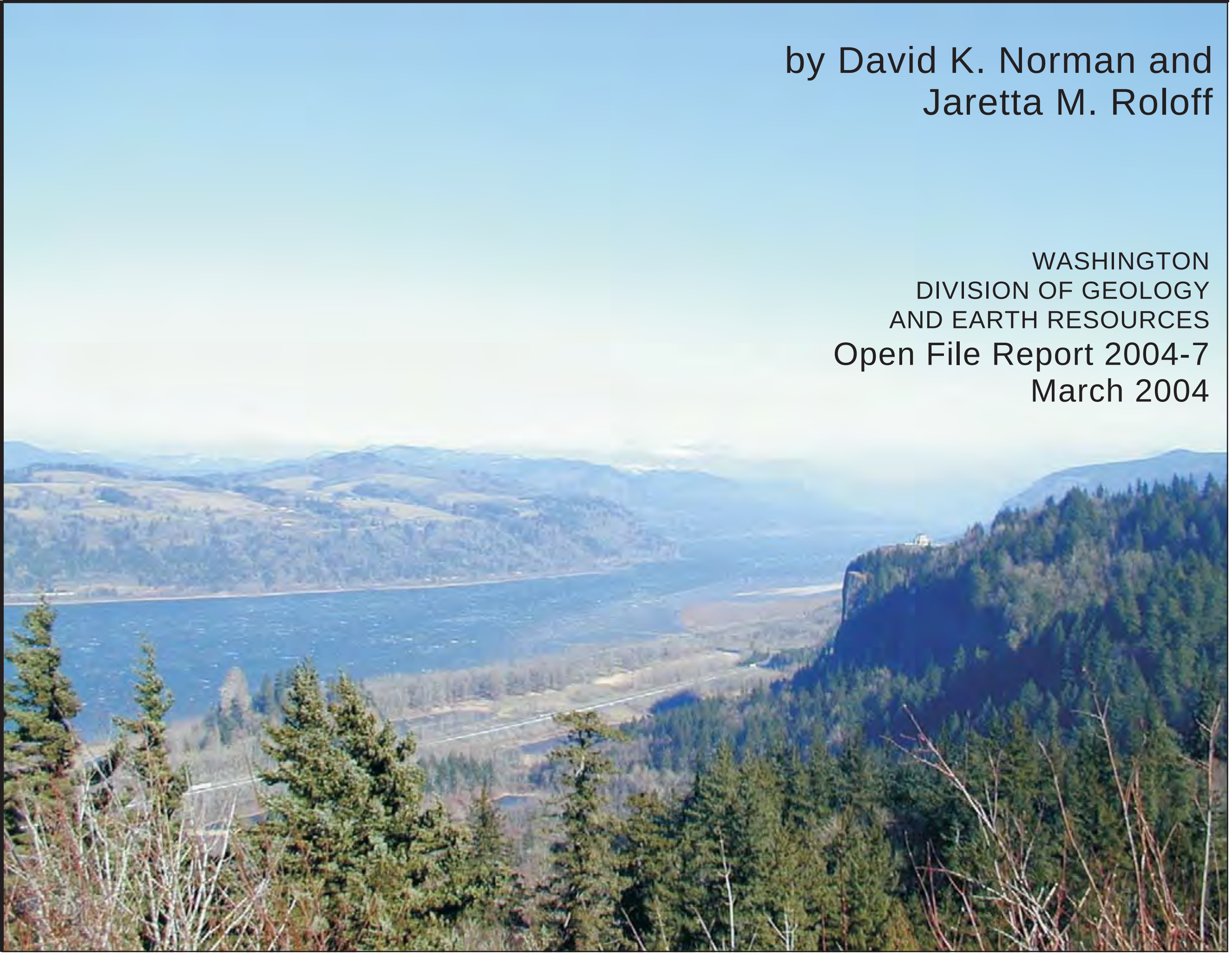
NATURAL RESOURCES

A Self-Guided Tour of the Geology of the Columbia River Gorge—Portland Airport to Skamania Lodge, Stevenson, Washington



by David K. Norman and
Jaretta M. Roloff

WASHINGTON
DIVISION OF GEOLOGY
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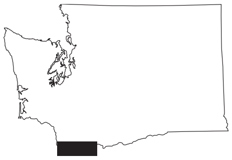
Open File Report 2004-7
March 2004



WASHINGTON STATE DEPARTMENT OF
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Cover photo: Looking east up the Columbia River Gorge from the Women's Forum Overlook. Crown Point and its Vista House are visible on top of the cliff on the right side of the river. I-84 runs below. Cape Horn is the sheer section of cliffs slightly upriver and across from Crown Point.

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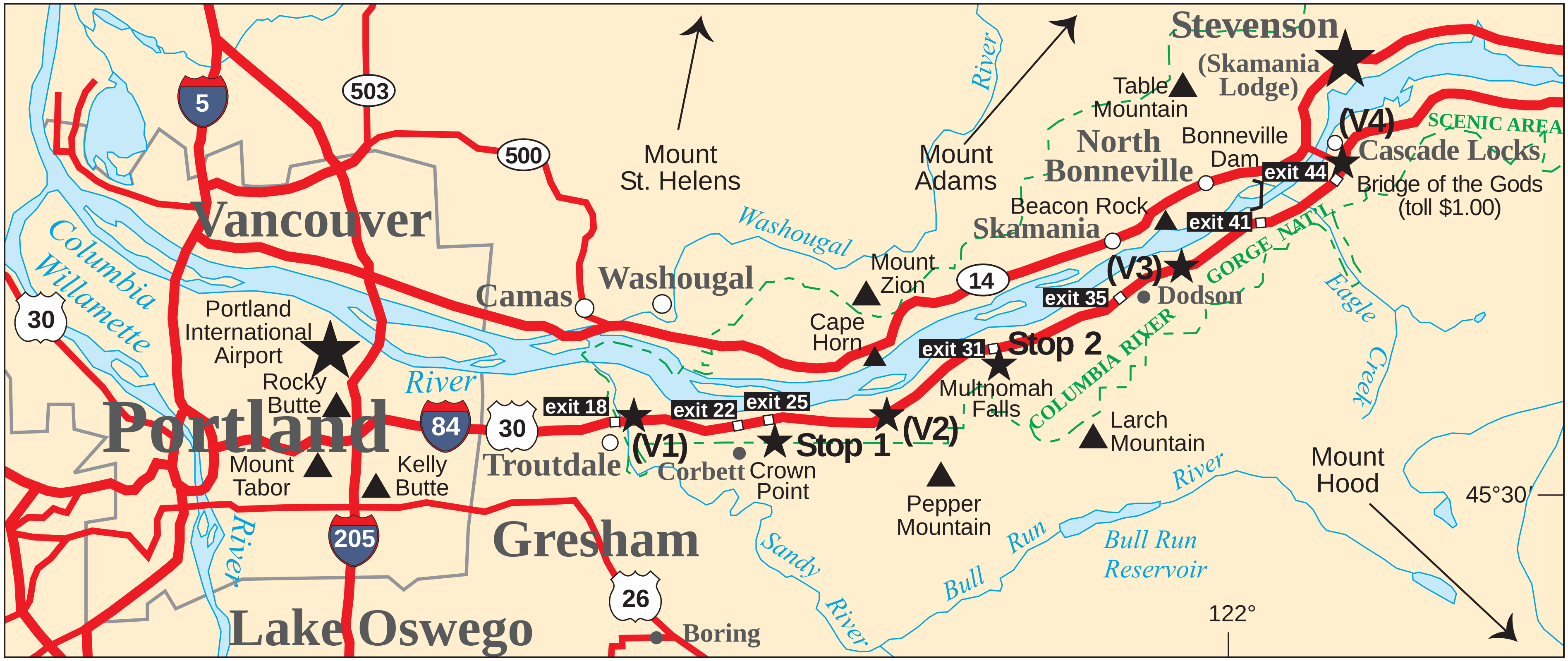


Figure 1. Location map.

A Self-Guided Tour of the Geology of the Columbia River Gorge—Portland Airport to Skamania Lodge, Stevenson, Washington

Prepared for the Association of American State Geologists
96th Annual Meeting, June 13–16, 2004

General Directions from the Airport to Skamania Lodge (N45°41′12.8″ W121°54′21.5″) (Distance approximately 42 miles): Leave the airport via I-205 South. Exit to Interstate 84 East (toward The Dalles) (Fig. 1). Continue east on I-84 until the Cascade Locks/Bridge of the Gods/Stevenson exit (44). Take the Bridge of the Gods over the Columbia River ($1.00 toll), then turn right (east) onto Highway 14. Travel a short distance (1.5 mi from the Bridge of the Gods to milepost 43 of Highway 14). Turn left onto Rock Creek Drive. Proceed 0.2 mi to the entrance to Skamania Lodge (on the left).

WASHINGTON STATE GEOLOGY

Washington is uniquely positioned for the study of the geologic and structural setting of western North America. To the south in Oregon and Nevada, extensional features predominate as reflected by basin-and-range terrain. To the east, the Rocky Mountains influence the geology of Idaho. To the north, western British Columbia is characterized by a massive coastal crystalline belt and remnants of the geologic continent Wrangellia. All of these major crustal features of the adjacent regions terminate in or near Washington. The state's uniqueness is further enhanced by three major geologic conditions. First, Washington is impacted by crustal tectonics as the oceanic Juan de Fuca plate is being subducted under the North American continent (Fig. 2). Second, the Columbia Basin (Fig. 3) in Washington and adjacent Oregon was subjected to great outpourings of basalt. Third, alpine and continental glaciation and glacial floods have created spectacular landforms in the North Cascades, Puget Sound, and the Channeled Scablands.

Washington's geology is highly diverse. Rocks of Precambrian age, as well as units from every geologic period, Cambrian to Quaternary, are represented. The state has been subject to continental collisions, metamorphism, intrusion of igneous rocks, volcanism, mountain-building episodes, erosion, glaciation, and massive flooding events. This diversity has a strong influence on soil productivity, location of mineral deposits, scenic grandeur, and even the climate. *(Modified from the USGS/Cascades Volcano Observatory website at* http://vulcan.wr.usgs.gov.)

The Columbia River

The Columbia River pours more water into the Pacific Ocean than any other river in North or South America. In its 1270-mi (2045-km) course to the Pacific Ocean,

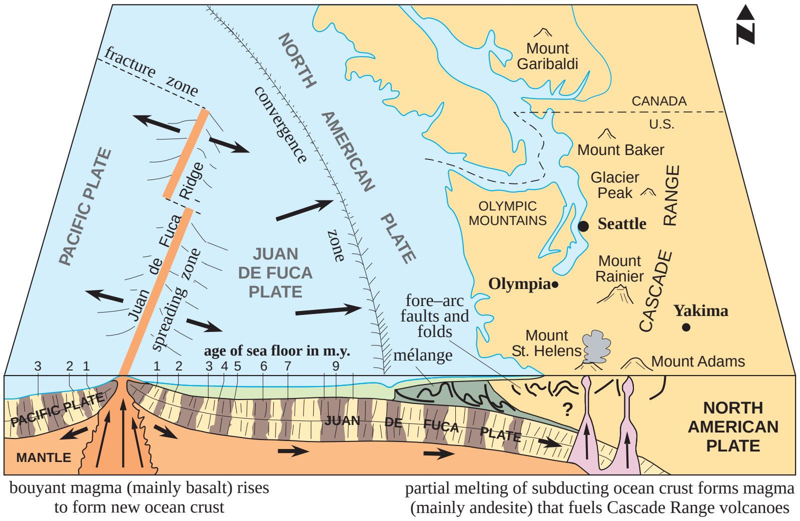


Figure 2. A diagrammatic cross section through the Juan de Fuca spreading ridge and the Cascadia subduction zone (the area from the convergence zone east to where the Juan de Fuca plate sinks beneath the North American plate), showing the magnetic orientation of the sea floor recorded at the Juan de Fuca spreading ridge. Darker stripes in the cross section of the sea floor indicate times when rock was created with a magnetic orientation of north. Notice that the age of the ocean floor is progressively older with distance from the spreading zone. The pattern of ages approximately parallels the ridge on both sides. Mélange is a jumbled mixture of continental shelf blocks and oceanic sediments that is faulted and sheared at shallow depths in the subduction zone. Fore-arc folds and faults occur in a zone of crustal deformation between the subducting sea floor and the volcanic arc. Redrawn from Foxworthy and Hill (1982), Uyeda (1978), and Pringle (2002).

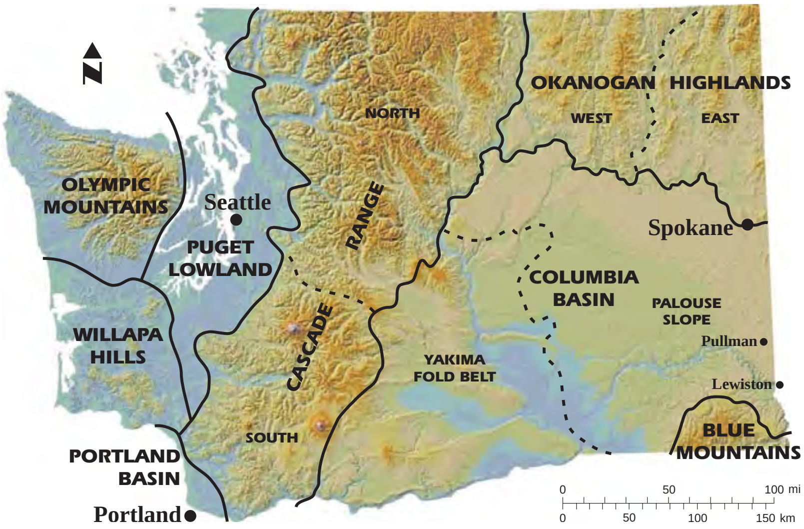


Figure 3. The physiographic provinces and subprovinces of Washington State. Subprovinces are separated by a dashed line. The Columbia River Basalt Group underlies the Columbia Basin, part of the Portland Basin, and part of the Willapa Hills, as well as adjacent areas of Oregon and Idaho.

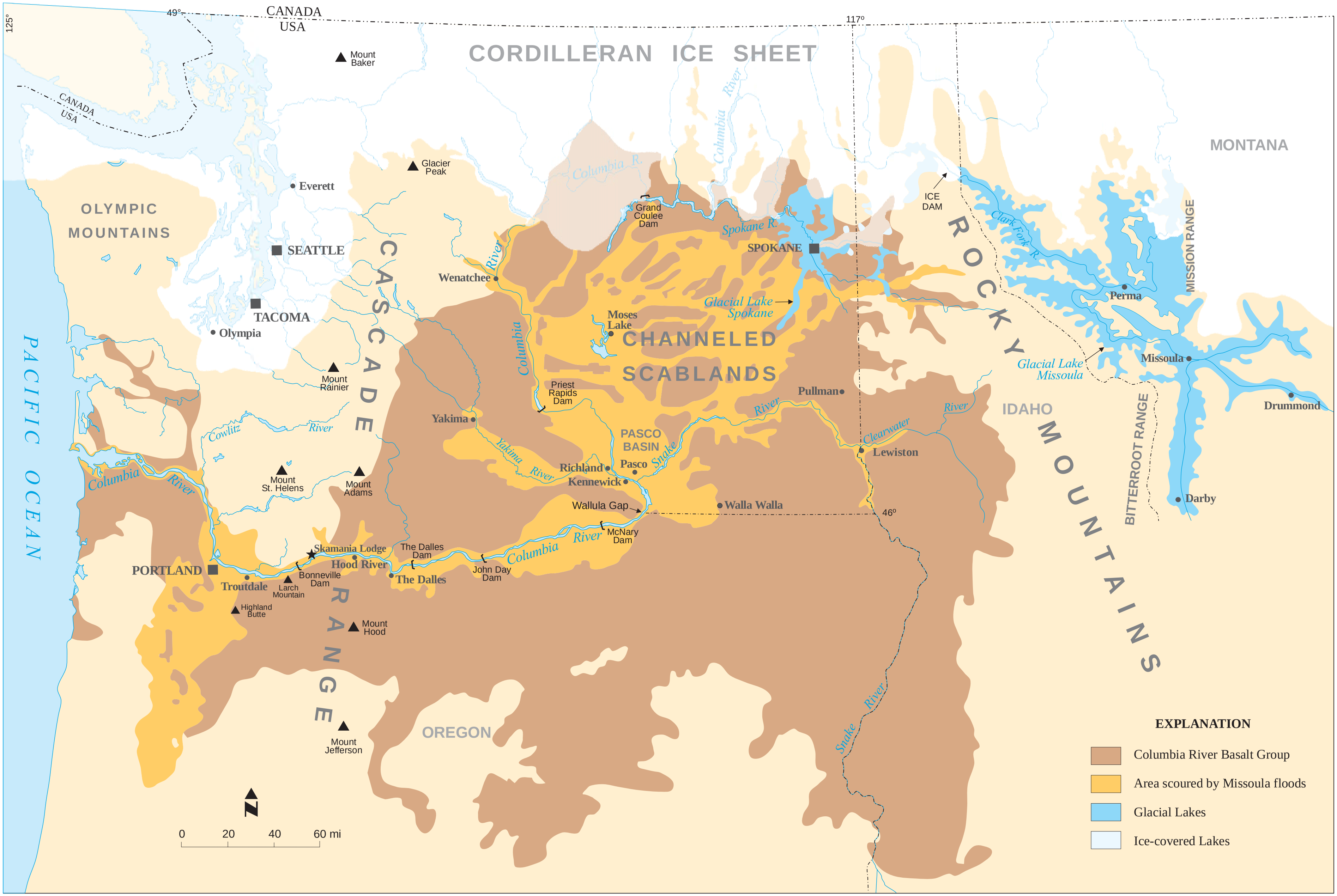


Figure 4. The probable extent of the Cordilleran ice sheet, ice-dammed glacial lakes, Missoula floods, and Columbia River Basalt Group. The failure of the ice dam of the Clark Fork River in western Montana released a 2000 ft (600 m) wall of water that rushed across eastern Washington again and again, eroding a series of intertwining canyons called coulees. This area is known as the Channeled Scablands. The various flood pathways converged in the Pasco Basin, where there was a narrow exit for the waters—Wallula Gap. The narrowness of the gap caused the floodwaters to back up and form a 1200-ft (365-m)-deep lake covering over 3500 mi^2 (9000 km^2). Several other temporary lakes were created by similar events near The Dalles and Portland, Ore. (Modified from Waitt, 1985, and Weis and Newman, 1989. Extent of the Columbia River Basalt Group from Reidel and others, 1994.)

the Columbia flows through four mountain ranges—the Rockies, Selkirks, Cascades, and coastal mountains—and drains 258,000 mi^2 (670,000 km^2). The main stem of the Columbia rises in Columbia Lake on the west slope of the Rocky Mountains in Canada. Its largest tributary, the Snake River, travels 1038 mi (1670 km) from its source in Yellowstone National Park in Wyoming before joining the Columbia.

The Columbia River Gorge is a spectacular canyon cutting through the Cascade Range. The Gorge is 80 mi (130 km) long and up to 4000 ft (1200 m) deep, with the north canyon walls in Washington State and the south canyon walls in Oregon State. The gorge is the only near sea-level passage through the Cascades.

When Lewis and Clark explored the region in the early 19th century, huge numbers of salmon returned to spawn every year. “The multitudes of this fish are almost inconceivable,” Clark wrote in the autumn of 1805. At that time, the Columbia and its tributaries provided 12,935 mi (20,800 km) of pristine river habitat. (*Modified from a U.S. Army Corps of Engineers information brochure)*

Figure 5. Mount Hood as seen from Highway 14 near Camas, Wash. View to the southeast.

Columbia River Basalt Group

The Columbia River Basalt Group (CRBG)(Fig. 4) is the principal rock unit in the gorge. The CRBG is a series of basalt flows (flood or fissure basalts) that were erupted between 17 million and 6 million years ago during the Miocene. The flows originated from northwest-striking feeder dikes in eastern Washington and Oregon and spread westward across the Columbia Basin (Figs. 3 and 4). Most of the lava flooded out in the first 1.5 million years—an extraordinarily short time for such an outpouring of molten rock. It is difficult to conceive of the enormity of these eruptions. Basaltic lava erupts at no less than about 1100°C. Basalt is a very fluid lava; it is likely that tongues of lava advanced at an average of 3 mi/hr (5 km/hr). Whatever topography was present prior to the CRBG eruptions was buried and smoothed over by flow upon flow of lava. More than 300 high-volume individual lava flows have been identified, along with countless smaller flows. Numerous linear vents, some over 100 mi (150 km) long, show where lava erupted near the eastern edge of the Columbia Basin, but older vents were probably buried by younger flows. *(From the USGS/Cascades Volcano Observatory website.)*

The flows now cover approximately 105,000 mi^2 (272,000 km^2) and total about 41,830 mi^3 (175,000 km^3) of basalt (Tolan and others, 1989). On the basis of geophysical evidence, the basalts are known to reach a maximum thickness of 16,000 ft (5000 m) in the Pasco Basin. Twenty-one of these flows poured through the Gorge, forming layers of rock up to 2000 ft (600 m) thick. The CRBG is divided into five formations, but only three, the Grande Ronde, Wanapum, and Saddle Mountains Basalts, are exposed in the tour area.

Geologists distinguish the various flows of the CRBG by examining their physical features, geochemistry, and paleomagnetism (Swanson and others, 1979a,b). Chemical composition and paleomagnetic data have proven to be the most reliable criteria for flow identification and correlation.

Glacial Floods

Quaternary deposits in the gorge are those of the cataclysmic Missoula (or Spokane) floods. The Cordilleran ice sheet from Canada advanced several times during the Pleistocene and covered parts of Washington, Idaho, and Montana. The ice formed dams on the Clark Fork River on the Idaho–Montana border and created glacial Lake Missoula (Pardee, 1910)(Fig. 4). The lake covered 3000 mi^2 (7800 km^2) of western Montana and held 600 mi^3 (2500 km^3) of water (Carson and Pogue, 1996).

The ice dams failed repeatedly releasing gigantic glacial floods that swept across northern Idaho, through the Spokane Valley, southwestward across eastern Washington, and down the Columbia River Gorge enroute to the Pacific Ocean (Carson and Pogue, 1996). The Missoula floods are the largest known floods on Earth in the last two million years; the flow of water was ten times the combined flow of all the rivers of the world. In eastern Washington, the floods created the Channeled Scablands, an area studied by J Harlen Bretz in the 1920s. Bretz was the first person to describe these gigantic glacial floods.

The flood crest at Wallula Gap on the Columbia River at the Washington–Oregon border was about 1200 ft (365 m) as evidenced by glacial erratics that were left stranded on the hillside. The water poured down the Columbia Gorge and widened the valley by cleaning off all the soil and talus up to 1000 ft (300 m) elevation as far as The Dalles, Oregon. By the time it reached Crown Point, the surface of the last flood had dropped to about 600 ft (180 m) elevation (Allen, 1979).

There may have been more than 40 major glacial floods (Waitt, 1980) recorded by bedded slack water deposits (rhythmites). The average interval between Missoula floods was about 30 years (Waitt and others, 1994). The last flood occurred 13,000 years ago.

SELF-GUIDING TOUR

The Portland Area

Metropolitan Portland sits on part of a Plio-Pleistocene volcanic field. The Boring Lava includes at least 32 and possibly 50 cinder cones and small shield volcanoes lying within a radius of 13 mi (21 km) of Kelly Butte. The volcanoes were probably active from at least 2.7 million to less than 500,000 years ago.

Northwest of the town of Boring, 20 eruptive centers are concentrated within about a 39 mi^2 (100 km^2) area. Vents in the east part of this cluster average less than 1.6 mi (2.6 km) in diameter and 1090 ft (333 m) in height above their bases. Lavas from Highland Butte and Larch Mountain shield volcanoes (Fig. 4) form gently sloping plains covering many tens of square miles. Well logs indicate that in most places, except near vents, Boring lava is between 100 and 200 ft (30–60 m) thick.

Partial summit craters remain only at Bobs Hill, 20.5 mi (33 km) northeast of Portland, and at a low cone enclosing a lake (Battleground Lake) north of Battleground, Wash., 20.5 mi (33 km) north of Portland. Most other volcanoes still have a low cone shape and are mantled with loess above 400 ft (122 m) elevation. Below this they were scoured by the Missoula floods about 13,000 to 15,000 years ago.

Boring Lava is characteristically a light-gray olivine basalt. A specimen from Rocky Butte is predominantly labradorite, with phenocrysts of olivine, mostly altered to iddingsite. The volcanoes locally contain scoria, cinders, tuff, tuff breccia, and ash. Weathering may extend to depths of 25 ft (8 m) or more, the upper 5 to 15 ft (2–5 m) commonly being a red clayey soil.

The best and most accessible exposure is the cross section of the cinder cone in Mount Tabor Park. Numerous quartzite-pebble xenoliths from the underlying Mio-Pliocene Troutdale gravels that make up the bulk of Mount Tabor have been found in the cinders here. The best view of the volcanic field is from the summit in Rocky Butte Park where massive cliffs of flood-scoured lava form the northeast face of the butte. (*Modified from the USGS/Cascades Volcano Observatory website.)*

As you leave the Portland area, you may be able to catch a glimpse of Mount Hood (Fig. 5) to the east and Mount St. Helens to the north if it is a clear day.

Figure 6. Looking east from I-84 toward Rooster Rock (just to the left of center) and Crown Point (upper right) with its vista house.

Figure 7. Cape Horn as seen from exit 28 on I-84 on the Oregon side of the Columbia. The cape is the part of these steep cliffs that juts out into the river.

VIEWPOINT 1 from I-84: Crossing the Sandy River

(Not a stop)

At Exit 18 (Lewis and Clark State Park and Sandy River) Mount Hood is the nearest active Cascades volcano to the Columbia River Gorge, sitting about 30 mi (50 km) south of the Gorge between Troutdale and Hood River (Fig. 4). The Sandy River originates on Mount Hood and drains into the Columbia River.

The Sandy River and several of its tributaries have been inundated by numerous lahars over the past 1800 years. These lahars have resulted both from collapse of Mount Hood's southwest flank and from dome-collapse pyroclastic flows from Crater Rock lava dome. Later remobilization of the pyroclastic deposits occurred during periods of high precipitation. Lahars attained depths of 30 to 40 ft (9–12 m) above the modern valley floor in the Sandy River valley and the deposits reached the Columbia River, a distance of over 55 mi (90 km) (Cameron and Pringle, 1987; Scott and others, 1997).

In 1805, Lewis and Clark named the Sandy River "Quicksand River" in recognition of the 4-mi (6.5-km)-wide saturated bar of remobilized lahar at the mouth of the river (Cameron and Pringle, 1986). The lahar forced the Columbia River channel to the north at the mouth of the Sandy River, a situation that most likely will be repeated during future volcanic-eruption-induced sedimentation (Wang and others, 2002).

Side Trip: Optional Waterfall Loop

If you are planning to take the Waterfall Loop on the Historic Columbia River Highway (U.S. 30), leave I-84 at exit 22 (Corbett). You will be able to see Crown Point and Rooster Rock from the top of the Gorge (cover photo). The loop returns to I-84 at exit 35 (Dodson).

STOP 1: View of Crown Point and Rooster Rock

Take exit 25 to Rooster Rock State Park, cross I-84, turn left, and follow the road to the end of the west parking lot, near the restrooms, and proceed on to the boat landing. *There is a $3.00 fee to actually enter the park.*

Crown Point (Fig. 6) is a remnant of a thick intracanyon flow of the Priest Rapids Member of the Wanapum Basalt of the CRBG (Tolan and others, 1984) that filled an early ancestral canyon of Columbia River to a total thickness of nearly 700 ft (200 m). In the face of the bluff, the lower 130 ft (40 m) of the fill is palagonite tuff, carried westward and foreset bedded by the ancestral Columbia River. Lava then advanced onto the hyaloclastic fill, piling up quickly in a series of flows to a thickness of 555 ft (170 m). The entire thickness of lava congealed as one cooling unit with an 80-ft (25-m) basal colonnade and a very thick (475 ft) hackly entablature (Waters, 1973).

Rooster Rock (Fig. 6) is a landslide of a portion of the Crown Point intracanyon fill. You can see the scar where the slide came from on the cliff above. Note the rotated-bedded palagonite capped by fan-jointed columns and hackly entablature in the slide. Several jumbled blocks are present. Rooster Rock itself is a spire from the entablature (Waters, 1973).

Return to I-84 and continue east. High bluffs of Columbia River basalt on the right are unconformably overlain by Troutdale gravels, which are capped in turn by olivine basalt flows from Larch and Pepper Mountains (Fig. 1).

VIEWPOINT 2 from I-84: Cape Horn

(Not a stop)

Across the river on the Washington side at Cape Horn (Fig. 7) flows of the Grande Ronde Basalt of the CRBG form steep cliffs that make an excellent stratigraphic marker. Troutdale gravels cap the basalt unconformably and are overlain in turn by lavas of the small Mount Zion olivine basalt shield (Waters, 1973).

STOP 2: Multnomah Falls

(If you are going to make one stop, this is it.)

Take exit 31 to your LEFT to Multnomah Falls (Fig. 8). Park and head toward the old 1925 lodge and visitor center. Multnomah Falls is the second-highest year-round waterfall in the nation. It consists of an upper and lower falls over basalt cliffs. The 620-ft (189-m) waterfall is fed by natural springs and melting snows from Larch Mountain to the south. You can hike up a winding path and view the falls from a bridge. You can also hike to the top of the falls and see where it all begins.

On September 4, 1995, at approximately 5:30 p.m., rocks from the face of upper Multnomah Falls broke loose and smashed down in the upper plunge pool. The upper falls are 541 ft (165 m) high. According to the USDA Forest Service, the dislodged rock had approximate dimensions of 40 by 20 by 6 ft (12 by 6 by 2 m) and fell a distance of 225 ft (69 m). The jointed basalt block did not remain intact but, for the most part, shattered. Twenty people who were standing on the 70-ft (21-m)-high bridge received minor injuries from being hit by flying pebble-size debris. The upper plunge pool is now permanently closed for public-safety reasons. In addition, landslide awareness signs have been erected in response to this event (Wang and others, 2002).

Figure 8. Multnomah Falls.

Eleven flows of the Grande Ronde Basalt of the CRBG are exposed along Multnomah Creek (Fig. 9). Six of these flows crop out from the Columbia River to the top of the upper falls; the rest are exposed upstream of the two falls you see here. Note the pillow sequence near the lip of the upper falls.

Observations of waterfalls over Columbia River basalt (M. H. Beeson, unpub. data, 1978) have shown that falls often occur where flows are flat lying or dipping upstream. This condition allows blocks produced by vertical joints to remain stable until support is withdrawn by erosion of softer interflow material at the base of individual flows. The rate of erosion of interflow areas probably largely controls the rate of retreat of the falls. Two falls were produced here because of a more easily eroded zone at the base of the upper falls. The amphitheater-shaped valleys common to many of the falls within the Gorge are due to the freeze–thaw action of water from the splash mist that has penetrated the joints (Tolan and others, 1984).

VIEWPOINT 3 from I-84: Beacon Rock

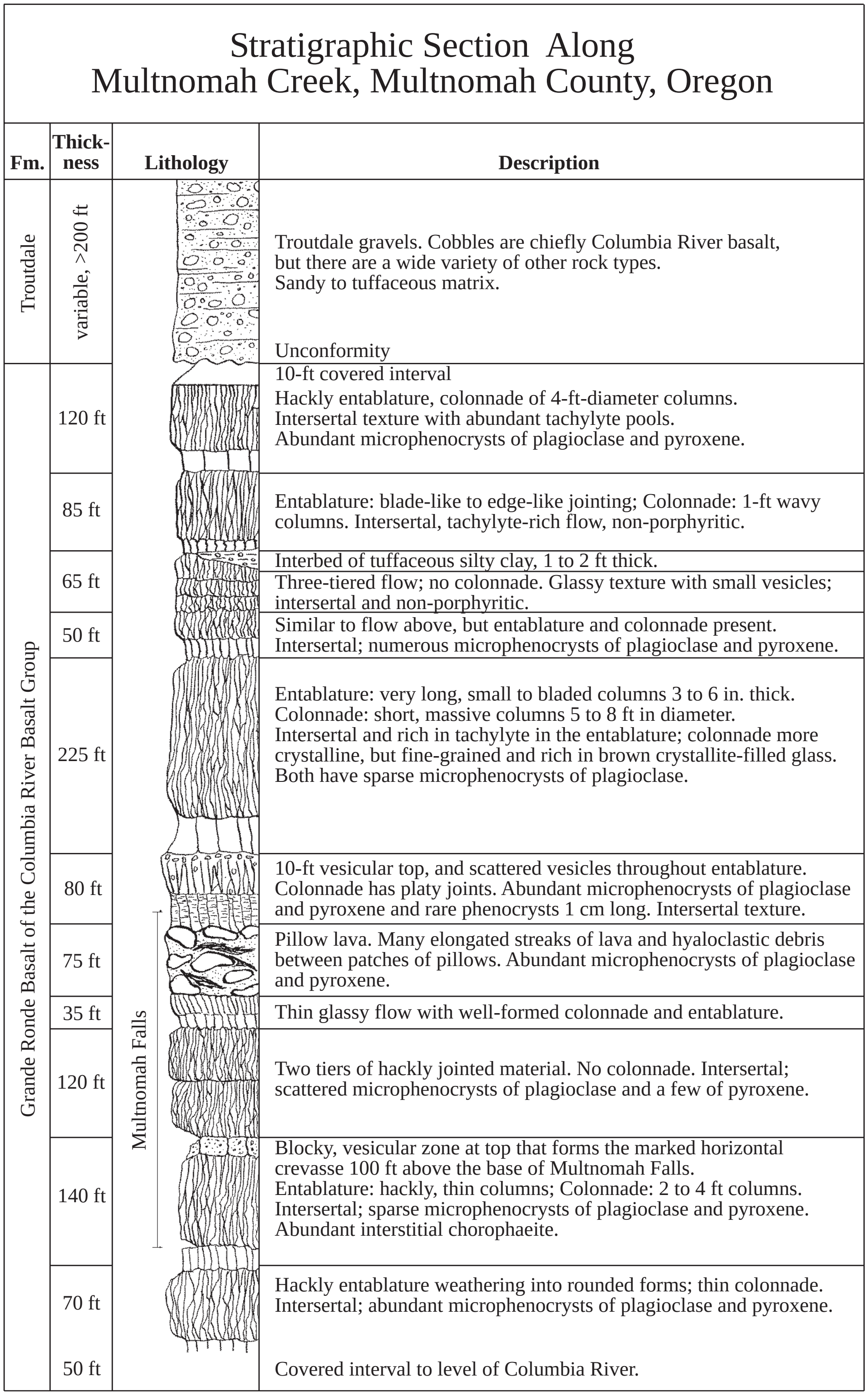
Across the Columbia, you can catch occasional glimpses of Beacon Rock (Fig. 10), an eroded olivine basalt plug that rises 840 ft (256 m) above river level. Beacon Rock was named by Clark in his journal on Nov. 2, 1805. It was here that the expedition first observed Pacific Ocean tidewater (Washington). The rock was once thought to be the eroded vent-filling of a Pliocene volcano, however, recent age dates by Jack Fleck of the USGS suggest a young age of 50 to 60 ka (Russ Evarts, USGS, written commun. 2004). It is actually the southernmost of several necks (or a great north–south dike) extending to the north for more than 2 mi (3 km). It is red, scoriaceous, and vesicular near the summit. Baked contacts with the Eagle Creek Formation are found to the south and southwest, and the columnar structure on the east side is horizontal, east and west; on the west side, the columns are vertical (Allen, 1979).

VIEWPOINT 4 from I-84: Cascade Landslide Complex and Bonneville Landslide

Looking north to Washington across the Columbia River from milepost 37 to milepost 44, you will have an excellent view of the Cascade landslide complex and Bonneville landslide (Fig. 11) as you drive along the freeway.

The Cascade landslide complex is an impressive example of mass wasting created by multiple events. The source area includes portions of Table Mountain and the Red Bluffs (Fig. 12) in Washington. The landslide complex covers 12 to 14 mi^2 (30–36 km^2), with individual slide deposits of about 2 to 5 mi^2 (5–13 km^2).

The Bonneville landslide (a lobe of the complex) has an area of about 5.5 mi^2 (14 km^2). Debris from the source area reached as far as 3 mi (5 km) to the southeast (Fig. 13) and buried the pre-slide Columbia River channel, which was about 1.5 mi (2.5 km) north of its present location (Shannon and Wilson, 1978). The landslide substantially diverted the river channel toward the Oregon shoreline (Wang and others, 2002; Palmer, 1977). The second powerhouse of Bonneville Dam abuts against the landslide. If you look north of the dam, you can see the cliffs that were exposed after the mountain gave way.



Fm.	Thickness	Description
Troutdale	variable, >200 ft	Troutdale gravels. Cobbles are chiefly Columbia River basalt, but there are a wide variety of other rock types. Sandy to tuffaceous matrix. Unconformity
Grande Ronde Basalt of the Columbia River Basalt Group	120 ft	10-ft covered interval Hackly entablature, colonnade of 4-ft-diameter columns. Intersertal texture with abundant tachylyte pools. Abundant microphenocrysts of plagioclase and pyroxene.
	85 ft	Entablature: blade-like to edge-like jointing; Colonnade: 1-ft wavy columns. Intersertal, tachylyte-rich flow, non-porphyritic.
	65 ft	Interbed of tuffaceous silty clay, 1 to 2 ft thick. Three-tiered flow; no colonnade. Glassy texture with small vesicles; intersertal and non-porphyritic.
	50 ft	Similar to flow above, but entablature and colonnade present. Intersertal; numerous microphenocrysts of plagioclase and pyroxene.
	225 ft	Entablature: very long, small to bladed columns 3 to 6 in. thick. Colonnade: short, massive columns 5 to 8 ft in diameter. Intersertal and rich in tachylyte in the entablature; colonnade more crystalline, but fine-grained and rich in brown crystallite-filled glass. Both have sparse microphenocrysts of plagioclase.
	80 ft	10-ft vesicular top, and scattered vesicles throughout entablature. Colonnade has platy joints. Abundant microphenocrysts of plagioclase and pyroxene and rare phenocrysts 1 cm long. Intersertal texture.
	75 ft	Pillow lava. Many elongated streaks of lava and hyaloclastic debris between patches of pillows. Abundant microphenocrysts of plagioclase and pyroxene.
	35 ft	Thin glassy flow with well-formed colonnade and entablature.
	120 ft	Two tiers of hackly jointed material. No colonnade. Intersertal; scattered microphenocrysts of plagioclase and a few of pyroxene.
	140 ft	Blocky, vesicular zone at top that forms the marked horizontal crevasse 100 ft above the base of Multnomah Falls. Entablature: hackly, thin columns; Colonnade: 2 to 4 ft columns. Intersertal; sparse microphenocrysts of plagioclase and pyroxene. Abundant interstitial chorophaeite.
	70 ft	Hackly entablature weathering into rounded forms; thin colonnade. Intersertal; abundant microphenocrysts of plagioclase and pyroxene.
	50 ft	Covered interval to level of Columbia River.

Figure 9. Stratigraphic section along Multnomah Creek (modified from Waters, 1973).

In the late 1970s, the U.S. Army Corp of Engineers studied the landslide for the purpose of additional construction. The study found that “the mechanics of failure involved a planar movement in the rock mass and a subsequent lateral spreading at the toe of the slide. Sand liquefaction was [interpreted as] the failure mechanism for this lateral spreading. Remnant slide blocks are found surrounded by a matrix of fine mica sand” (Shannon and Wilson, 1978). It has been proposed that the high-energy deposition resulted in liquefaction and injection of sandy dikes of the debris-covered alluvium up into the landslide deposit (Wang and others, 2002; Scofield and others, 1997).

The river water impounded by the Bonneville landslide dam rose tens of meters, creating a lake that stretched almost 70 mi

Figure 10. Beacon Rock (front) and Hamilton Mountain (background) on the Washington State side of the Columbia River.

Figure 11. Aerial-oblique photo of the Bonneville landslide. View is to the northeast with Mount Adams volcano in the distance. The Bonneville Dam and powerhouses (lower left) and the "Bridge of the Gods" highway (far right) flank the landslide. *(Photo courtesy of Derek Cornforth.)*

Figure 12. Bonneville landslide (wooded area) as seen from Cascade Locks. Table Mountain (3417 ft/ 1042 m) is on the left and Greenleaf Peak (3422 ft/ 1043 m) is on the right. Red Bluffs is the scarp area just below Greenleaf Peak. The Bridge of the Gods is just out of camera view to the left, and Skamania Lodge is just out of camera view to the right.

(113 km)(up to the present-day John Day Dam). After a few months, the Columbia rose high enough to wash through the southern side of the landslide creating a flood of water that was 100 ft (30 m) deep at Troutdale (Scofield and others, 1997). Afterwards, things returned to normal, except that the river was displaced a mile to the south and the Cascade Rapids had formed.

Evidence for the landslide dam includes submerged tree stumps observed upstream (Lawrence, 1937; Lawrence and Lawrence, 1958). Evidence for catastrophic flooding from the breach has been observed downstream near the mouth of the Sandy River and at other locations (O'Connor and others, 1996; Lunney and Taylor, 2000). The Cascade Rapids, which developed from the breaching of the landslide dam, and the submerged forests were later inundated by the reservoir from the 1938 Bonneville Dam (Schuster and Pringle, 2002).

Although the slide complex has been extensively studied, the exact age of the slide remains a controversy. An 1830s account of an early Native American legend describes the Cascade Rapids as follows: "The Indians say those falls are not ancient, and that their fathers voyaged without obstruction in their canoes as far as The Dalles. They also assert that the river was dammed up at this place, which caused the waters to rise to a great height far above and that after cutting a passage through the impeding mass down to its present bed, those rapids first made their appearance" (Lawrence, 1937). Another version tells of the sons of Old Coyote, Wy'east (Mount Hood) and Pahto (Mount Adams), as powerful braves both in love with a maiden (Mount St. Helens). Because they crossed the "Bridge of the Gods" to fight over their love for her, Old Coyote collapsed the land bridge to keep his sons from fighting.

This "Bridge of the Gods" landslide dam was formed by the Bonneville landslide, which is the youngest and largest of four portions of the Cascade landslide complex. Recent radiocarbon studies indicate a calendar age of some time during the 15th century for this landslide (Pat Pringle, Wash. Divn. of Geology and Earth Resources, oral commun., 2004).

Take exit 44 toward CASCADE LOCKS/STEVENSON.

Turn onto BRIDGE OF THE GODS and cross the Columbia River into Washington State.

This a toll bridge and you will need $1.00 both ways.

This steel bridge was named for the “Bridge of the Gods” landslide dam.

At the junction with State Route 14, turn right (east) and travel 1.5 mi.

You are now skirting the toe of the Cascade landslide complex. Note the hummocky ground and the jumble of rocks from different formations in the slide. As you pass Ashes Lake (Fig. 13), you have a good view of the cliffs forming the scarp at the head of the landslide.

Immediately after entering Stevenson city limits, turn left onto Rock Creek Drive and go 0.2 mi to the entrance to Skamania Lodge.

You have arrived at Skamania Lodge, Washington. Skamania Lodge was constructed on the eastern edge of the large Cascade landslide complex, which is generally considered to be stable ground. The lodge provides an excellent view of the river, the gorge, and the landslides.

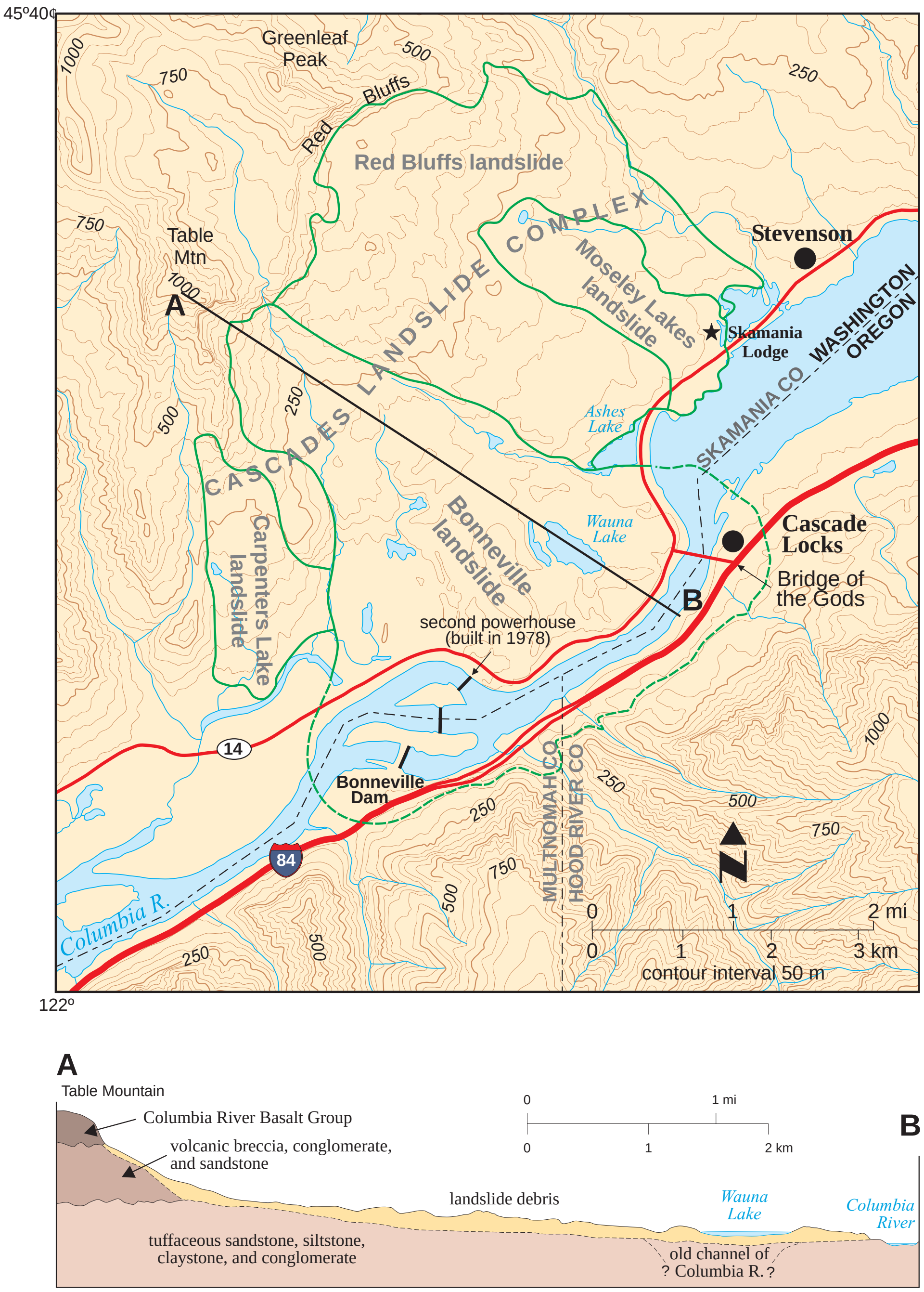


Figure 13. Approximate boundary of the Bonneville landslide within the Cascades landslide complex, dashed where approximate maximum extent inferred (after Schuster and Pringle, 2002); simplified cross section (A–B) through the Bonneville landslide from Table Mountain to the southern shore of the Columbia River (after U.S. Army Engineer District, 1976).

REFERENCES

Allen, J. E., 1979, The magnificent gateway—A layman’s guide to the geology of the Columbia River gorge: Timber Press [Forest Grove, Ore.] Scenic Trips to the Northwest’s Geologic Past 1, 144 p.

Cameron, K. A.; Pringle, P. T., 1986, Post-glacial lahars of the Sandy River basin, Mount Hood, Oregon: Northwest Science, v. 60, no.4, p. 225-237.

Cameron, K. A.; Pringle, P. T., 1987, A detailed chronology of the most recent major eruptive period at Mount Hood, Oregon: Geological Society of America Bulletin, v. 99, no. 6, p. 845-851.

Carson, R. J.; Pogue, K. R., 1996, Flood basalts and glacier floods—Roadside geology of parts of Walla Walla, Franklin, and Columbia Counties, Washington: Washington Division of Geology and Earth Resources Information Circular 90, 47 p.

Foxworthy, B. L.; Hill, Mary, 1982, Volcanic eruptions of 1980 at Mount St. Helens—The first 100 days: U.S. Geological Survey Professional Paper 1249, 125 p.

Hill, R. L., 1999, repr. 2001, A new look at an old landslide—Radiocarbon dates indicate the Bonneville landslide may be far younger than thought: Washington Geology, v. 29, no. 1/2, p. 35-38. [http://www.wa.gov/dnr/htdocs/ger/pdf/1news01.pdf]

Lawrence, D. B., 1937, Drowned forests of the Columbia River gorge: Geological Society of the Oregon Country Geological News Letter, v. 3, no. 8, p. 78-83.

Lawrence, D. B.; Lawrence, E. G., 1958, Bridge of the Gods legend—Its origin, history, and dating: Mazama, v. 40, no. 13, p. 33-41.

Lunney, Meghan; Taylor, J. M., 2000, Analysis of probable Bridge of the Gods landslide dam outburst sediments in the lower Columbia River basin [abstract]: Geological Society of America Abstracts with Programs, v. 32, no. 6, p. A-26.

O’Connor, J. E.; Pierson, T. C.; Turner, Daniel; Atwater, B. F.; Pringle, P. T., 1996, An exceptionally large Columbia River flood between 500 and 600 years ago—Breaching of the Bridge-of-the-Gods landslide? [abstract]: Geological Society of America Abstracts with Programs, v. 28, no. 5, p. 97.

Palmer, L. A., 1977, Large landslides of the Columbia River gorge, Oregon and Washington. *In* Coates, D. R., editor, Landslides: Geological Society of America Reviews in Engineering Geology, v. III, p. 69-83.

Pardee, J. T., 1910, The glacial Lake Missoula: Journal of Geology, v. 18, p. 376-386.

Pringle, P. T., 2002, Roadside geology of Mount St. Helens National Volcanic Monument and vicinity; rev. ed.: Washington Division of Geology and Earth Resources Information Circular 88, rev. ed., 122 p.

Reidel, S. P.; Tolan, T. L.; Beeson, M. H., 1994, Factors that influenced the eruptive and emplacement histories of flood basalt flows—A field guide to selected vents and flows of the Columbia River Basalt Group. *In* Swanson, D. A.; Haugerud, R. A., editors, Geologic field trips in the Pacific Northwest: University of Washington Department of Geological Sciences, v. 1, p. 1B 1 - 1B 18.

Sager, J. W., 1989, Bonneville Dam. *In* Galster, R. W., chairman, Engineering geology in Washington: Washington Division of Geology and Earth Resources Bulletin 78, v. I, p. 337-346.

Schuster, R. L.; Pringle, P. T., 2002, Engineering history and impacts of the Bonneville landslide, Columbia River gorge, Washington-Oregon, USA. *In* Rybar, Jan; Stemberk, Joseph; Wagner, Peter, editors, Landslides—Proceedings of the First European Conference on Landslides: A. A. Balkema, p. 689-699.

Scofield, D. H.; Harvey, A. F.; Burns, S. F., 1997, Engineering geology of the Columbia River gorge—Association of Engineering Geologists 40th Annual Meeting field trip: Association of Engineering Geologists, 27 p.

Scott, W. E.; Pierson, T. C.; Schilling, S. P.; Costa, J. E.; Gardner, C. A.; Vallance, J. W.; Major, J. J., 1997, Volcano hazards in the Mount Hood region, Oregon: U.S. Geological Survey Open-File Report 97-89, 14 p., 1 plate. [http://vulcan.wr.usgs.gov/Volcanoes/Hood/Hazards/OFR97-89/framework.html]

Suchanek, Ron, 1974, The Columbia River gorge—The story of the river and the rocks: Ore Bin, v. 36, no. 12, p. 197-214.

Swanson, D. A.; Anderson, J. L.; Bentley, R. D.; Camp, V. E.; Gardner, J. N.; Wright, T. L., 1979a, Reconnaissance geologic map of the Columbia River Basalt Group in eastern Washington and northern Idaho: U.S. Geological Survey Open-File Report 79-1363, 12 sheets, 26 p. text.

Swanson, D. A.; Wright, T. L.; Hooper, P. R.; Bentley, R. D., 1979b, Revisions in stratigraphic nomenclature of the Columbia River Basalt Group: U.S. Geological Survey Bulletin 1457-G, 59 p., 1 plate.

Tolan, T. L.; Beeson, M. H.; Vogt, B. F., 1984, Exploring the Neogene history of the Columbia River—Discussion and geologic field trip guide to the Columbia River gorge; Part II, Road log and comments: Oregon Geology, v. 46, no. 9, p. 103-112.

Tolan, T. L.; Reidel, S. P., compilers, 1989, Structure map of a portion of the Columbia River flood-basalt province. *In* Reidel, S. P.; Hooper, P. R., editors, Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, plate, scale 1:500,000.

Tolan, T. L.; Reidel, S. P.; Beeson, M. H.; Anderson, J. L.; Fecht, K. R.; Swanson, D. A., 1989, Revisions to the estimates of the areal extent and volume of the Columbia River Basalt Group. *In* Reidel, S. P.; Hooper, P. R., editors, Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 1-20.

U.S. Army Corps of Engineers, 1976, Bonneville dam—Second powerhouse; Design memorandum no. 7, Supplement no. 5, Hamilton Creek bridge and west highway underpass tunnel: U.S. Army Corps of Engineers, 4 p., 5 plates.

U.S. Army Corps of Engineers, 1976, Columbia River basin, Oregon-Washington, Bonneville lock and dam; 2nd powerhouse railroad tunnel, design memorandum no. 7, supplement no. 4: U.S. Army Corps of Engineers, 1 v.

Uyeda, Seiya, 1978, The new view of the Earth— Moving continents and moving oceans: W. H. Freeman and Company, 217 p.

Waitt, R. B., Jr., 1980, About forty last-glacial Lake Missoula jokulhlaups through southern Washington: Journal of Geology, v. 88, no. 6, p. 653-679.

Waitt, R. B., Jr., 1985, Case for periodic, colossal jokulhlaups from Pleistocene glacial Lake Missoula: Geological Society of America Bulletin, v. 96, no. 10, p. 1271-1286.

Waitt, R. B.; O'Connor, J. E.; Benito, Gerardo, 1994, Scores of gigantic, successively smaller Lake Missoula floods through Channeled Scabland and Columbia valley. *In* Swanson, D. A.; Haugerud, R. A., editors, Geologic field trips in the Pacific Northwest: University of Washington Department of Geological Sciences, v. 1, p. 1K 1 - 1K 88.

Wang, Yumei; Hofmeister, R. J.; McConnell, Vicki; Burns, S. F.; Pringle, P. T., 2002, Columbia River gorge landslides—Field trip guidebook for the National Academies: [Privately published by the authors], 22 p.

Waters, A. C., 1973, The Columbia River gorge—Basalt stratigraphy, ancient lava dams, and landslide dams. *In* Beaulieu, J. D., Geologic field trips in northern Oregon and southern Washington: Oregon Department of Geology and Mineral Industries Bulletin 77, p. 133-162.

Weis, P. L.; Newman, W. L., 1989, The channeled scablands of eastern Washington—The geologic story of the Spokane flood; 2nd ed.: Eastern Washington University Press, 24 p. ■