip toward us—you are now traveling through the Naches syncline.

3.5 *5.6* Stoplight at Old Naches Highway.

4.8 *7.7* The rounded features in the distant hillside to the left are lava flows with columns arranged like a fan, most likely related to cooling within lava tubes. The highway traverses the lower Naches terrace, an abandoned flood plain.

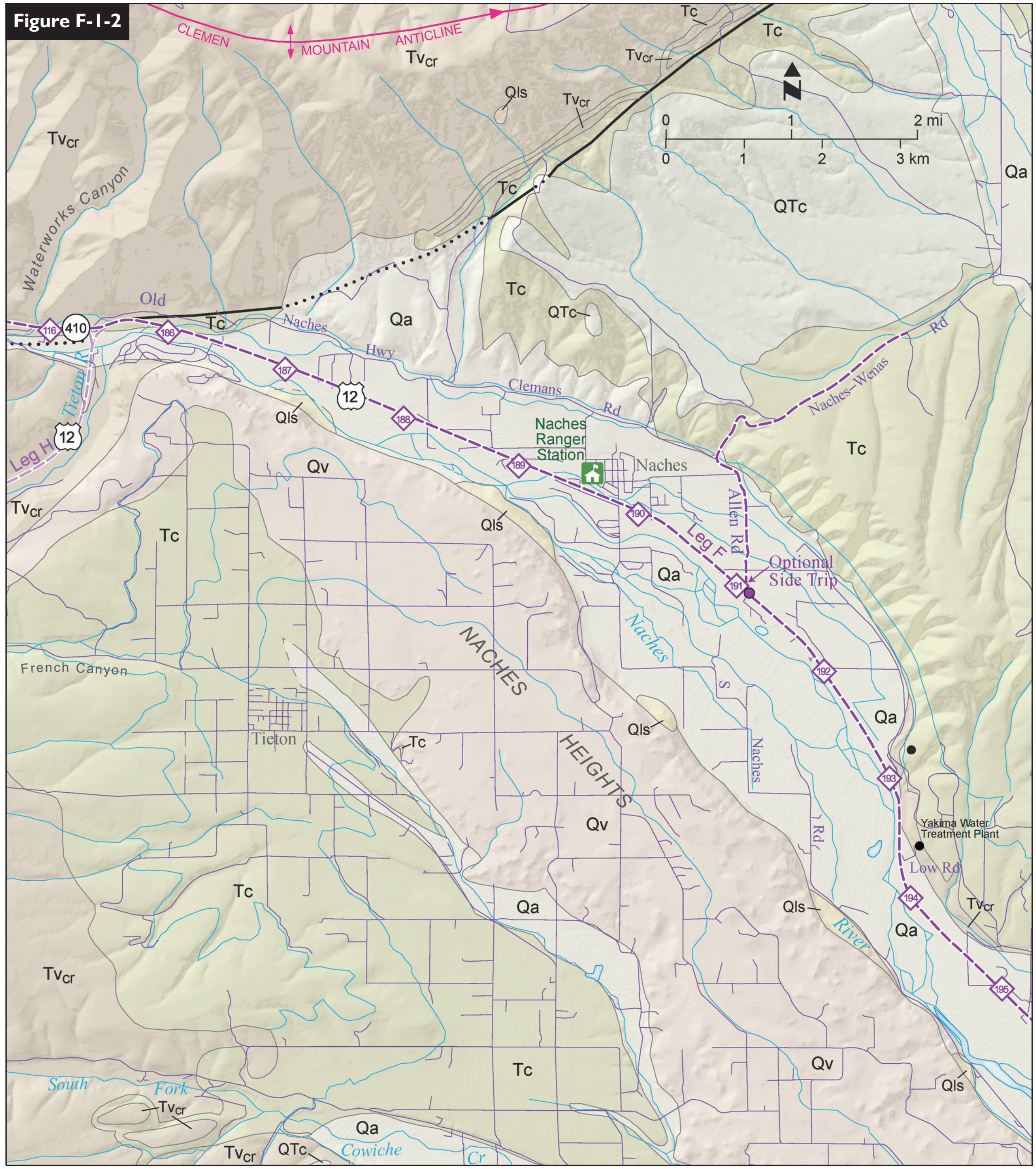
7.0 *11.3* Kershaw Drive. The cliff on the right is made up of the top flow of the Wanapum Basalt of the Columbia River Basalt Group. The youngest unit in the Wanapum Basalt is about 14.5 Ma.

7.8 *12.6* Yakima water treatment plant at Low Road. On the right, sedimentary interbeds lie atop the Roza and Frenchman Springs Members of the Wanapum Basalt and beneath the Pomona Member of the Saddle Mountain Basalt, all parts of the Columbia River Basalt Group.

8.4 *13.5* The water power station here is situated at the westernmost extent of the upper Wanapum flows. Some of the Wanapum flows are invasive into the generally coeval Ellensburg Formation in this area; that is, because of their greater density, they sank into the soft sediments and squeezed between layers. Many of the older Grande Ronde lava flows traveled farther west in this area.

8.8 *14.1* The white horizontal beds in the distant rounded hills on the right are composed of the Ellensburg Formation; the type section is exposed there. Note the shape of hills, which is determined by the softer sediments (Fig. F-3). The Ellensburg Formation here is made up of coarse lahar runouts, conglomerates, and interbedded pumiceous and ashy, stream-worked deposits that were laid down between approximately 7 and 13 Ma. Smith (1988a) reported ages of 7.4 to 13.3 Ma using K-Ar dates from tuff and pumice in combination with stratigraphic relations with other dated rock units. These Ellensburg Formation deposits are the distal or downvalley facies of the lahars produced by Miocene volcanoes. Although the volcanoes them-

Figure F-1-2



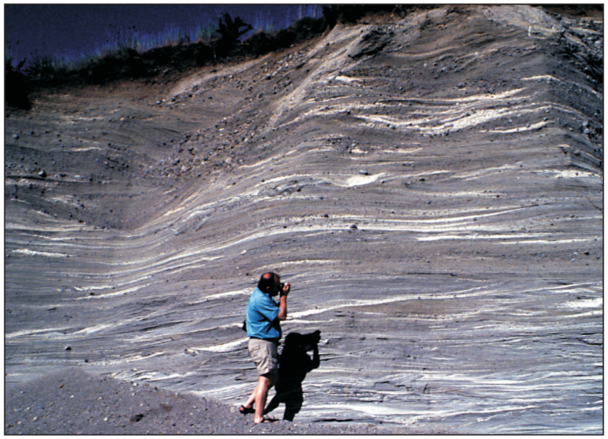


Figure F-3. Geologist Matt Brunengo examines pumice from fluvial deposits of the Ellensburg Formation along Wenas Road north of Naches. The bedded fluvial material sits on several massive laharic units. Whitish discontinuous caliche soils have developed atop these lahar deposits. These Miocene-age lahars were generated by eruptions in the Cascade Range about 12 to 4 m.y. ago. Geologist Paul Hammond has made chemical correlations of likely intrusive bodies with volcanic sediments of the Ellensburg Formation and has identified at least six large dacite plugs in the Cascade Range east of Mount Rainier that are remnants of domes or dome-producing volcanoes that were the sources of Ellensburg. (See Fig. 16, p. 20.)

selves have since been eroded away, these deposits provide important evidence of the past eruptions.

Ahead, an N_2 flow of the Grande Ronde Basalt of the Columbia River Basalt Group caps the Cleman Mountain anticline.

10.4 *16.7* **OPTIONAL SIDE TRIP:** Allan Road/Naches–Wenas Road to volcanic deposits. To see laharic and fluvial deposits of volcanic origin, you can turn right onto Allan Road, then left on Naches–Wenas Rd at 0.8 mi (1.3 km), pass under the old aqueduct (1.1 mi or 1.8 km), and proceed for 0.7 mi (1.1 km) along the type section of the Ellensburg Formation. You are traveling 'up section', through successively younger deposits, as you drive up the grade. The Ellensburg Formation is noteworthy for its assemblages of volcanic deposits, including lahars and lahar runouts whose main lithic component is a hornblende-rich dacite. These deposits were generated by explosive volcanism in the Cascades about 12 Ma, but they

photo by Dvae Norman

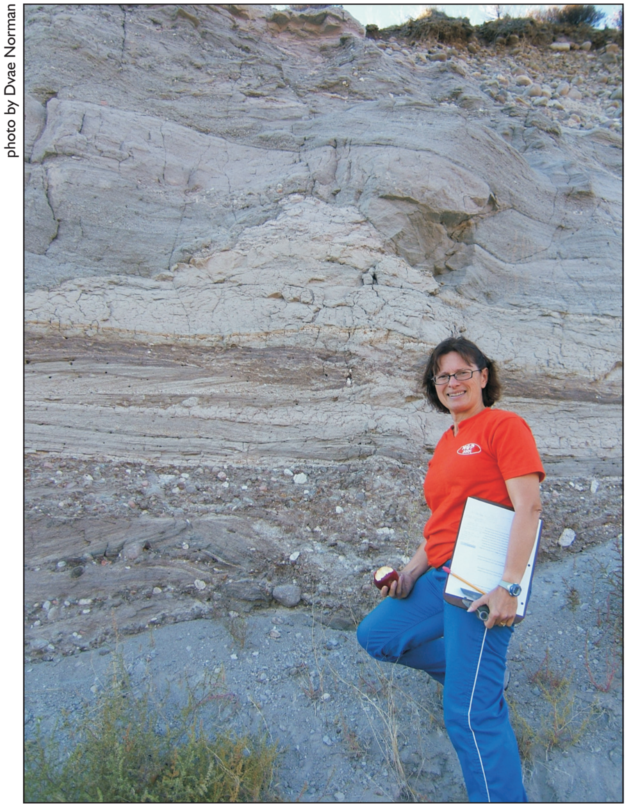


Figure F-4. Ellensburg Formation beds showing classic sedimentary features, such as dish structures, crossbeds, flaser bedding, and graded bedding. This outcrops is located along the Naches–Wenas Road.

are one of the few relics of this volcanism aside from some recently discovered vent areas. The volcanoes that produced these slurries and volcanic floods have largely been eroded away. You can see many classic sedimentary features (such as dish structures, crossbeds, flaser bedding, and graded bedding) in the Ellensburg deposits (Fig. F-4).

Continue to 1.9 mi (3 km) for a safer place to turn around for the return trip to Naches. *Remember to compensate for mileage along the side trip.*

10.5 *16.9* MP 191.

11.0 *17.7* Extensive gravel bars in the river on the left are evidence of large-scale sediment transport. Features such as gravel bars and point bars are continually

Figure F-5. A landslide scarp is visible a little over halfway up the hill behind the house between MP 188 and 187 on US 12.

being modified, especially during years of high river discharge.

11.2 *18.0* Entering the town of Naches. The elongate hills and valleys, extending north of here and trending north-northwest, make up the Yakima Fold Belt. (See "The Yakima Fold and Thrust Belt", p. 17.)

11.7 *18.8* U.S. Forest Service Naches Ranger Station on the right.

12.5 *20.1* MP 189. Notice the fan-like arrangement of joints and columns in the lava flows on the slopes across the river to the left. These formed as the lava cooled; they are oriented perpendicular to the arched cooling surface. Ahead is the Cleman Mountain anticline, cored by complex thrust faults (see mile 17.4).

13.0 *20.9* On the left are more fanned columns. These are sometimes informally called 'Mayan Sunrise' features.

13.8 *22.2* A landslide scarp is visible on the left (Fig. F-5).

14.0 *22.5* On the right, note an alluvial fan that emanates from the hills on the north.

16.2 *26.1* Junction of US 12 with SR 410. This marks the end of Leg H, which follows US 12 from SR 123 and over White Pass to this location. Continue west on SR 410.

16.5 *26.4* MP 116.

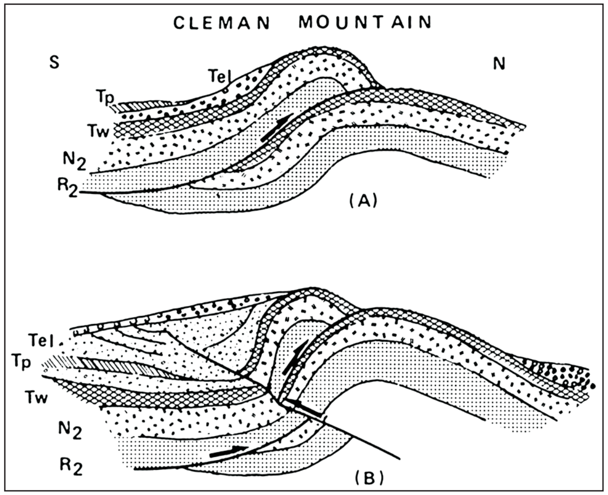


Figure F-6. Generalized cross sections of the Cleman Mountain structure as interpreted by R. D. Bentley and N. P. Campbell. Section A shows a growing anticline in post-Wanapum Basalt time (~14.5 Ma). Section B shows the structure at post-Saddle Mountains Basalt time (~6 Ma). Geologic units shown are Tel, Ellensburg Formation; and the following members of the Columbia River Basalt Group: Tp, Pomona Member of the Saddle Mountains Basalt; Tw, Wanapum Basalt; N_2 and R_2, members of the second normal and second reversed polarity intervals, respectively, of the Grande Ronde Basalt. (See Fig. 20, p. 25, for the stratigraphic position of these units.)

16.8 *27.0* The columnar Tieton Andesite flow of Pleistocene age is across the Naches River to the left and a little behind us. Note the fan-like flow features mentioned earlier. These may form owing to differential cooling as water from lava-dammed streams inundates the top of the cooling flow and percolates down into cracks as the lava cools. The Tieton Andesite may have been too viscous to create extensive networks of lava tubes, such as those that form in basaltic lava flows. (Ape Cave at Mount St. Helens is a fine example of a lava tube. It is in basalt.) Caves that formed where parts of columns have fallen away from the exposure were once used by local tribes as shelter and for storage.

Recreational rafters rush to float the Tieton River in the autumn when Tieton Reservoir is lowered in preparation for storage of winter precipitation. They put in about 17 mi (27.4 km) up US 12.

photo by Beth Norman

Figure F-7. Ellensburg Formation deposits, including lahars and lahar-derived sediments, are exposed in a quarry. The equipment suggests scale.

17.4 *28.0* Here you are entering a canyon cut in south-dipping Miocene Columbia River Basalt. Cleman Mountain is the highest of the Yakima Fold Belt anticlines at more than 600 m (1970 ft) of amplitude. Mapping of the fold by geologists Robert Bentley and Newell Campbell showed that this structure is complexly faulted, both by a south-dipping thrust fault and by a later north-dipping back thrust (Fig. F-6). The south-verging fault, which is along the crest of Cleman Mountain, has been called a 'piggyback thrust' by some workers because it evidently overrode an older thrust that verges to the north (Tolan and others, 1989). The Sanford Pasture landslide probably moved along several weak interbeds that may be made up of sediments, rubbly tops or bottoms of basalt flow layers, or palagonite breccia, basaltic debris partially quenched to glass by cooling in contact with water.

17.7 *28.5* The gnarled-looking outcrop on the right is a sheared breccia, part of the folded thrust fault in Cleman Mountain known as the Waterworks Canyon fault.

18.4 *29.6* Trailhead to Mud Lake, which sits on the Sanford Pasture landslide. Mud Lake (out of sight above the road) is a sag pond. It is formed in a depression between slide blocks. Rotated blocks of basalt are

Figure F-8. Horseshoe Bend dike. This dike-like feature near MP 114 is cemented breccia (caliche) of the Sanford Pasture landslide, which originated on Cleman Mountain behind the viewer. Cougar Canyon is in the background. View is to the southwest.

visible in several places along the roadway. The main body of this late Quaternary slide appears to be stable at present. However, if you look carefully at the hillsides, you may notice smaller, younger slides within the blocks of the original slide.

18.6 *29.9* MP 114. An Ellensburg Formation lahar deposit is exposed in a quarry near the bend in the road (Fig. F-7). A thick deposit of alluvium of unknown age cores the prominent terrace adjacent to the river. Also at mile 18.6 is Horseshoe Bend. This curve in the river channel is the only sharp meander along the Naches River. The meander likely became entrenched during the uplift of the Cleman Mountain anticline (Campbell, 1975). The river used to flow east of the highway but is now confined to a channel west of the road. Horseshoe Bend is of historic significance in that it was an obstacle to early foot travel. This meander is controlled by the local geology—the river could cut easily through the unconsolidated landslide deposits, but was forced to turn southwestward where it flowed along the basalt bedrock now exposed in the lower quarry walls.

The large mass of rock across the river straight ahead on the south side of the highway is a dike-like pillar of debris of the Sanford Pasture landslide that has been cemented by mineral-rich fluids along a fault (Fig. F-8). This fault breccia overlies the entablature of the in-place R_2 flow of the Grande Ronde Basalt and is in lateral contact with a large gravel bar extending eastward into the river channel. The dense patterns of narrow trails, called terracettes, on hillsides on the side of the valley are a result of animals moving along the contour as they graze.

If you look north from here, you can see the easternmost edge of the Sanford Pasture landslide and more fault breccia on the skyline. The breccia is roughly across the valley from the landslide block on the south side of the river.

Notice that the river bed to the right (northeast) is dry. The meander was cut off, probably by the construction of the road. Gravels have been mined out of old river deposits here. The upper walls of the gravel pit expose a terrace of Quaternary age whose origin is still a matter of discussion. The terrace may consist of landslide material of Miocene-age sedimentary rocks overlying the top of an unspecified R_2 flow of the Grande Ronde Basalt. At this location the flow is invasive into the surrounding sediments.

19.3 *31.2* In the next 5 to 6 mi (8–9.6 km), the highway traverses and is cut into deposits of the large Sanford Pasture landslide. Much of the deposit within the valley is composed of basalt blocks and alluvium that slid southward from Cleman Mountain. To appreciate the scale of this landslide, consider that Cleman Mountain, the ridge to the northeast, is the landslide's headscarp as well as the largest anticline in the Yakima Fold Belt (elev. 6000 ft or 1829 m) (Fig. F-6). The landslide likely moved along a weak interbed or interbeds within the Columbia River Basalt flow sequence, or possibly along a thrust fault plane between the R_2 and N_2 lava flow sequences.

19.4 *31.2* A roadcut on the right exposes landslide deposits. Hyaloclastite deposits are present within the landslide debris at the west end of the cut.

21.0 *33.8* For the next 0.5 mi (0.8 km), rubbly basalt and more landslide jumbles are exposed on the right.

22.0 *35.4* Good examples of stone stripes are off to the right (Fig. F-9).

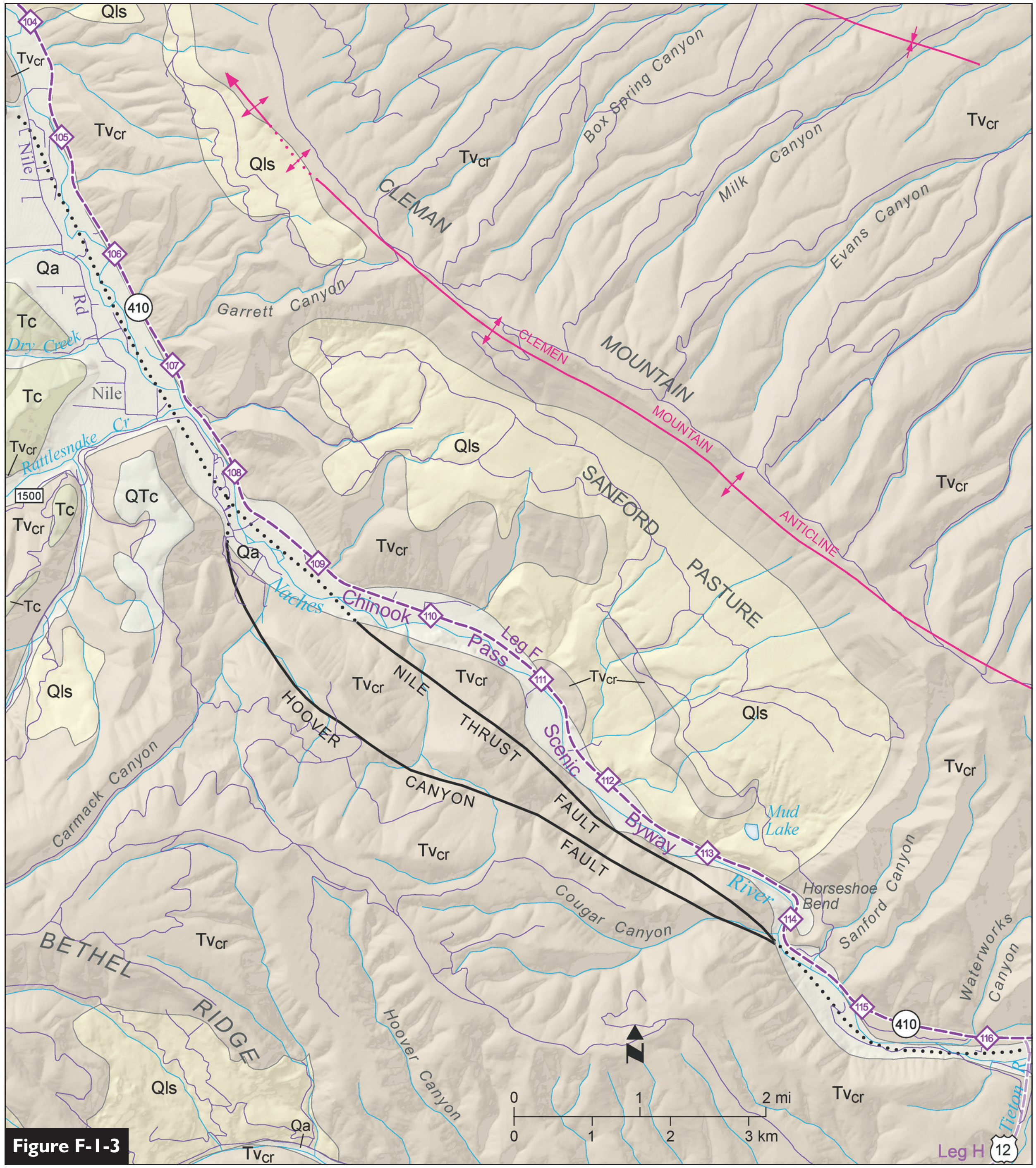


Figure F-1-3

Figure F-9. Stone stripes on a valley wall north of SR 410 near Naches. As with other types of patterned ground, the processes that form them are complex and vary somewhat from location to location. The stripes shown range from about 2 ft to 12 ft (0.6-3.7 m) in width. This photo was taken in the fall, when the color contrast tends to be greatest.

22.4 *36.0* MP 110. As the road curves to the right, you can see on the right (north) side an outcrop of blocky basalt with an interbed of river gravels and cobbles (Fig. F-10). The clasts of the interbed are imbricated, and a close inspection of the basalts reveals pillow structures, indicating that the lava flowed into water. This outcrop may be in place (not a part of the landslide). Because of the curve and visibility limitations, this location is not a good place to stop.

24.1 *38.8* **OPTIONAL SIDE TRIP:** Nile Road loop. At the intersection with Nile Road (to the west), the synclinal dip of Columbia River Basalt on both sides of the highway is easy to see. Via Nile Road from 0.2 to 0.5 mi (0.3–0.8 km), the basalts are hackly and fractured with several flows evident. About 1.4 mi (2.2 km) west of SR 410, Nile Road intersects FR 1500 up Rattlesnake Creek. Nile Road runs parallel to SR 410 and rejoins it roughly 3.2 mi (5.1 km) west of the FR 1500 intersection, at about mile 27.8 in this roadlog. A good place to view the Ellensburg Formation is from the Nile Library at 0.4 mi (0.6 km) from the 1500 Road junction. A side trip 0.6 mi (1.0 km) up FR 1500 provides views of fluvial sediments and lahar deposits of the Ellensburg Formation across the valley (Fig. F-11). From mile 1.5 to 7.5 (km 2.4–12.0) along

photo by Dave Norman

Figure F-10. An outcrop of blocky basalt with an interbed of river gravels and cobbles near MP 110.

Nile Road, you can see excellent examples of both spectacular columns and entablatures (**Fig. F-12**) in the lava flows across the canyon to the northwest. There, an N_2 flow of the Grande Ronde Basalt overlies an R_2 flow. About 9.4 mi (15 km) from the junction of SR 410, you can park in a quarry south of the road. The extensive slope to the east is Devils Table, a southeast-dipping lava flow of Grande Ronde Basalt. At about 10.1 mi (16. 2 km), FR 1502 (gravel) leads to a viewpoint (11.6 mi or 18.6 km from SR 410) where there is a fine view to the west of Rattlesnake Creek basin, Mount Aix, and other features (Fig. F-13).

Remember to compensate for mileage along the side trip.

25.1 *40.4* Sediments of the Ellensburg Formation are visible in cliffs across the river to the left. At least 800 ft (244 m) of Ellensburg sediments have been measured in the center of the Bethel Ridge anticline. Near Dry Creek, outcrops in the hillside to the west are Ellensburg Formation; the competent layers are lahar deposits. The upper part of Ellensburg section has leaf fossils in this location. Here landslide material of rubbly basalt overlies Ellensburg sediments. This is the northwest edge of the Sanford Pasture landslide from Cleman Mountain.

A roadcut on the right exposes sediments of an unnamed interbed, about 16 Ma in age, near the base of the Grande Ronde Basalt sequence. The

photo by Beth Norman

Figure F-11. Nearly horizontal layers of laharic deposits of the upper Miocene Ellensburg Formation. The bluff is more than 800 ft (245 m) high. View is to the north at the intersection of Nile Road and FR 1500.

buff-colored silts and sands contain mica, and therefore they may have originated to the north or east, perhaps from highlands near modern-day Wenatchee or from the Okanogan highlands.

25.9 *41.7* Continue driving through a syncline. From here to about MP 105, Grande Ronde lava flows of the Columbia River Basalt Group dip steeply to the road on the north side of valley and strike roughly parallel with the valley, whereas the beds on the southwest have a shallower dip (Fig. F-14).

26.2 *42.2* MP 106. Note the very steeply dipping basalt columns on the right (north) for the next 0.7 mi (1.1 km) to the west as you drive in the syncline.

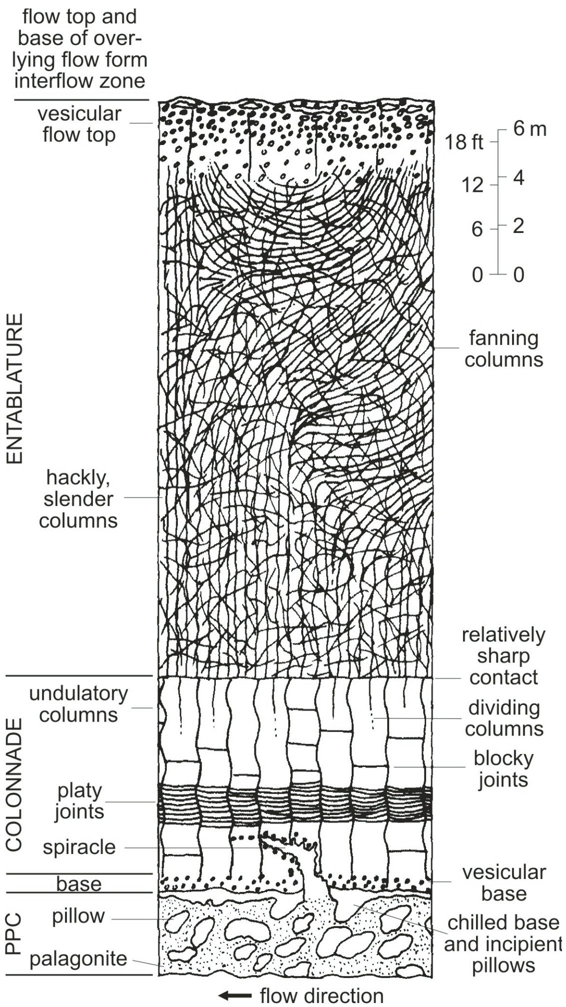
27.8 *44.7* Junction with the east end of Nile Road on the left. If you took the Nile Road/FR 1500 side trip, this is where you would rejoin the main route of this leg. More basalt is on the right.

28.4 *45.7* MP 104.

29.1 *46.8* Bald Mountain Road (FR 1701) on the right extends up Benton Creek.

29.2 *47.0* Elk Ridge Lodge on the left.

29.6 *47.6* Fractured and faulted Grande Ronde Basalt with slickensides is on the right (westbound), as is the contact of the Columbia River Basalt Group with



the underlying Fifes Peak Formation (sandy bed) of upper Oligocene to lower Miocene age (Fig. F-15).

30.4 *48.9* MP 102, Squaw Rock area. FR 1702 (mi 30.1 or km 48.4) on the right leads up Rock Creek near here. A Fifes Peak phyric andesite lava flow and breccia also are exposed along a curve on the right.

31.3 *50.4* MP 101. Eagle's Nest development area. Although this is not a good place to stop, it is worth noting that there are exposures of a poorly sorted (laharic?) deposit of Fifes Peak age overlying weathered pink andesite. A conglomerate overlies eroded lava flows and breccias. The slickensides visible where the conglomerate is in contact with the andesite on the east indicate that these rocks have been deformed (Fig. F-16).

32.1 *51.7* Pinecliff.

32.3 *52.0* MP 100. Enter Wenatchee National Forest; a turnout with information about the Mather Memorial Parkway is on the right.

32.9 *52.9* Slightly past the turnout, on the northeast side of the highway (and slightly south of Cottonwood

Figure F-12. *(left)* Diagrammatic cross section of a typical flow in the Columbia River Basalt Group showing, in idealized form, basal colonnade, jointing patterns, and other structures. PPC is pillow-palagonite (hyaloclastite) breccia complex, which forms where the base of a flow enters water. Spiracles are vents created where steam explosions occur at the base of flows. Columnar jointing generally forms perpendicular to local cooling surfaces; however, formation of these jointing features is complex (see, for example, Long and Wood (1986) and Schaefer and Katterhorn, 2004). Modified from Swanson (1967) and Mangan and others (1986).

Figure F-13. *(below)* Panoramic view from the Mount Aix Viewpoint (elev. 3300 ft or 1006 m), looking west over the Rattlesnake Creek basin. This viewpoint is on FR 1500 about 11.6 mi (18.7 km) west of the SR 410 junction. FR 1500 is accessed 2.3 mi (3.7 km) west of 410 off the Nile Loop Road, its east junction. Timberwolf Mountain is the southern remnant of a large andesite volcano that has associated rectilinear dikes; ages on the volcano are about 25 to 27 Ma. Bismarck Peak (7585 ft; 2312 m) and Mount Aix (7766 ft; 2367 m), the highest peaks of Nelson Ridge, are the highest exposures of Tertiary-age volcanic rocks in the Cascade Range. The east margin of the Mount Aix caldera passes along the east face of Dog mountain. These Wildcat Creek tuffaceous sediments, first described by Swanson (1964, 1978) might be fine-grained equivalents of the Ohanapecosh Formation (Vance and others, 1987).

Figure F-14. Steeply dipping columnar lavas of the Grande Ronde Basalt near MP 106 along SR 410. View is to the northwest.

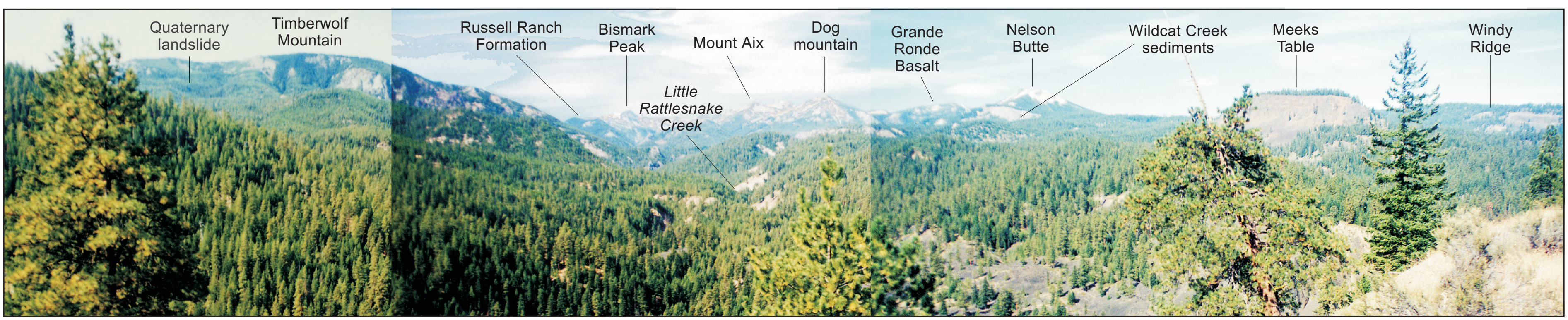


photo by Dave Norman

Figure F-15. Complexly faulted and fractured Grande Ronde Basalt with slickensides and contact (at shoulder level) of the Columbia River Basalt Group with the underlying Fifes Peak Formation (sandy bed) of uppermost Oligocene to lower Miocene age. View is to the north, slightly east of MP 103.

Creek Campground), nearly vertical dikes intrude a Fifes Peak lava flow from Edgar Rock volcano (Fig. F-17). Rocks in some parts of the outcrop have been worn away more than others, possibly because they were weakened by hydrothermal alteration when the volcano was active, as well as being sheared. This might be particularly important because we are near the core of the Edgar Rock volcanic edifice. Scientists studying the rocks in the Mount St. Helens Crater, for example, noticed that rocks there were similarly sheared where mechanical stresses were exerted as viscous magma pushed up through the brittle rock in the throat of the volcano (Swanson and others, 1995). This process weakens the internal strength of a volcano and encourages susceptibility to collapse as well as to erosion. The dikes and sheared rocks were formerly mapped by Carkin as Eocene-age volcanic rocks of Gold Creek. However, Hammond dated one of these dikes near the campground at 27.7 Ma and found that its chemistry is similar to that of the Edgar Rock volcano. This suggests that these Gold Creek rocks are part of an intrusive center that was buried by Edgar Rock volcano and that they represent the oldest part of the Fifes Peak Formation.

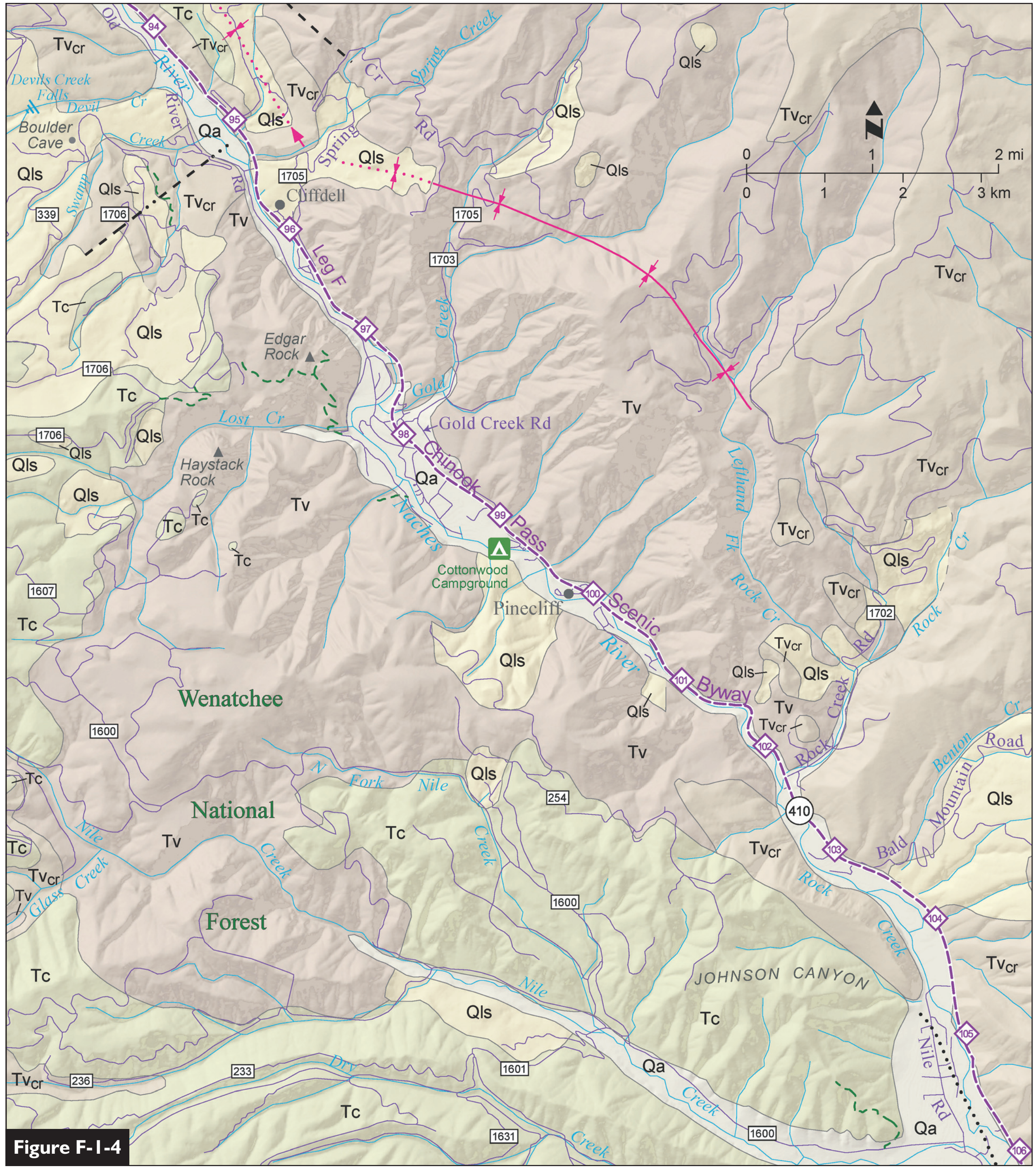


photo by Beth Norman

Figure F-16. Poorly sorted (laharic?) deposit of Fifes Peak age overlying weathered pink andesite. A conglomerate overlies eroded lava flows and breccias.

33.0 *53.1* Cottonwood Campground on the left (westbound).

33.3 *53.6* MP 99. FR 1703 (Gold Creek Road) on the right loops to FR 1705. Many north-trending, nearly vertical dikes cut steeply dipping beds of volcanic breccias here. There are so many dikes that the relation between the steeply dipping bedding planes and dikes is confusing at first glance. Good examples of spheroidal weathering are exposed about 300 ft (~100 m) up FR 1703 from SR 410. These rocks yielded Ar-Ar ages from 30 to 26 Ma and include breccias, conglomerates, and intrusive dikes that have been sheared—there are no other rocks similar to them in the area.

Haystack Rock is composed of andesite of Edgar Rock volcano. An outcrop on the east side of SR 410, slightly south of Cliffdell (at mi 36.0 below), exposes bedded breccias that are interpreted to be part of the compact lava flow and lava breccia, as well as laharic deposits of the volcano. On clear days there are grand views of mountain peaks, including Mount Rainier to the west.

Figure F-17. Dikes intrude the beds of Edgar Rock volcano, one source of the Fifes Peak Formation volcanic rocks, along SR 410 near Edgar Rock. This is near the base of the Edgar Rock deposits. The bedding (arrow) here strikes about 350 degrees and dips 30 degrees to the west. The dikes of a volcano commonly radiate about the center of volcano like the spokes of a wheel; therefore, by evaluating the geometry of the dikes of Edgar Rock volcano, Carkin (1988) was able to estimate the location of the volcano's central edifice to the southwest of here. The dikes range from 1 to 3 ft (0.3–0.9 m) thick. View is to the northeast. Photo by Brad Carkin.

33.7 *54.2* Gold Creek Station and Mercantile. Edgar Rock, a Fifes Peak Formation volcanic remnant of Miocene age, is ahead and lies southwest of the highway (Fig. F-18). Carkin (1988) estimated an age of about 26 Ma for Edgar Rock volcano. He used the orientation of the radiating dikes (Fig. F-17) to infer that the main body of the volcano was to the southwest of the present remnant. The dip of the beds to the northeast may reflect that of the outer flank of the original cone at that location.

33.9 *54.6* Edgar Rock is straight ahead (westbound).

34.0 *54.7* A subhorizontal dike cuts the tilted rocks on the right. Rocks of the Ohanapecosh Formation crop out in Gold Creek about 0.6 mi (1 km) upstream of the road.

Figure F-18. Edgar Rock at Cliffdell. This remnant of the volcano, about 1300 ft (400 m) in height, consists of lava flows and laharic breccias that dip 45 to 50 degrees to the northwest. View is approximately to the west. Photo by Brad Carkin, taken in the late 1980s.

34.6 *55.7* Old River Road on the left. Use great caution here at this blind curve! The turnout on the left at 34.8 mi or 55.7 km (southwest of the highway) is more safely accessed by eastbound travelers. From the turnout there is a view across the river to Edgar Rock. The roadcut on the northeast side of the highway exposes altered volcanic rocks of the volcano that overlie a fascinating mish-mash of volcanic dikes and megaclast-bearing lahar or debris avalanche deposits, the source of which is unknown. Note the cross-cutting relations and sheared dikes. These dikes are likely part of a radial dike swarm of Edgar Rock volcano. The base of the volcano lies slightly to the north. Deposits of the large alluvial fan of Gold Creek cap the cut and have controlled the course of the river and therefore the location of the highway.

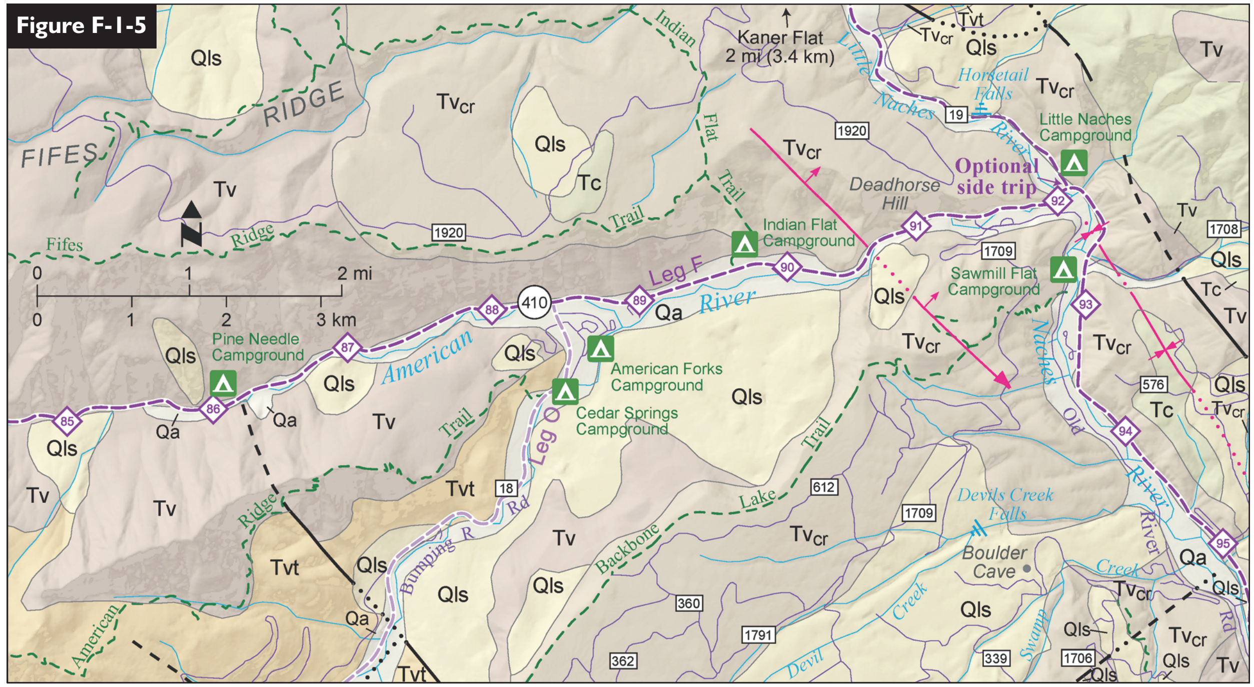
35.2 *56.6* Edgar Rock is to the left (westbound) across the river slightly before MP 97. Dikes, flow breccias, hyaloclastites, and a variety of volcanic deposits related to the Edgar Rock volcano are exposed along this stretch of the highway.

35.8 *57.6* FR 1705 on the right connects with the other end of the FR 1703 loop (Spring Creek Road).

36.0 *57.9* Cliffdell. Whistling Jack Lodge and Shell station at mi 36.1 (km 57.8) adjacent to Edgar Rock volcanic rocks.

photo by Beth Norman

Figure F-19. Gravels on top of Grande Ronde Basalt near MP 92 that are likely alpine glacial outwash deposits of Evans Creek age (22–15 ka).



36.8 59.2 Old River Road is on the west (left, if westbound). It accesses Boulder Cave and Devils Creek Falls. On the north are active landslides in Edgar Rock volcanic rocks. Boulder Cave is about 3 mi (4.5 km) to the west on FR 1706-200. Those wishing to hike through the cave, which is now run by a concession, should bring a good flashlight. (Most spelunkers carry back-up lighting as well.) The cave was formed when erosion of interbeds between two Columbia River Grande Ronde Basalt N_2 lava flows created a void and allowed blocks of the overlying flow rock to collapse. The cave is closed from November 1 to April 1 to protect a hibernating colony of Townsend's big-eared bats. Few locations provide the stable environment and lack of disturbance that these bats require for hibernation. Explorers passing through the cave during the winter would waken the bats, causing them to use valuable energy moving around and changing roosts.

38.1 61.3 Grande Ronde Basalt north of the highway exhibits columns with a hackly entablature.

38.3 61.6 MP 94. Grande Ronde Basalt.

38.9 62.6 Sawmill Flat Campground on the left. Here, Grande Ronde lavas define a syncline whose axis runs roughly northwest through the valley.

39.1 62.9 A pullout with information on the Mather Memorial Parkway is on the right (north side).

39.4 63.4 MP 93. This is not a safe place to stop, but note that there are pillows at the base of the Grande Ronde Basalt in the roadcut on the east side of the road. The presence of pillows indicates that, as the flows advanced from the east into higher ground to the west, the lava was flowing into water that may have been ponded. Thus highlands existed here, although as noted in the Introduction, most uplift of the Cascade Range postdates 15 Ma (Reiners and others, 2003). Note that the lava flows to the west across the river dip east.

39.6 63.7 FR 1708 on the right accesses Milk Creek and the 'Devils landslide'. This area may be worth a side trip (not detailed here) on a gravel road to examine a large deep-seated landslide and its badlands topography of jumbled rock debris. The Naches Formation of Eocene age is exposed in the headscarp of the landslide. The Naches Formation rocks consist of micaceous, arkosic sands and abundant volcanic sediments deposited between about 44 and 40 Ma (Walsh and others, 1987). Its lower units comprise lava and rhyolite flows that may have originated from a vent near present-day Mount Clifty. Some of the units yield thunder eggs.

The Grande Ronde flows of the Columbia River Basalt Group exhibit classic columns with overlying entablatures in this area and for the next half mile or 0.8 km (Fig. F-12). Some columns are subhorizontal. Note that the beds dip to the west, so you are now east of the axis of the syncline.

40.2 64.7 **OPTIONAL SIDE TRIP:** Little Naches River and Raven Roost. (Remember to note the mileage and adjust for the distance driven.) The paved forest road (FR 19) on the right (north) extends up the Little Naches River to Little Naches Campground and accesses an optional side trip to the Raven Roost viewpoint area on FR 1902 (off leg map). More landslides are visible en route to the campground and from Raven Roost.

North of Little Naches Campground at Horsetail Falls and farther north, a fish ladder and weir are located in the axis of the syncline in Grande Ronde N_2 basalt. Slightly downstream are placer claims where miners reported finding gold in the

Figure F-20. Geologist Rob Viens examines flattened pumice from a pumiceous rhyolitic lapilli-tuff deposit along SR 410. Note the charred log projecting out of the deposit in the upper right. Carkin (1988) noted a radiometric age of about 20 Ma for the deposit. Samples of this deposit, provisionally named the "tuff of Indian Flat" by Hammond, have yielded K-Ar ages of about 25 Ma.

gravel at its contact with the bedrock. No obvious source for the gold, such as mineralized land in the drainage basin of the river, has been documented. Is it possible that the placer deposits are reworked gold from Naches sandstone, or derived from the abundant silicified and altered rhyolite lava flows in the Naches Formation? At the righthand curve not far after Kaner Flat (2.2 mi or 3.5 km), a roadcut exposes a bed of gravel, possibly correlative with nearby interbeds, at road elevation at the base of the flow.

To help visualize the amount of structural deformation in the last 5 m.y. in the bedrock near here, note that the Columbia River Basalt Group lavas lie in the Naches Valley at an elevation of about 2600 ft (793 m), yet at Manastash Ridge, 5 mi (8 km) to the northeast, those same lavas are exposed at about 6000 ft (1829 m) at the top of a fold—a total of 3400 ft (1037 m) of structural relief, presumably related to a regional combination of faulting and folding. Note also that the northwest alignment of the Little Naches and Naches River valleys is roughly parallel to, and likely controlled by nearby faults and folds, as well as by the Olympic–Wallowa lineament (OWL). Reidel and Campbell (1989) have described the structural features and aspects of this area.

photo by Beth Norman

Figure F-21. Platy jointing in an andesite flow of Fifes Peaks volcano with a thin tan pumice layer sandwiched between flow breccias. This outcrop is north of the highway near MP 87.

There are no signs for Raven Roost until the turnoff 2.6 mi (4.2 km) north of the highway. To get to Raven Roost, you must drive on an unpaved road for 14 mi (22.4 km) up FR 1902; this road is not recommended for trailers or large campers. From Raven Roost and the radio tower site, there are excellent views of Fifes Peaks, Mount Rainier, and the Cascade crest to the southwest, as well as the valley of Crow Creek into which feed several large landslides. At least one of the lakes in the valley, Crow Creek Lake, was formed by a large landslide and contains a submerged forest (not yet dated). This area is the southern margin of the OWL near where it meets the north-trending Straight Creek fault (see Fig. 14, p. 18), which bisects the North Cascades and is truncated at the OWL (see Fig. 5, p. 7).

Figure F-22. Fifes Peaks from the viewpoint along SR 410. The dark, castle-like mass in the center is an eroded caldera fill of welded volcaniclastic debris; arrows show its approximate contact with the pre-eruption caldera rim (Hammond and others, 1994). View is to the north.

Upon returning to SR 410, remember to compensate for mileage along the side trip.

Cross the Little Naches River. The route now follows the American River. On the right (north) are gravels that likely are glacial outwash deposits of Evans Creek age (22–15 ka) atop a Grande Ronde Basalt outcrop (Fig. F-19). Outcrops for the next several miles are basalt.

40.3 *64.8* MP 92 is at the west end of the Naches River bridge.

40.7 *65.5* FR 1709 on the left leads south up Devil Creek via Old River Road. FR 1709 provides good access to east side of the William O. Douglas Wilderness. Many landslides are exposed along FR 1709 from Boulder Cave to the headwaters of Devil Creek.

41.2 *66.3* For about the next 1.5 mi (2.4 km) Grande Ronde lava columns are oriented nearly horizontally and in places chaotically.

42.0 *67.6* Trailhead for Indian Flat Trail to the right.

42.9 *69.0* Indian Flat Campground on the left.

43.6 *70.2* A cut on the right exposes a light tan pyroclastic flow breccia of Fifes Peak Formation age that contains charred logs and flattened pumice, both preferentially aligned with the direction of the flow (Fig. F-20). Carkin (1988) obtained a date of about 20 Ma on this fragmental deposit, indicating that it may predate the eruption of the Grande Ronde flows. How was such an easily erodable fragmental deposit preserved? Perhaps by being covered by lava not long after being emplaced. The source of the pyroclastic flow deposit is not known, but it could have originated from any one of a number of volcanic centers, such as a dacite plug near Union Creek or other domes near Crystal Mountain.

Along the road, landslide blocks, probably of the upper N_2 flow of Grande Ronde Basalt, have been displaced downslope about 330 ft (~100 m). Many of the bluffs for the next 2.5 mi (4 km) surrounding this basin display headscarps and landslide blocks.

43.8 / *70.5* Turnoff for Leg O, Bumping Lake on FR 18/Bumping River Road, an 11-mi (17.5 km)-long route up the glaciated valley of the Bumping River from its confluence with the American River to Bumping Lake reservoir. Fine views of peaks to the south await as you head upstream in the American River drainage. The road passes volcanic and intrusive rocks and the deposits of large landslides originating from surrounding ridges.

44.0 / *70.8* Landslide blocks are common near here, slightly east of MP 88.

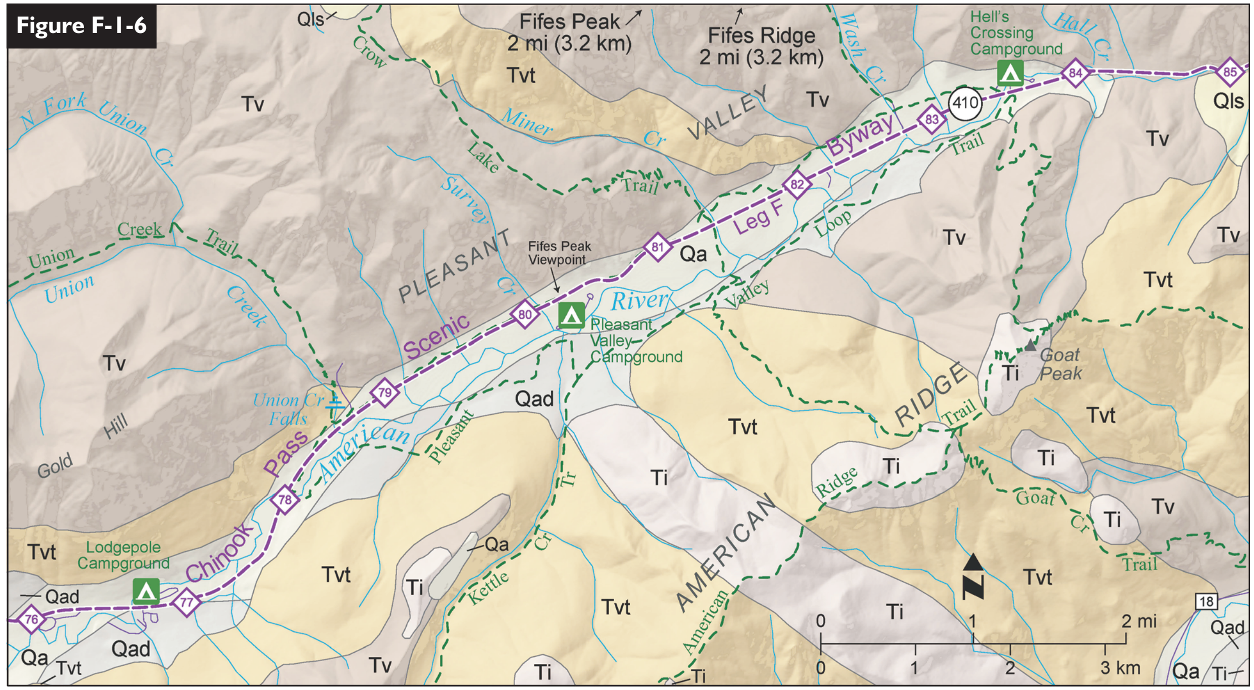
45.1 / *72.6* The turnout to the north (right) is in more landslide deposits.

45.3 / *72.9* Platy jointing is visible in an andesite flow of Fifes Peaks volcano with a pumice layer sandwiched between flow breccias (near MP 87)(Fig. F-21).

46.0 / *74.0* Pine Needle Campground is on the left. There are many breccias of the Fifes Peak Formation over the next few miles. Lava flows and breccias of underlying Goat Peak volcano are also exposed.

46.3 / *74.5* MP 86. Till deposits crop out in this area. Campbell (1975) concluded that this represents the "farthest advance of valley glaciers during the Pleistocene". The unconsolidated debris in roadcuts is probably morainal material from those glaciers. There are many landslides between Pine Needle Campground and Hall Creek near mile 48.1.

Figure F-1-6



46.6 / *75.0* Note the fragmental volcanic deposits of the Fifes Peak Formation that contain large blocks.

47.0 / *75.6* Fragmental deposits, probably of glacial origin, are in cuts on both sides of the road. Subrounded and faceted rocks such as those seen here commonly characterize glacial till and coarse outwash deposits. The house-sized boulder in the river slightly south of the highway is likely part of a landslide deposit.

47.3 / *76.1* MP 85. Outcrop of volcanic rocks with possible till deposited over it.

47.9 / *77.1* View of Fifes Peaks ahead to the north.

48.1 / *77.4* Cross the American River.

48.3 / *77.7* MP 84. Till and landslide deposits are visible here.

48.6 / *78.2* Hells Crossing Campground on the right (north) and the trailhead for Goat Peak Trail and Pleasant Valley Loop Trail on the left, with a view of Fifes Peaks ahead. The terminal moraine (not on map) of the most recent major alpine glaciation, which is called the Evans Creek glaciation (22–15 cal yr ka) at Mount Rainier, is near this area, but not visible from here.

48.8 / *78.5* American River. Hells Crossing Snow Park and Pleasant Valley groomed ski trail system.

49.1 / *79.0* Dry wash.

49.3 / *79.3* MP 83. Wash Creek and trailhead for Fifes Ridge Trail, which accesses higher country to the north. Note the U-shaped American River valley, carved by multiple glaciations.

50.7 / *81.6* Fifes Peaks Viewpoint and trailhead for Crow Lake Way Trail (#953). This spectacular geological viewpoint was constructed by the Washington State Department of Transportation (Fig. F-22). Look for mountain goats on Fifes Peaks.

From this location you get a dramatic look at the caldera margin of the Fifes Peaks volcano. The flows forming the castle-like jagged eastern ridge that rises as high as 6917 ft (2108 m) are a part of the Fifes Peaks caldera-fill deposits.

photo by Beth Norman

Figure F-23. Dikes, chiefly of rhyolite, intrude well-stratified beds of the Ohanapecosh Formation. The dike is at the bottom of the photo, below the hammer handle.

The existence of the 4-mi (7 km)-wide caldera was discovered during detailed mapping of the volcano at Fifes Peaks (Hammond and others, 1994). The mapping produced a detailed stratigraphic section of the Fifes Peak deposits. The caldera is filled to a maximum depth of 2800 ft (~850 m); the fill includes volcaniclastic lakebed deposits, glassy lava flows, lithic-rich surge deposits, and palagonitic beds that provide evidence of water and of phreatomagmatic eruptions. One can imagine that a lake once existed in the caldera before it was filled to the brim with lava flows and debris.

Hammond and his colleagues (2000) made a detailed study to clarify some uncertainty over the source and relations of the lava flows in this area with chemically similar lavas west of here in Mount Rainier National Park. These two groups of lavas were originally thought to have erupted from the same source. However, fission-track and uranium-lead (U-Pb) dating of rocks from both areas showed a significant difference in their ages: 25–24 Ma for the Fifes Peaks area and ~22 Ma for the strata to the west of Dalles Ridge, 18 mi (29 km) northeast of Mount Rainier (see Leg D). This suggests that there must have been a different source area for the two groups of lava flows.

The Bumping River tuff underlies the basal units of the Fifes Peaks volcano. Underlying all of these are the more steeply east dipping lava flows and tuffs of Goat Peak volcano of the Ohanapecosh Formation.

The Crow Lake Way Trail winds up the Miner Creek drainage and along an east–west to north–south ridgeline on Union Creek lava flows of the Ohanapecosh Formation. This trail offers excellent views into the American River valley. From the trail, you can look across the valley to a large landslide (not shown on map) that pushed the American River to the northwest side of valley. In this area, it is not uncommon to see mountain goats or to hear elk bugling in the autumn.

50.9 *81.9* Pleasant Valley Recreational Site and campground on the left. In the late 1980s, road builders straightened curves in this area.

53.1 *85.4* A large glacial erratic sits on morainal deposits north of the highway.

53.3 *85.8* MP 79. A rhyolitic sill exposed in a roadcut just west of the MP is overlain by a poorly sorted deposit or diamict that is probably till. Other deposits here are of fluvial origin or possibly are glacial outwash.

54.1 *87.1* Trailhead for the Union Creek Trail (#956) and the Pleasant Valley Loop Trail (#999), which parallels SR 410 south of the river.

More dikes, chiefly of rhyolite, intrude well-stratified beds of the Ohanapecosh Formation between the #956 trailhead and the American River (Fig. F-23). The graded bedding seen in the Ohanapecosh rocks is common in deposits of sediment-rich streamflow and slurries.

54.3 *87.4* Cross the American River at MP 78.

54.6 *87.9* A quarry on left in the toe of landslide deposits reveals a dacite porphyry intrusive rock with hexagonal biotite phenocrysts. It contains inclusions of Bumping River granite, showing that the dacite intruded the granite. More Ohanapecosh rocks are on the right and at mile 55.1.

55.6 *89.5* Lodgepole Campground on the right. The hills of American Ridge to the south are composed of the Ohanapecosh Formation and multiple dikes.

photo by Beth Norman

Figure F-24. Bumping Lake granite with inclusions of dark andesite slightly east of MP 73.

56.3 *90.6* MP 76. Mesatchee Creek Road. The trailhead for the Mesatchee Creek Trail is on left; ahead is a view of the Cascade crest.

57.1 *91.9* Greenish rock here is part of the Ohanapecosh Formation.

57.4 *92.4* Trailhead for the Bear Gap Trail, slightly west of MP 75.

57.5 *92.5* Cross Morse Creek upstream of the Morse Creek–Mesatchee Creek confluence with the American River. Some gold and copper have been discovered in several prospects in this area, although mining claims were dropped just prior to the designation of the Norse Peak Wilderness area in 1984. The rocks along this stretch of road have been altered by hydrothermal fluids that deposited sulfides such as pyrite (iron sulfide). This mineral-bearing area extends north-northwest to Crystal Mountain and south-southeast into Mesatchee Creek. (See the "Alteration and Mining North and East of Mount Rainier" sidebar on p. 117.)

The hydrothermal fluids that stewed the rocks in this area were associated with the intrusion of several dacite plugs along the north margin of the Bumping Lake pluton.

The Bumping Lake pluton is a giant lozenge-shaped body of granite and granodiorite whose exposed area is about 61 mi^2 (157 km^2). SR 410 passes through the northwest margin of this

Alteration and Mining North and East of Mount Rainier

by Rebecca A. Christie and Katherine M. Reed

Geology of Altered Rocks Northeast of Mount Rainier

The alteration in the Summit mining district was described by Slater (1915), a mining engineer working in the area, although his descriptions are mainly lithologic. There are no published dates on the age of alteration of rocks in this area. Slater, however, did describe the alteration along intrusive boundaries and along a zone of sheared rocks that trends N 50°W, roughly parallel with the fault zones described by Blakely and others (2007), so it is possible some of the alteration is contemporaneous with that in the White River area (p. 89). The altered rocks in the Summit mining district evidently include some pre-Miocene rocks in addition to rocks of the Fifes Peak Formation.

Early Activity in the Summit Mining District

Placer mining was first recorded in the area that later became the Summit mining district in about 1880, particularly near the head of Morse Creek. Placer ground in that area yielded gold nuggets worth as much as $140 each, and $1.50 nuggets were not uncommon (Moen, 1962; gold at that time was worth $20.67 per ounce). Subsequent prospecting in this area for the source of this gold revealed lode deposits that assayed as much as 13 ounces of gold per ton* and as much as 50 ounces of silver per ton, as well as minor amounts of copper and lead. The area around Morse Creek is still popular with gold prospectors, and there are numerous unpatented mining claims in the Mount Baker–Snoqualmie National Forest.

Prospectors filed the first claim at Gold Hill (on the northeast side of Morse Creek) in 1888. Mining for gold and silver exploded in this area during the late 1800s and again in the early 1900s. Much of the gold is very fine and was commonly found free on the ore's surface, owing to the oxidation of iron, or in veins in fractured andesite.

The Summit mining district, organized in 1891, is in the Cascade foothills east of Mount Rainier's summit in the area north and south of SR 410 between Lodgepole Campground and Chinook Pass (Butler, 1934). It covers about 8 mi^2 (20 km^2) in parts of Pierce and Yakima Counties. The Cougar Lake Limited Area (Moen, 1962) covers land in both the Summit and Bumping River districts; it contains the area of the Copper Mining Company's claims.

Numerous mining properties were located in the district. Wernex (1962) reported that an elderly local resident had estimated there were more than 250 claims in the district—probably a low estimate. Hodges (1897) noted there were at least 31 by 1896. There was abundant timber for supporting the roofs of the numerous tunnels and plenty of water. Some of the operations were: Gold Hill Consolidated (36 claims; said to have an "unusually large body of quartz porphyry and quartz veins carrying gold" [P. C. Stoess, unpub. report, 1943]); mines on Pickhandle Ridge and Crystal Ridge (large areas of low-grade ore at the surface); and Manitau Mining and Milling Co. (40 claims on shear zones, veins, contact metamorphism; pyrite and pyrrhotite with associated gold, silver and copper, as well as minor nickel and cobalt). Near the headwaters of Silver Creek were at least three mines that produced more than $1000 before 1945. The bedrock source is likely the Stevens Ridge Formation.

Generally, however, the value of any mined mineral per ton was disappointingly low. Stoess (unpub. report, 1930) wrote, "the average samples taken quite generally showed values from 50¢ to about $4.00 or $5.00 per ton in gold", concluding, however, that "even a casual inspection of the showings on the West side indicate the possibility of large if low grade gold deposits". More details for the district are available in Derkey and others (1990) and Huntting (1956).

Interest in Summit district gold lodes waned, partly because it was not thought to be economical to mill the low-grade ores, partly because the area was difficult to reach (P. C. Stoess, unpub. reports, 1930, 1934). Hodges (1897) had reported that it was more than 50 mi (90 km) by trail up the White River from Buckley and nearly 70 mi (112 km) by horse trail from an outfitting station up the Yakima River. In addition, both the Yukon gold rush and the Great War may have drawn some interest away from this area. Nevertheless, the Works Progress Administration had a crew in the area in 1936 to gather information that might spur development (P. H. Knowles, unpub. report, 1938).

Bumping Lake Mining District

A second area of mining activity, the 175-mi^2 (~450 km^2) Bumping Lake mining district, was organized in 1913. This district is bounded on the northwest by the crest of American Ridge and on the east by the Tieton drainage basin. (The leg maps for Leg O cover some of the district's area.) A district map for that year shows numerous claims and several mines.

At the Copper Mining Company's 42 claims on Miners Ridge, about 3 mi (4.8 km) south of the west end of Bumping Lake, copper, molybdenum, gold (trace), and silver, as well as tungsten (trace) locally, were found in hydrothermally altered rock near granite (Culver and Broughton, 1945). Geologist Paul Hammond has mapped Miners Ridge as Bumping Lake granite, which was dated by R. A. Duncan of Oregon State University at about 24 Ma (Hammond, Portland State Univ., written commun., 2000). Exploration work began in 1906, and in 1934, a 50-ton (45 metric ton) mill was set up to concentrate the ore. During the life of the operation, 22,000 lb (~10,000 kg) of copper concentrate and 650 lb (295 kg) of tungsten concentrate were shipped to the smelter (Moen, 1962). The company was dissolved in 1961 for nonpayment of incorporation fees.

About 1917, $30,000 was spent to open a tungsten mine between Bumping Lake and the Copper City camp, a site that can be reached by FR 162, which follows the drainage of Deep Creek south from Bumping Lake. (This road branches south off FR 1800 beyond the end of Leg O.) The mine proved valueless, however.

Wernex (1962), following an interview with a long-time local resident, wrote: "In 1956, the quest for uranium set off a stampede in the area of Copper City and Bumping Lake, resulting in claim jumping and lawsuits". However, nothing came of this flurry of action. ■

* 1 troy ounce per 2000 avoirdupois pounds = 34.276 milligrams per kilogram.

batholith. Many dikes have intruded the Bumping Lake granite and are therefore younger, ranging from 3.4 to 11 Ma, whereas an average of four $^{40}Ar/^{39}Ar$ ages on biotites of the Bumping Lake pluton is 23.75 Ma. The chunks of Ohanapecosh Formation scattered between dikes are remnants of intruded country rock. The beds in the Ohanapecosh are generally east dipping because they lie in the east limb of the north–south-trending Chinook Pass anticline.

58.8 *94.6* Outcrops of intrusive rock with yellow alteration for the next 0.7 mi (1.1 km).

59.1 *95.1* Bumping Lake granite with inclusions of dark andesite is exposed at a pullout (Fig. F-24).

59.3 *95.4* MP 73.

59.5 *95.7* Yellowish grus is exposed to the north slightly west of MP 73. You are on the northwest margin of the Bumping Lake batholith.

59.7 *96.1* View of Chinook Pass area (for those westbound) ahead and of a glacial hanging valley and cirque(s) to the left.

59.9 *96.4* Well-developed bedding is visible here in the Ohanapecosh Formation. Outcrops from miles 60.0 to 60.2 (km 96.0–96.3) are granodiorite intrusive rocks.

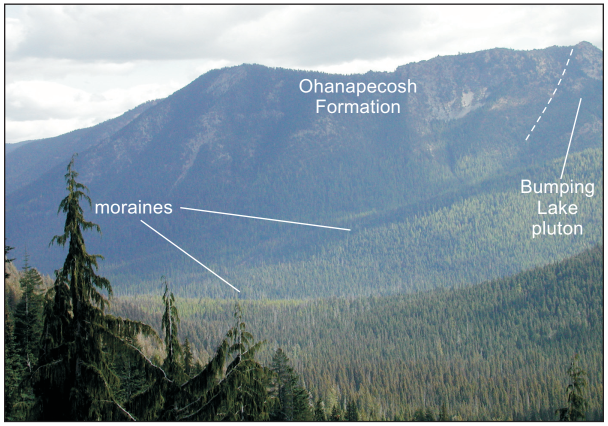
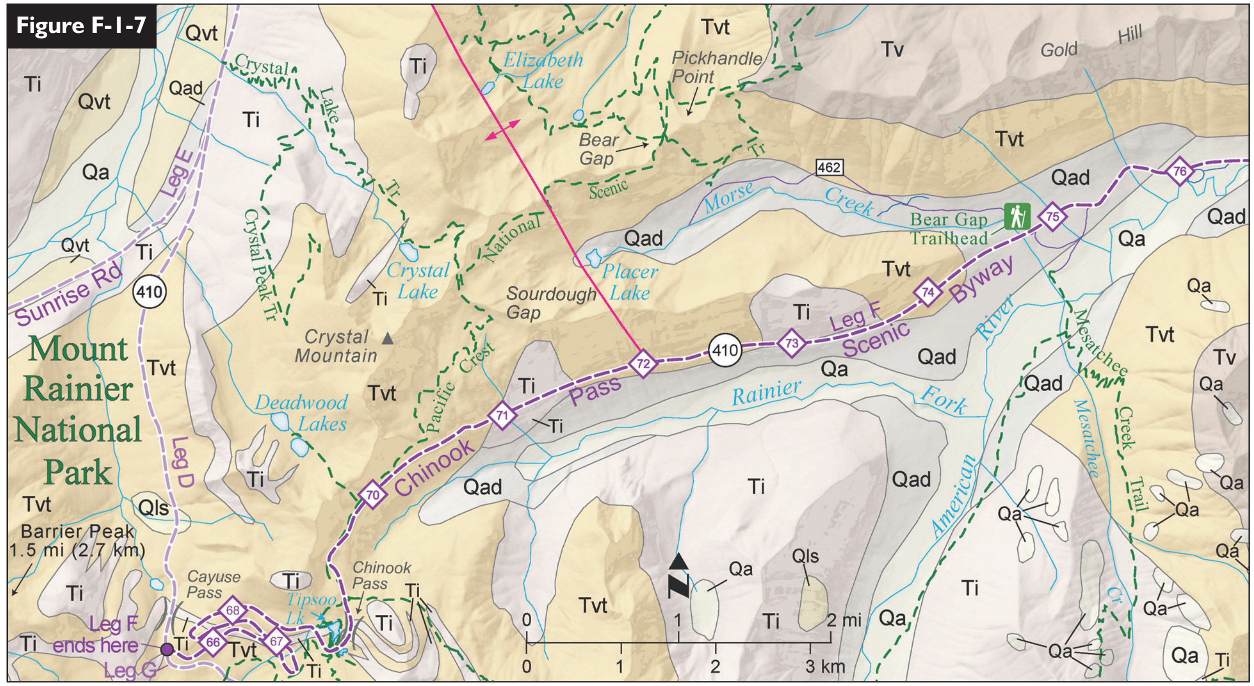


Figure F-25. Recessional lateral moraines in the American River valley at the confluence of the Rainier Fork American River (foreground) and the American River (background). Note the contact between the northwest tip of the approximately 25 Ma Bumping Lake pluton (extreme upper right) and the older (36–27 Ma) Ohanapecosh rocks that make up the southwest tip of American Ridge. View is to the southeast.



60.3 MP 72. Riprap has been used in an attempt to sta-
97.0 bilize small landslides in an area where colluvium overlies glacial deposits.

60.4 A till is exposed north of the highway near here.
97.2 Recessional moraines of alpine glaciers that occupied the American River valley are visible in the valley to the southeast from two small pullouts on the south side of the highway (Fig. F-25).

61.3 MP 71. At a small pullout about 430 ft (130 m)
98.6 west of MP 71, an unsorted deposit, probably glacial till, overlies glacially polished bedrock. In the bedrock, a dike cuts an inclusion-bearing intrusive rock. A second larger turnout slightly farther west is also near well-polished bedrock.

61.4 A probable till deposit is exposed at a small turn-
98.8 out.

62.0 Outcrops of Ohanapecosh Formation volcanic
99.8 rocks are cut by dikes and sills from here to Chinook Pass. MP 70 is just west of here.

62.8 Chinook Pass viewpoint. (There are restrooms
101.1 here.) This overlook (elev. 5432 ft or 1656 m) offers a beautiful vista to the southeast down a glaciated U-shaped valley of the Rainier Fork American River (Fig. F-26). Ohanapecosh bedrock, including a welded tuff, and many andesite dikes and sills crop out on the north side of the highway at the pass.

62.9 Enter Mount Rainier National Park. The Pacific
101.2 Crest Trail, a National Scenic Trail that stretches from Mexico to Canada, crosses the highway here. Many tephra layers are visible in outcrop on the south side of the highway about 150 ft (46 m) west of the national park boundary. USGS geologist Jim Vallance (written commun., 1999) identified Mount St. Helens layers X (~A.D. 1500) and Wn (A.D. 1479), Mount Rainier layer C (~2,200 yr B.P.), Mount St. Helens layer P (~2,500 yr B.P.) containing an interbedded Mount Rainier ash, Mount St. Helens set Y layers (~3,500 yr B.P.), Mount Rainier layers F, N, D, L, and an unnamed layer and not-yet-named pumice (mostly of the Osceola and Cowlitz Park eruptive episodes; see Fig. 34, p. 37), and the orange Mount Mazama ash that was erupted about 7,500 cal yr B.P. in the great eruption that created the Crater Lake caldera.

63.3 The view to the north of Tipsoo Lake and Mount
101.9 Rainier is spectacular if the weather is clear (Fig. F-27). The craggy peaks visible on the horizon to the southwest are the Cowlitz Chimneys (Ohanapecosh Formation).

63.6 Tipsoo Lake parking lot. (There are restrooms
102.3 here.) The parking lot on the right (westbound) has trails that lead around the lake and connect with several major trails including the Eastside Trail and Pacific Crest Trail. A rhyolite sill 650 ft (~200 m) northwest of the parking area along the highway has been dated at 25.8 Ma by Mattinson (1977). From here to Cayuse Pass are spectacular outcrops of bedded Ohanapecosh rocks cut by dikes and sills.

64.1 This small pullout has a view of Mount Adams
103.1 volcano (south), the Tatoosh Range (southwest), and Sawtooth Ridge, a cuesta of south-dipping volcaniclastic rocks of Oligocene age (southwest).

64.5 Welded lapilli-tuff with fiamme, or flattened pum-
103.8 ice, near here is cut by nearly horizontal dikes. A similar feature in the Stevens Ridge Formation is

photo by Beth Norman

Figure F-26. Chinook Pass viewpoint offers a beautiful vista to the southeast down a glaciated U-shaped valley of the Rainier Fork American River.

shown in Figure B-11. As the road switches back, you descend through older strata in this section of Ohanapecosh Formation rocks.

64.9 *104.4* A cirque is visible to the west on the east face of Barrier Peak, and to the southwest is a view of the Tatoosh Range and Sawtooth Ridge.

65.2 *104.9* A dike is visible to the north.

65.7 *105.7* Denser rock with slickensides locally—these may indicate right-lateral offset. However, the rock on either side of the fault appears to be the same welded tuff exposed up the road. The nearly vertical joints visible here likely had a role in the failure/creation of the big talus blocks. There is a nice view to the west from this area. Note the nearly vertical dikes that crop out in the cliffs to the north. They appear to dip just slightly west and strike to the north-northeast.

Figure F-27. Mount Rainier from Tipsoo Lake. Cowlitz Chimneys are silhouetted in front of Mount Rainier. View is to the west.

66.0 *106.2* This is a fine area to view the mid-lower part of the Ohanapecosh section of rocks, including some thick tuffs and bedded volcanic rocks dipping to the east-southeast (Fig. F-28).

Figure F-28. Volcaniclastic rocks of the mid-lower part of the Ohanapecosh section and a reddish altered zone adjacent to an overlying sill. The view is to the northeast along SR 410, a short distance east of Cayuse Pass.

66.4 *106.8* Cayuse Pass (elev. 4694 ft or 1432 m); junction with SR 123. You can continue on SR 410, driving Leg D in reverse, or go south on SR 123 (Leg G) toward the Stevens Canyon Entrance to Mount Rainier National Park or to access US 12 (Legs C and H).

Remember to reset your odometer when you start another leg. ■