Beyond the Channeled Scabland

A field trip to Missoula flood features in the Columbia, Yakima, and Walla Walla Valleys, Washington and Oregon—Part 2: Field trip, Day one

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DAY ONE

Day 1 includes stops at some of the most spectacular Missoula flood features between The Dalles and Arlington. Trip route remains on the Oregon side of the river for the entire day. (Maps: U.S. Geological Survey (USGS) The Dalles 1°×2° sheet; USGS Hood River and Goldendale 1:100,000 sheets)

En route to Stop 1.1

From the Deschutes River Recreation Area, head west to The Dalles and then up the valley of Fifteenmile Creek. The local geology is dominated by the Columbia River Basalt Group, a thick sequence of middle and late Miocene (regionally, 17–6 Ma, locally 17–12 Ma) basalt flows that were issued from vents in northeastern Oregon and adjacent Washington and Idaho. In this region, the Columbia River Basalt Group has been deformed by a series of east-trending folds and high-angle reverse faults and by northwest-trending right-lateral strike-slip faults. Between the Deschutes River and the Hood River, the Columbia River Basalt Group is overlain by the Dalles Formation, a late Miocene (mainly 9–7 Ma) volcaniclastic and alluvial fan shed northeast from the Cascade Range. The Dalles Formation, with its several-meter-thick cover of loess, forms the rolling topography of the uplands, interrupted locally by gullies, landslides, and Missoula flood features.

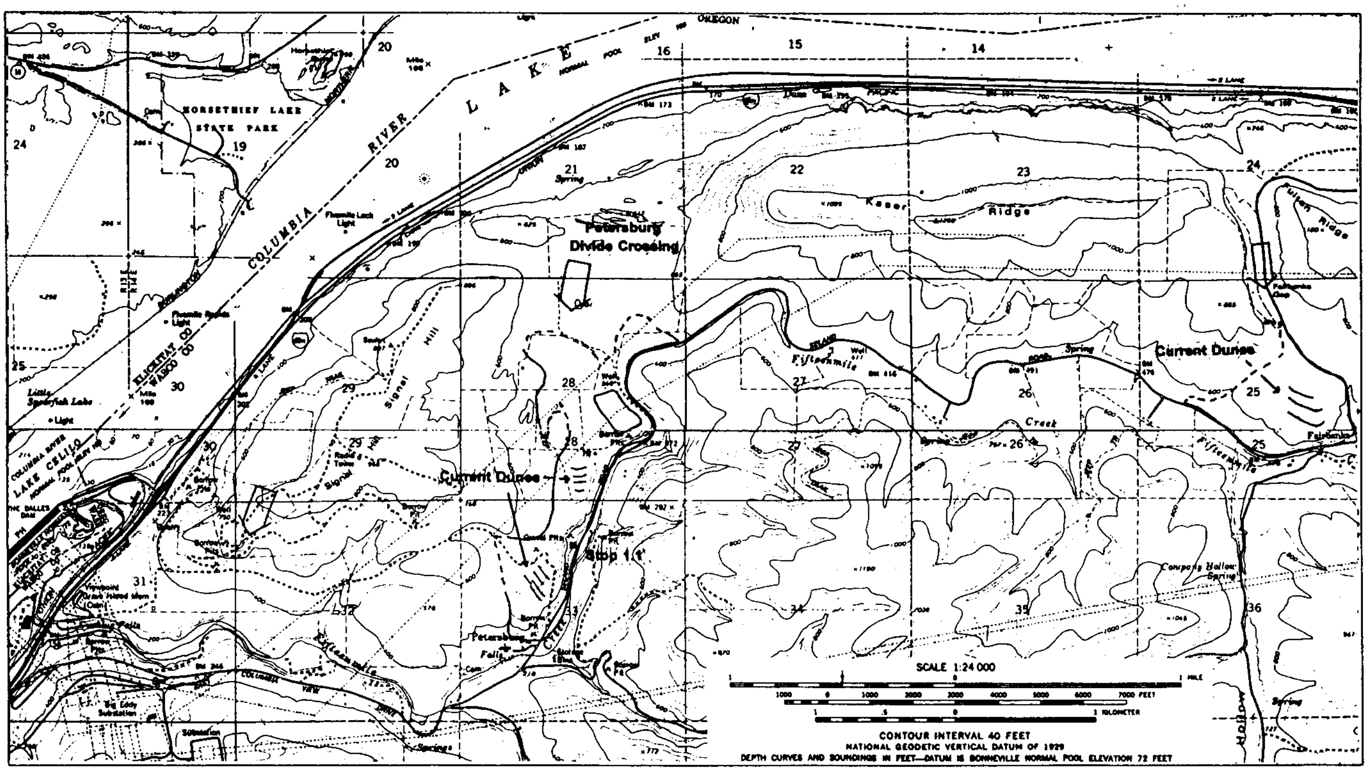


Figure 7. Topographic map of the settings of Petersburg and Fairbanks divide crossings, with approximate extent of the gravel bars that were deposited as flow (arrows) spilled into the valley of Fifteenmile Creek. Topographic base from Stacker Butte and Petersburg USGS 7½′ quadrangles.

Fifteenmile Creek parallels the Columbia River for about 15 km before joining it near The Dalles. Flow from the Missoula floods overtopped the ridge between the Columbia River and Fifteenmile Creek and spilled south into the valley of Fifteenmile Creek at two locations, forming two large "flood deltas" (Figure 7).

Stop 1.1. Petersburg bar

This is a privately owned gravel pit. Please do not enter without permission of the property owner! This large gravel pit exposes deposits from flow(s) spilling south into the valley of Fifteenmile Creek (Figure 7). Boulders, gravel, and sand were deposited in steeply dipping foresets, apparently as this "flood delta" prograded southward. Many of the contacts between thick gravel beds are unconformable, indicating erosion of the underlying unit before subsequent deposition. The topmost gravel bed is distinctly coarser with a more openwork texture. The entire deposit is capped with about 1 m of loess that contains a weakly developed soil typical of late Pleistocene age. The surface of the bar displays two small sets of giant current dunes. Exposures 0.5 km to the northeast at the east edge of the bar also show several units that are finer, thinner, and more gently dipping than the deposits here.

One question here is: Do each or any of these unconformity-bound units represent individual floods? Without definitive evidence of subaerial exposure between units or good chronologic information, it is difficult to answer this with certainty. Yet, based on other exposures of coarse-grained deposits that do have evidence of subaerial exposure (such as loess deposition) between units, we tentatively infer that each of the coarse depositional units here, some capped with fluvially deposited sand, is the result of a separate flood. If true, depending on how one counts, there are 6–10 floods. Hence, perhaps at least that many separate floods overtopped the divide. A similar number of unconformity-bound gravel and sand couplets are exposed in the pit to the northeast.

The present altitude of the divide crossing is about 180 m (600 ft). According to our modeling, a discharge of at least 3 million m^3/s would be required to overtop this divide (Figure 8). So we conclude tentatively that there were at least 6–10 separate floods that had peak discharges greater than 3 million m^3/s.

Radiocarbon dates from this exposure, all from low in the stratigraphic sequence, yield ages between 16,720±210 ^{14}C yr B.P. to >40,000 ^{14}C yr B.P. The youngest date (16,720±210 ^{14}C yr B.P.) came from a plant fragment within an organic-rich silt clast, which yielded a bulk date of 24,200±1,900 ^{14}C yr B.P. Additional bulk analyses from similar clasts of organic-rich silt at this site yielded ages of 23,400±250, 31,870±650, and 45,500±2700 ^{14}C yr B.P. We have also dated a soil clast high in the stratigraphic sequence at the east end of the bar. The stratigraphic relation between the deposits at the east end of the bar and those exposed at the trip stop is uncertain, although the deposits at the east end of the bar may simply be a finer facies.

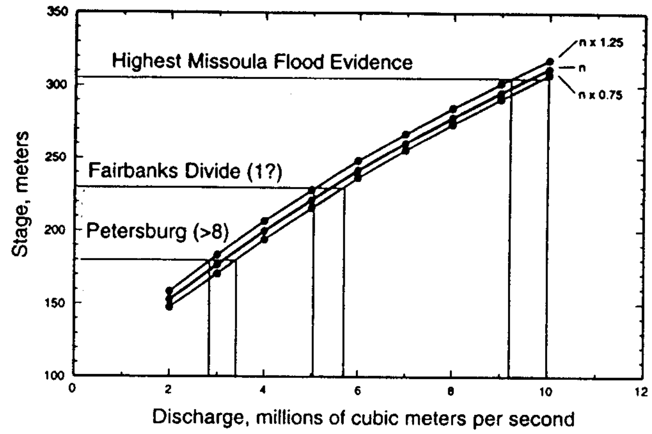


*Figure 8. Stage-rating curves constructed on the basis of step-backwater calculations for the reach near the Fairbanks Gap and Petersburg divide crossings. The sensitivity of the step-backwater calculations to uncertainty in Manning **n** values is shown by the three separate curves, one based on a best guess of roughness, the other two based on adjusting those values by ±25 percent. At sites such as these that are upstream of critical-flow sections, sensitivity to Manning **n** values is usually small. The numbers after the names of the divide crossings are the number of unconformity-bound depositional units exposed in the downstream delta bars.*

A whole-sample analysis of the sample from the east end of the bar yielded an age of 32,920±650 ^{14}C yr B.P.; an analysis of the separated humic acids (NaOH extract) gave an age of 14,480±145 ^{14}C yr B.P., which is probably a close age for the deposit.

En route to Stop 1.2

From Petersburg bar continue east along the valley of Fifteenmile Creek. In valleys to the south, ice-rafted erratics and a thin layer of sandy silt 0–4 m thick were deposited over the loess-covered landscape to an altitude of at least 285 m (940 ft).

About 5 km up Fifteenmile Creek, another large bar was deposited by flow diverging from the valley of the Columbia River across the divide through Fairbanks Gap (Figures 7 and 9). This bar has large crescentic current dunes on its surface, expressed by crenulations in the contour lines. An exposure of the delta front near the intersection with Company Hollow Road reveals coarse gravel deposits that lack the sweeping unconformities and interbedded sand layers of the deposits at Petersburg bar. A possible explanation for the coarseness is that the Fairbanks Gap divide crossing is much narrower than the Petersburg crossing and produced higher flow velocity as water passed through. Possible explanations for the lack of unconformities in the exposed section include that (1) stratigraphic exposure is too shallow; (2) the contacts are just not visible where bouldery units are amalgamated together; and (3) only one flood overtopped the divide here. Two radiocarbon analyses of organic-rich silt clasts gave >40,000 ^{14}C yr B.P. dates. The weak soil, however, indicates that this deposit is of late Wisconsin age.

Turn left on Old Moody Road and climb up the east margin of the bar. The undulating topography on the bar surface (wheat field) is created by giant current dunes. Proceed through Fairbanks Gap, a divide crossing cut through the Dalles Formation down to the contact with the Columbia River Basalt Group. The upper limit of erosion is about at altitude 300 m (1,000 ft). The col of the Fairbanks Gap divide is at altitude 250 m (820 ft), some 70 m higher than the Petersburg divide, requiring a minimum discharge of about 5 million m^3/s for overtopping (Figure 8). Note that the apex of the bar is higher than the divide crossing, which indicates that the flow was tens of meters deep through the divide as the bar was being formed.

Continue about 2 km east, high along the south side of the Columbia River valley, traveling across a small pendant bar. Stop 1.2 is at a promontory above the railroad bridge. Beware of traffic on this narrow gravel road.

Stop 1.2. Celilo Falls overlook

Before closure of The Dalles Dam in 1956, one had a good view of Celilo Falls from here (Figure 10). Altogether the sets of rapids between Celilo Falls and The Dalles were known by the name "The Dalles of the Columbia," the steepest section of the Columbia River, where the water-surface dropped 25 m in the 19 km between the head of Celilo Falls and The Dalles. At low water, Celilo Falls had a sheer drop of about 6 m. The topography of this reach consisted of narrow chutes, several kilometers long and locally less than 50 m wide, separated by large holes. The holes at Big Eddy and at the head of Fivemile Rapids are more than 40 m deep, with bottoms more than 30 m below sea level. At low water, the Columbia River was confined to the chutes and holes, but at high water, the entire basalt-floored valley bottom was inundated. It is not clear to us whether the channel-bottom topography here is largely a relict of the Missoula floods or whether Holocene flows sculpted the present channels as suggested by Bretz (1924). Nevertheless, Bretz (1924) felt that the processes and topography at this site served as a good analogy for Missoula flood features in the Channeled Scabland.

Topography clearly related to the Missoula floods can be seen across the river above the town of Wishram, where Columbia River Basalt Group flows have been stripped of their surficial cover and eroded into a butte-and-basin "scabland" topography. A local set of northwest-aligned joints or minor faults has been preferentially excavated. At higher altitudes, the basalt has been stripped of loess and regolith but not much eroded. Alluvial fans, talus, and landslide debris shed southward off the Columbia Hills anticline were locally trimmed back, which resulted in Holocene entrenchment of many of the small streams draining the valley slopes. Landslides are ubiquitous on both sides of the river and in major tributary valleys throughout this reach of the Columbia. Many of the most visible of these landslides have pristine morphology, which indicates that they probably postdate passage of the flood peak(s). Nevertheless, they were perhaps triggered by the floods because of excavation of supporting sediment and saturation and excess pore pressures caused by a few days of inundation and subsequent dropping of the water level.

On the north side of the river, forming the high part of the ridge to the east, is Haystack Butte (towers on top). This Quaternary volcano erupted basalt that flowed south into the Columbia River valley at about 900 ka (Bela, 1982). The lowest exposure of these flows is along the southeast margin of Miller Island, a mid-channel island south of Haystack Butte. These rocks at Miller Island, less than 60 m above sea level, indicate that (1) regional base level has not changed much during the last million years and thus the Missoula floods caused little or no overall downcutting of the river bed, at least not more than a few tens of meters; and (2) because the basalt of Haystack Butte must have flowed down a continuous slope to its present position, the entire intervening channel north of Miller Island must have been carved in the last half of the Quaternary, probably by erosion during the Missoula floods. If this channel was carved by flood, it is a huge example of a landform that Bretz noted in various parts of the Channeled Scabland and termed "trenched spurs." Trenched spurs are analogous to flood chutes cut across alluvial meander bends but are instead cut through bedrock.

Along this stretch of the Columbia valley, the floods left a wide spectrum of other erosional features, ranging from streamlined hills formed in the surficial loess and sedimentary deposits, to stripped, plucked, and channelized surfaces on the basalt flows. We compare flow velocities from our modeling (Figure 11) to mapped erosional features for a 30-km reach extending upstream from Celilo Falls to the John Day River confluence. Figure 12 shows how these erosional features plot with respect to the flow depth and velocity calculated for the peak stage of the largest flood. Hills composed of loess and semiconsolidated alluvial deposits were streamlined and channelled under flow depths of 0–40 m and velocities less than 5 m/s. In areas of more intense flow, the loess and alluvial deposits were completely removed, exposing surfaces of the Columbia River Basalt Group. Intact but stripped and grooved basalt surfaces correspond to maximum flow depths between 25 and 125 m and flow velocities of 3–9 m/s. Local erosion of these basalt surfaces into a butte-and-basin morphology was probably a result of unsteady and complex flow phenomena such as vertical flow vortices and cavitation that cannot be directly described by the step-backwater results. Nevertheless, average flow conditions at these sites are characterized by depths of 100–270 m and velocities of 6–24 m/s. Hydraulic conditions at sites of inner channel formation were most intense; flow depths exceeded 250 m at maximum discharge and velocities were greater than 13 m/s. Because many of the features may have been the cumulative product of several floods with hydrographs that spanned a large range of dura-

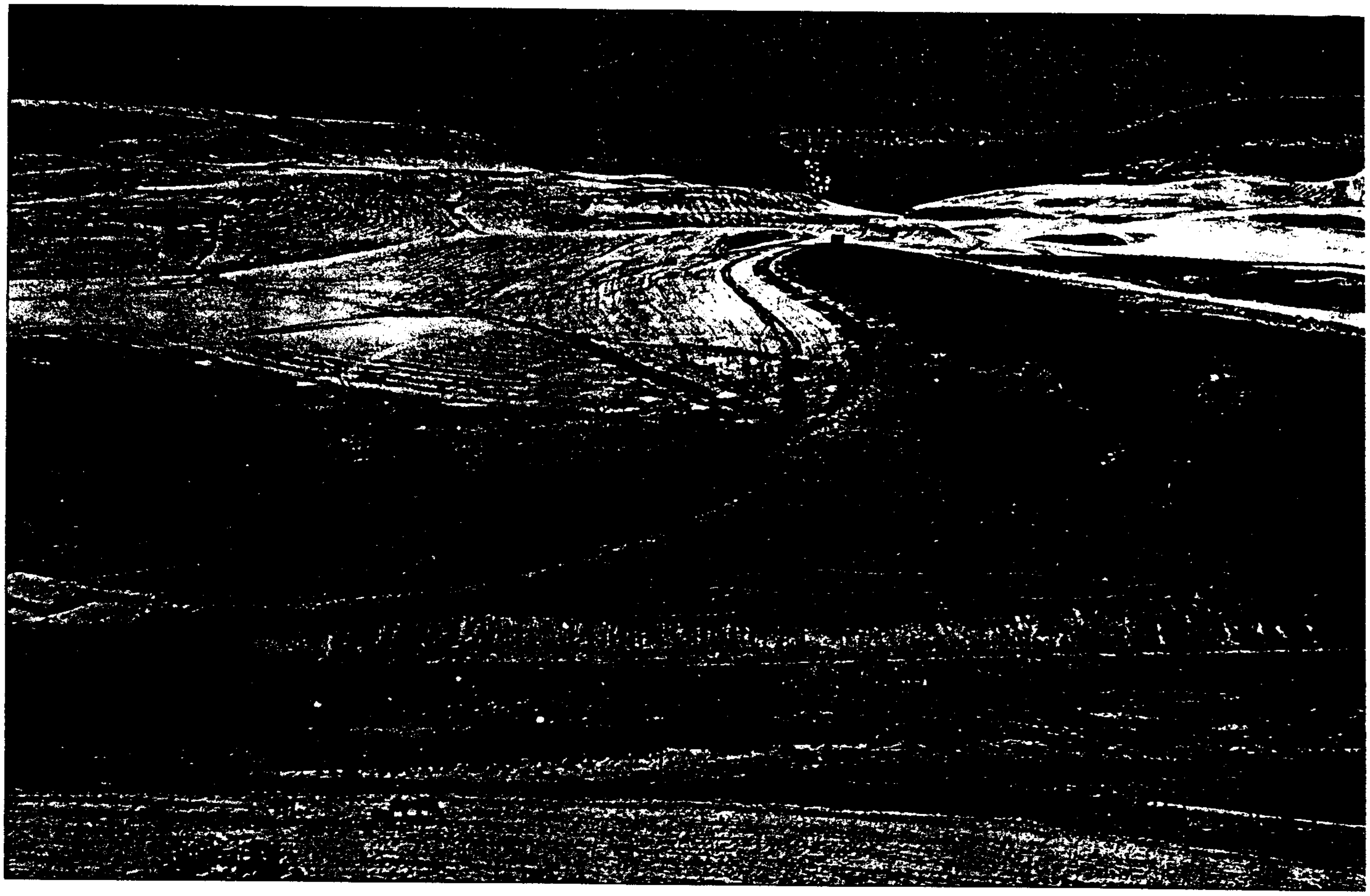


Figure 9. Panorama view generally north of the delta bar (not cultivated, dark) deposited by water spilling out of the

tions and discharges, the depth and velocity fields of specific "facies" of erosional landscapes should not be viewed as definitive. Yet it is apparent from the high spatial correlation between flood features and local flow conditions that there are important thresholds that must be exceeded for certain types of erosional features to be produced. Did all, a few, or perhaps just one flood cause most of the erosion along the flood route? Different parts of the Channeled Scabland would probably give different answers.

En route to Stop 1.3

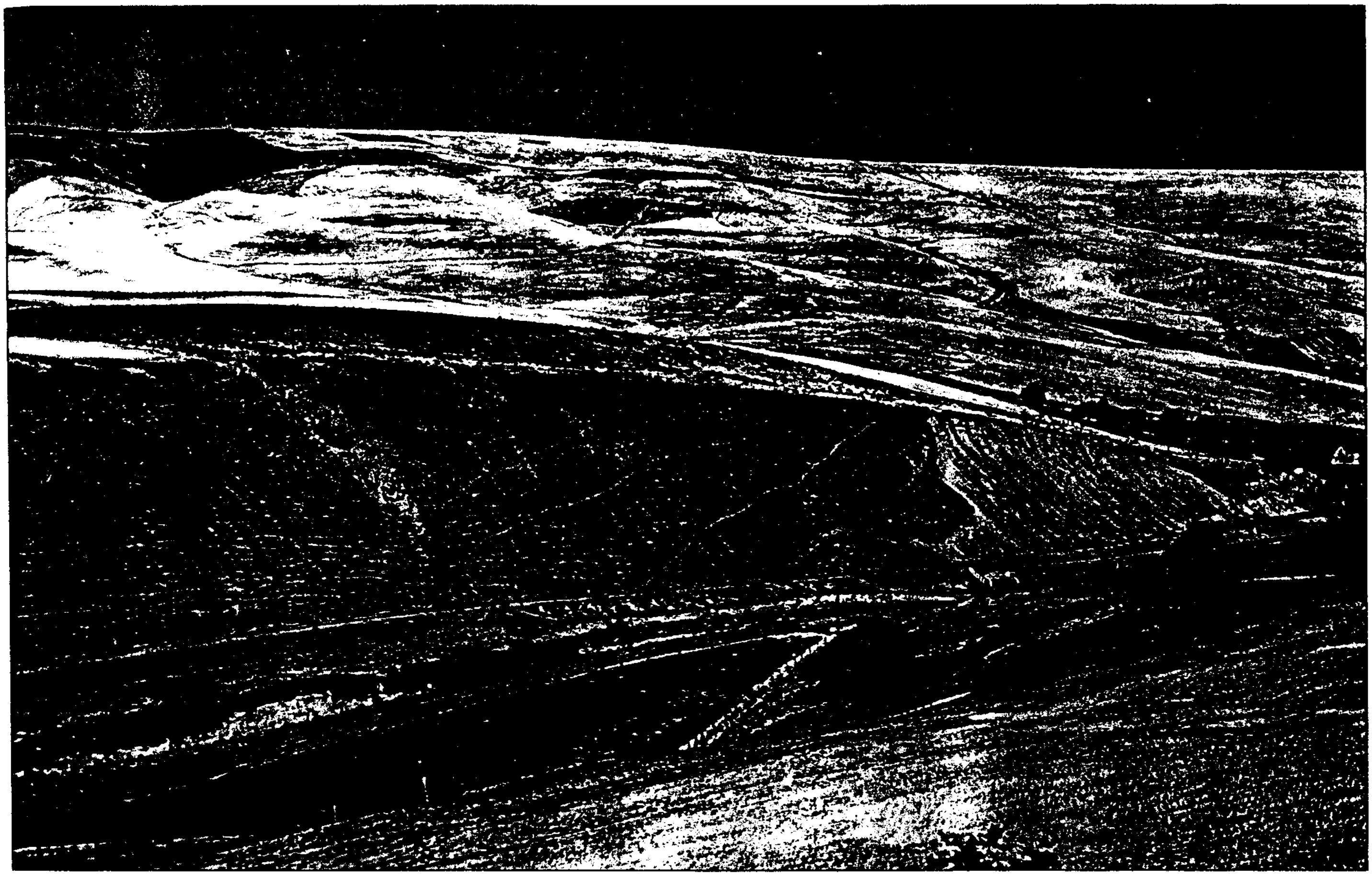
Continue east on Old Moody Road, passing over high-level and locally high-relief butte-and-basin scabland before descending into the valley of the Deschutes River. A prominent trimline cut into the slopes above indicates that maximum flood stage exceeded altitude 315 m (1,040 ft). At river level, a large pendent bar extends downstream from the southeastern edge of Miller Island.

A large bar lies along the west side of the Deschutes valley, extending upcanyon about 3 km. An Oregon Department of Transportation gravel pit near the top of it previously exposed seven alternating sand and gravel couplets, ranging from 1 m thick near the bottom to less than 30 cm at the top. Each couplet consists of well-sorted micaceous medium sand deposited in north-dipping foresets unconformably overlain by openwork coarse sand and gravel deposited in south-dipping foresets. Most of the sand units are partly to nearly completely truncated by the gravel unit, except for a trace of sand between the gravel units. The upper 0–3 cm of each coarse unit has a silt matrix that indurates the upper few centimeters of each unit. We infer that this silty matrix resulted from loess deposition between separate floods. The distinct change in texture and current direction within the couplets may result from changing eddy circulation patterns as each flood waxed and waned. If each of these seven units were deposited by individual floods, they all achieved discharges of greater than about 2 million m^3/s, based on their altitude relative to our modeling results.

Proceed east along the frontage road to Biggs Junction and enter Interstate 84 eastbound. Continue 19 mi east, passing the John Day Dam and the mouth of the John Day River, exiting at Philippi Canyon (Exit 123).

Ascend Philippi Canyon, where a large eddy bar has been deposited along the eastern valley margin. Near the road junction is the col of a major divide crossing between the Columbia and John Day River valleys (Figure 13). Bretz (1928, p. 686–690) described this region in detail, using it as a cornerstone in building a case for huge flows downs the Columbia.

The following section is on private property. Be sure to obtain permission before entering! (If you wish to bypass the private land, go on to Stop 1.4.)



valley, through Fairbanks Gap, and into the valley of Fifteenmile Creek (foreground). USGS photograph by A.M. Piper.

Turn right (west) at the intersection and follow the private road that flanks the north edge of a channel and cataract complex that has been eroded through the Columbia River Basalt Group and overlying Tertiary gravel. To the west, a large flood entering the John Day valley from the Columbia deposited an immense bar, 150 m (500 ft) high and mantled with rounded boulders 2–3 m in diameter.

Stop 1.3. Columbia River overview

This superb view of the valley of the Columbia River is from 310 m (1,020 ft) above what used to be the normal river level but is now submerged 25 m due to the John Day Dam. Some 15–30 m (50–100 ft) above the maximum flood stage, this site would have been a good if somewhat frightful place to watch the largest Missoula flood(s). In this area, the maximum flood stage can be confidently constrained as being less than 340–350 m (1,120–1,150 ft) by a divide 300 m to the east that was apparently not crossed. However, about 5 km west, laminated sand and silt mantle loess to an elevation of at least 330–340 m (1,080–1,120 ft). Another divide crossing, 2 km west, has a minimum elevation of more than 310 m (1,020 ft), with evidence of erosion as high as 340 m (1,120 ft).

A tremendous current must have developed between the Columbia and John Day River valleys to erode the scabland of this divide. Such a current indicates a substantial difference in the water surface elevations between the flooded Columbia River valley and the backflooded John Day River valley, a rather quick rise in flood stage. The travel distance over which this gradient was developed was only about 30 km. We can speculate about what the rate of rise may have been by assuming that the divide crossing was not eroded significantly below the level of backflooded water in the John Day River valley at the time of the initial crossing, hence putting that water level at about 230 m (750 ft). The water level at initial overtopping of the divide may have been about 300 m (1,000 ft). Assuming that the flood wave moved downstream at the celerity of the flow velocity at peak stage (about 10–15 m/s), it would have taken 50–75 minutes for water levels to translate down the Columbia River valley and back up the valley of the John Day River. Considering the ~70-m elevation difference between the water levels tenuously indicated by the field evidence, this translates into a water level rise of about 1 m/min.

En route to Stop 1.4

Continue westward on the peninsula between the John Day and Columbia Rivers and turn around at the divide crossing at about the 310-m (1,020 ft) elevation. Here, flow overtopped a low point in the ridge between the two rivers,

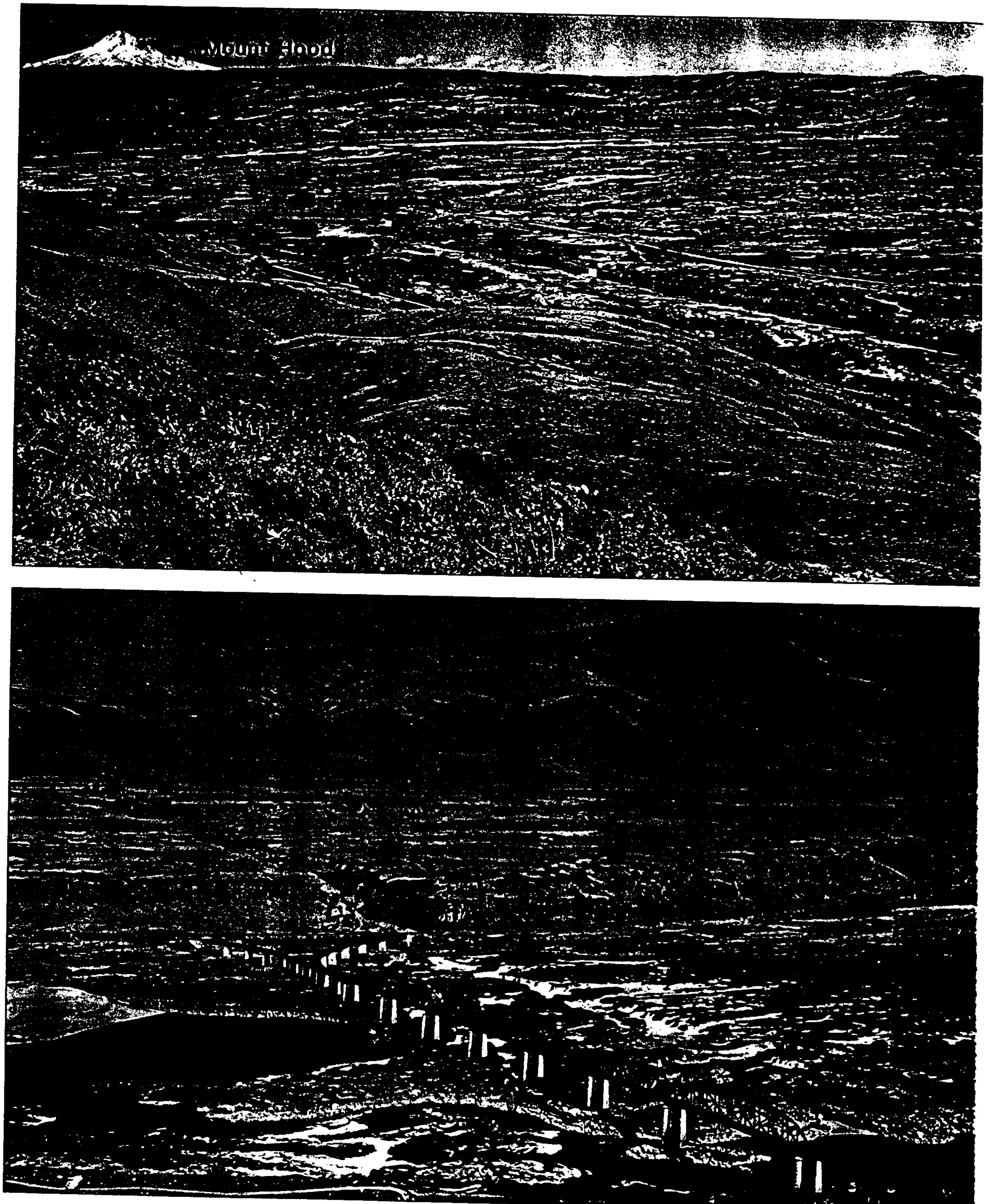
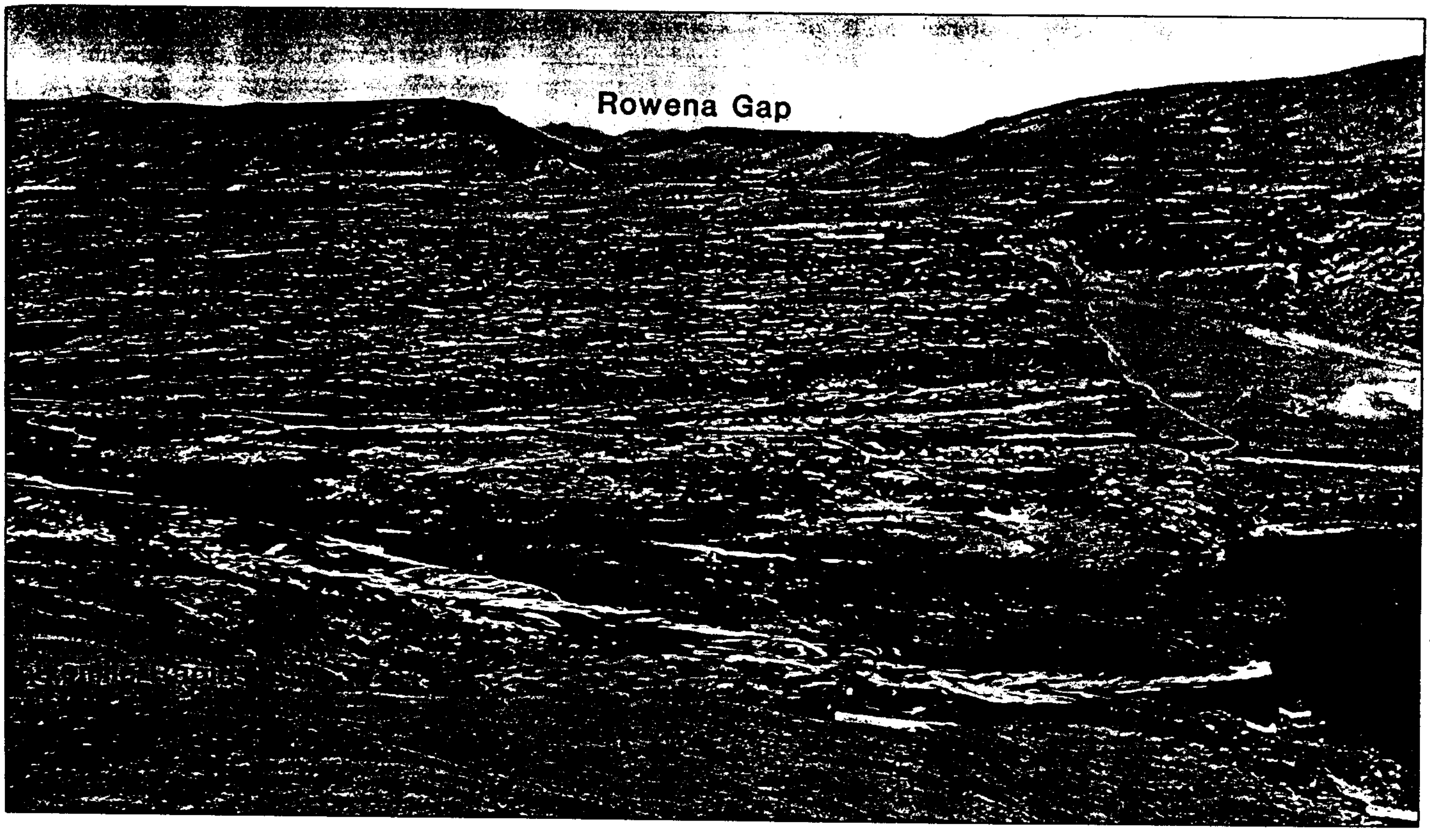


Figure 10. Panoramas of "The Dalles of the Columbia" before inundation by The Dalles Dam. Views are from south valley side an



generally west-southwest in the upper panorama, generally north from near Stop 1.2 in the lower. USGS photos by A.M. Piper.

eroding through Tertiary gravel (Alkali Canyon Formation of Farooqui and others, 1981) but not entrenching into the Columbia River Basalt Group that floors the channel.

Turn around and drive back to Philippi Canyon road. Stop 1.4 is just south of the intersection on that road.

Stop 1.4. Scabland

Take some time to walk around this "amazingly wild scabland" (Bretz, 1928, p. 688). Note the closed rock basins and the basalt protrusions, the steep-sided canyons with floors that slope in various directions. Imagine what the landscape looked like before the floods.

Much of the coarse debris eroded from this scabland was deposited in two large bars whose apices lie just downcurrent from each of the two sets of cataracts formed by water overflowing into the John Day valley (Figure 13). The smaller bar, south of the southeastern flow route, has giant crescentic current structures on its surface. Together, these bars displaced the John Day River southward onto a shelf of basalt that forms the south valley side.

The John Day valley is mantled by rhythmically bedded sand and silt deposits from its mouth to more than 30 km upstream. These deposits have not been examined systematically and in detail, but apparently they were deposited by several Missoula floods that backflooded up the valley. At a site 30 km upstream from the mouth, there is a section of at least 14 rhythmites, each rhythmite probably representing a separate flood. The field evidence includes bioturbation and loess deposition at contacts. The eighth rhythmite from the top contains a faint tephra couplet, probably the 13-ka Mount St. Helens "set S." The relation of these rhythmite sequences to the coarse deposits at the divide crossings is not clear, but it seems doubtful that rhythmites along the John Day River valley downstream from the large bars near the point called the "Narrows" could have survived a deluge traveling down the John Day River from the Philippi Canyon divide crossings. We speculate that the rhythmites in the John Day River valley, especially those in the lowest reaches, postdate the flows that formed the scabland and great bars resulting from overflow at Philippi Canyon.

According to our flow-modeling results, flow over the divide at Philippi Canyon requires a minimum of about 5 million m^3/s. In contrast, emplacement of the 14 rhythmites requires minimum discharges of only about 1.5 million m^3/s.

The only chronologic information we have regarding the deposits at the Narrows is a radiocarbon age from a soil clast in a colluvial deposit below a single Missoula-flood deposit north of the large bar. The bulk radiocarbon analysis of the clast yielded a result of 29,845±470 ^{14}C yr B.P. An analysis of the humic acids (NaOH extract) resulted in

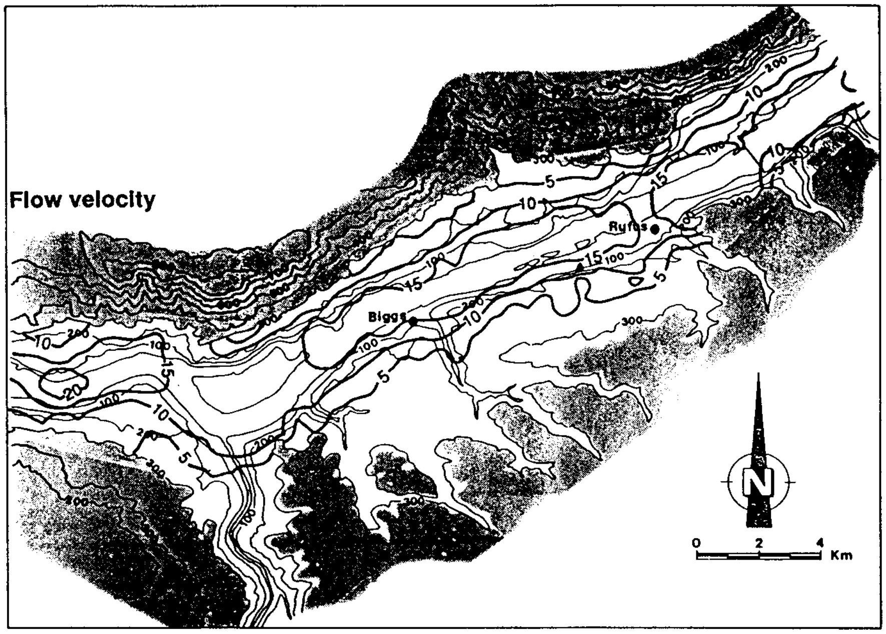


Figure 11. Isovel (equal velocity) map for a 10 million m^3/s discharge near the confluence of the Columbia and Deschutes Rivers. Velocity values are in m/s. Area above flood limits shown by stipple pattern.

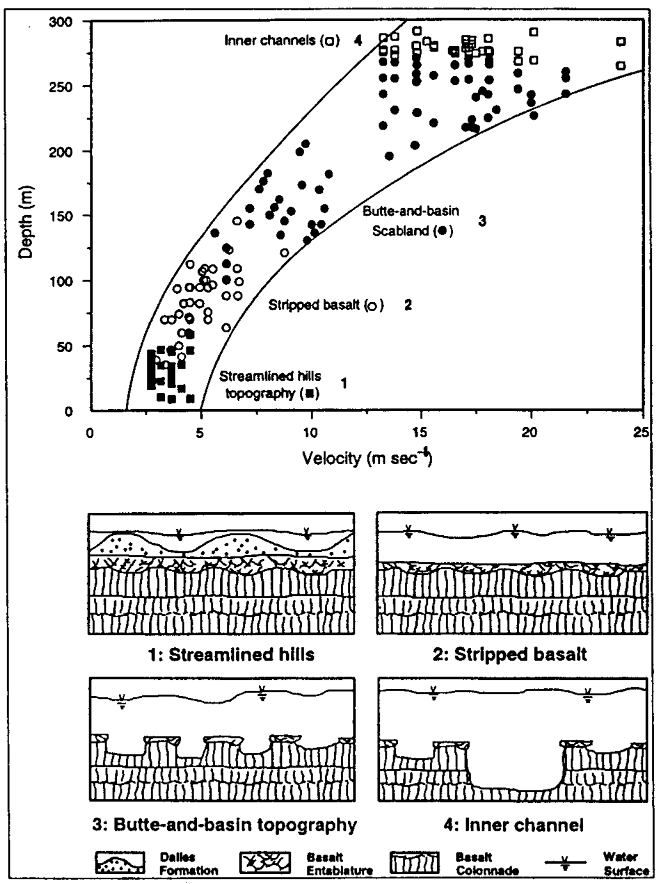


Figure 12. Relation of erosional features in the area of Figure 11 to local flow depths and velocities calculated for a 10 million m^3/s discharge. The various "facies" of erosional features are portrayed in lower part of figure.

19,015±145 ^{14}C yr B.P. In this case, these dates provide a maximum age for the overlying flood deposit and simply confirm that the most recent flow(s) over this divide were during the late Wisconsin.

En route to Stop 1.5

Continue east, traveling up Philippi Canyon. From this point eastward, almost to Wallula Gap, the largest Missoula floods spilled well out of the Columbia River valley, inundating large tracts of upland surfaces. These high surfaces are underlain by basalt gravel and tuffaceous sediment of the late Miocene to early Pliocene Alkali Canyon Formation (Farooqui and others, 1981; Smith and others, 1989), which in turn overlies the Columbia River Basalt Group.

Stop 1.5. Ice-rafted erratics

Near the telephone pole are some ice-rafted erratics. Commonly, accumulations of diverse rocks are found in concentrated zones, locally forming mounds. Many, like these, are on the east sides of ridges that stood up above the maximum flood stage. The erratics here have been cleared from the fields but probably have not been moved far. They are at an elevation of about 325 m (1,060 ft), consistent with the high-water evidence discussed at Stop 1.3 and local divide crossings and trimlines up to an altitude of 335 m (1,100 ft). For the next 80 km upstream, to the downstream end of the constricted reach at Wallula Gap, maximum stage evidence closely hovers about the 1,100-ft contour (335 m), indicating that there was little gradient to the largest flood at peak stage. The flatness of the water-surface profile in this reach fueled Allison's (1933) speculation that physical damming downstream was the cause of the high water levels in the Columbia valley.

En route to Stop 1.6

Continue east to Blalock Canyon road, then southwest to Alkali Canyon and north to Oregon Highway 19. Alkali Canyon was the largest of several overland flow routes from the north that spilled water into the John Day valley. A gravel eddy bar at the junction of Blalock Canyon and Alkali Canyon roads attests to the flow velocity. Westward travelers of the Oregon Trail ascended out of Alkali Canyon via this eddy bar after following the south side of the canyon for several kilometers.

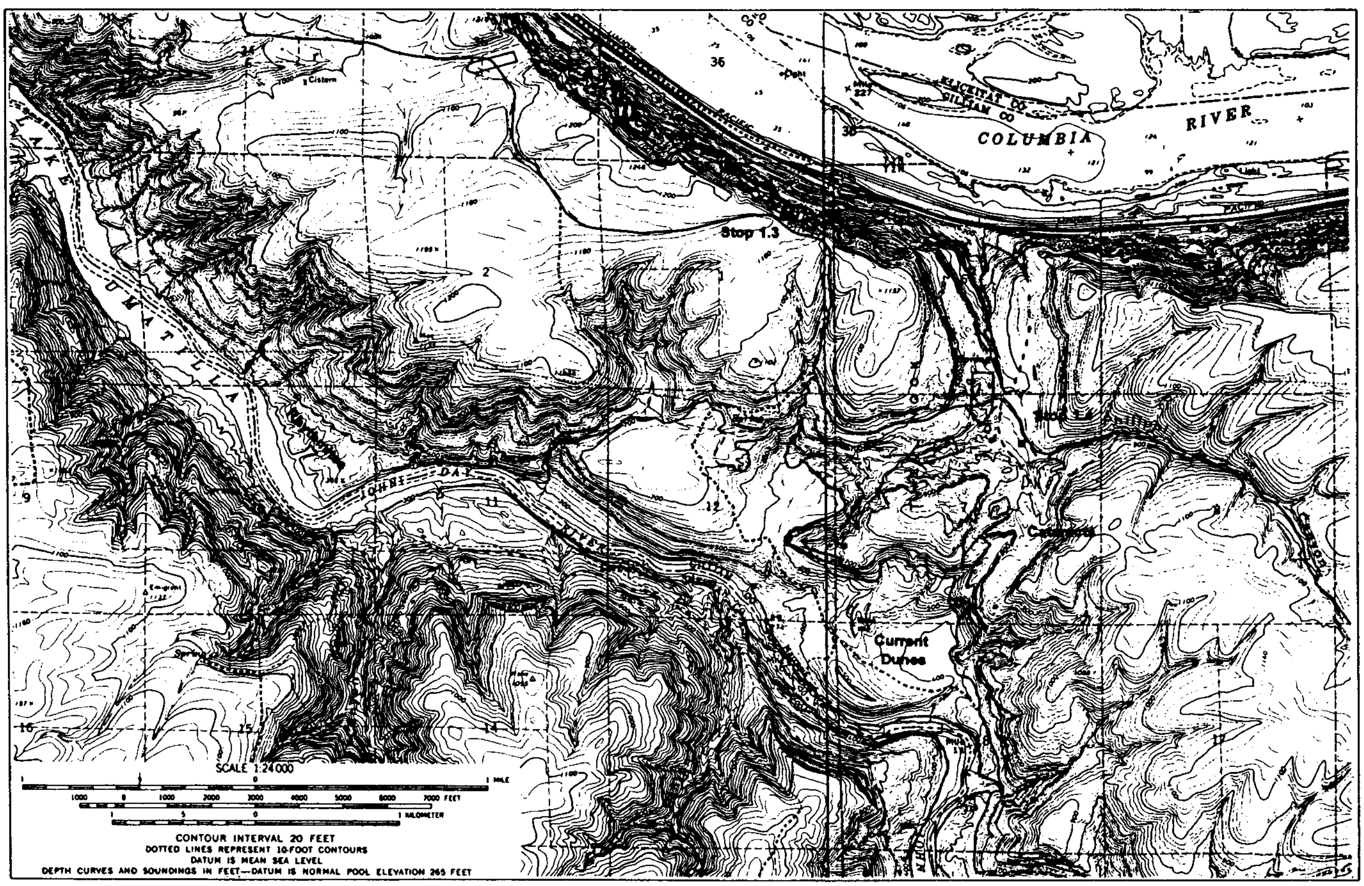


Figure 13. Topographic setting and approximate distribution of Missoula flood deposits in the area of the divide crossing between the Columbia and John Day valleys near the "Narrows." Topographic base from Quinton and Sunrise NW USGS 7½′ quadrangles.

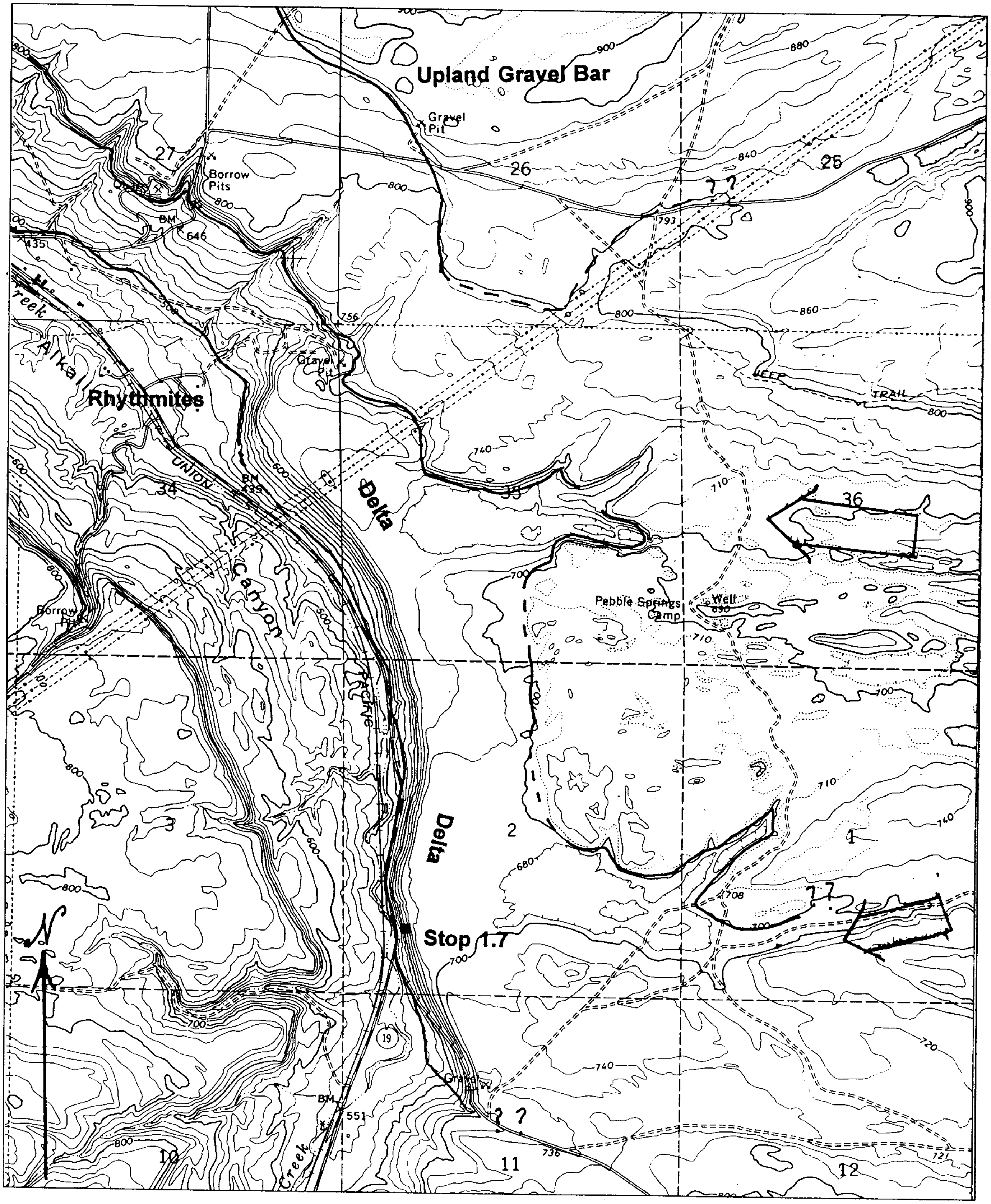


Figure 14. Topographic setting and approximate distribution of Missoula flood deposits southeast of Arlington. The delta bars were mainly deposited by flow spilling into Alkali Canyon from the two upland channels to the east. There was substantial flow over the entire upland surface, however, as evidenced by the large gravel bar deposited on the upland surface that is depicted on the north part of the map. Topographic base from Arlington USGS 7.5′ quadrangle. Land sections (numbered) are 1 mi (1.6 km) across.

Stop 1.6. Arlington rhythmites

This stop is an appetizer for the stops on Day 2. About 15 fining-up sand-to-silt beds are deposited over preexisting landscape. Thin stringers of Mount St. Helens "set S" tephra lie at the top of about the fourth bed from the top. Is it possible that each of these beds was deposited by a separate flood? Day 2 stops will address this question in detail.

En route to Stop 1.7

As you continue north on Highway 19, you gain a view of a large delta that enters and partially fills Alkali Canyon from overland flow routes to the east.

Stop 1.7. Arlington flood delta

The final stop is at an exposure of a large delta complex of bouldery gravel deposited in Alkali Canyon about 4 km southeast of Arlington (Figure 14). Bretz (1925, p. 243–244) described this feature in his first report on Missoula flood features in the lower Columbia River valley. Bretz did not fully understand how high the water had risen here, even in his last report on the lower Columbia valley (1928, p. 681–686). But Allison (1933) did, and the question was one element of the contest between those two.

The entire upland surface south of the Columbia River was in fact submerged by water during the largest Missoula floods, although two channels (Figure 14) identified by Bretz (1925) that eroded through the Alkali Canyon Formation down to the surface of the Columbia River Basalt Group probably conveyed most of the upland flow. The exposure here lies at the south end of a large delta complex that was deposited as flow dropped into Alkali Canyon from those overland channels. The exposed part consists of 30°-W.-dipping foresets of gravel with clasts as large as small boulders. Many of the clasts are well-rounded basalt cobbles, 10–20 cm in diameter; these were probably reworked from the Alkali Canyon Formation. Coarser and angular to subrounded Columbia River Basalt Group clasts, as well as clasts of soil and loess, were clearly transported only short distances. The steep dip of the foresets precludes viewing much of the stratigraphic sequence in this exposure. Nevertheless, there are no sweeping unconformities like those in some other delta deposits, such as at Petersburg. Perhaps the forsets exposed here were deposited by just one flow. Other exposures in this delta complex, however, both near the apex of the northern channel and down near the toe, indicate that perhaps at least two flows were vigorous enough to transport gravel over the 215-m-high upland surfaces to the east.

An exposure 5 km to the southeast, also at an altitude of 215–220 m (710–720 ft), gives more clues to the number and magnitude of floods that inundated this area. A roadcut exposes silt and fine sand deposited in six or seven cycles of fining-up sequences. The cycles themselves thin and fine upwards from 20–30 cm thick near the bottom of the exposure to a few centimeters thick at the top. Three stringers of tephra are also exposed, two near the top of the fifth cycle down, and one at the top of the fourth cycle from the top. Similar in setting and stratigraphy to exposures to be discussed on Day 2, these tephras are probably also Mount St. Helens "set S." If each of these rhythmites was deposited by separate floods, then there were at least seven floods that achieved stages of 215–220 m (710–720 ft), equivalent to a discharge of 3–4 m^3/s, with four of these flows postdating 13 ka. Many of these flows, however, may not have had the strength to transport gravel across the upland surfaces and contribute to formation of the Arlington delta.

En route back to Deschutes State Park

Proceed northwest on Oregon Highway 19 toward Arlington. For the first couple of kilometers, we follow the curved delta front of deposits from the overland channels to the east. The west side of the valley is covered with numerous landslides and is locally mantled with Missoula flood sand and silt. Shortly after leaving the delta front, we pass an exposure of rhythmically bedded sands and silts that compose the flat but gullied surface along part of the valley floor (Figure 14). These deposits, apparently inset against the gravel delta bars, were left by tens of floods that probably postdate the delta bars. Although we have not done a thorough search, we have not found the "set S" tephra, so the floods represented by these deposits may all postdate 13 ka.

Enter Interstate 84 westbound and head back to Biggs Junction. Along the way note the abundant bars deposited on the downstream side of valley protrusions and in tributary mouths. Bretz (1924, 1928) described many of these, noting:

> "In this part of its valley are numerous deeply trenched tributary canyons. . . Deposits of fresh, dominantly little-worn basalt gravel occur at various altitudes in this canyon portion. If they are remnants left by dissection of a once complete fill, they should be most extensive between the tributary mouths, not in them. If they are original deposits left by a very great flood and individually determined by local conditions, tributary mouths would be logical places for them." (Bretz, 1928, p. 684)

DAY 1 ROAD LOG (mileage is approximate)

Miles

- 0.0 Deschutes State Park overflow area.
- 0.2 Turn left (west) onto Oregon Highway 206 (old US 30).
- 3.4 Turn right (north) and pass under I-84.
- 3.6 Turn left (west) and enter I-84 westbound.
- 14.0 Exit I-84 at Exit 87. Turn left (south) onto Oregon 197.
- 14.3 Stop sign at junction of Oregon 197 and US 30. Turn left, continuing south on Oregon 197.
- 14.6 Turn sharply left onto Columbia View Drive, proceed up the hill with good views of The Dalles Dam, including fish ladders on the east and west sides of the dams. To the west, on Sevenmile Hill (northwest of The Dalles), a prominent trimline is visible about halfway up the slope.
- 16.0 Cross under power lines from The Dalles Dam.

16.4 Stop sign. Turn right (east) onto Seland Road.

17.6 Cross bridge over Eightmile Creek. Bear left at yield sign, ~~continuing~~ on ~~Seland Road~~.

18.1 Cross bridge over Fifteenmile Creek.

18.2 Abandoned gravel pit on left, south margin of Petersburg Delta. Site of Petersburg settlement and school.

18.7 **Stop 1.1,** Petersburg Bar. Pull off and park on gravel parking strip on the right side of the road. When you leave, continue north on Seland Road.

19.9 North margin of Petersburg delta exposed along road. Roadcuts for next few miles are in the Columbia River Basalt Group.

22.8 Roadcuts expose western margin of Fairbanks bar.

23.7 Junction with Company Hollow Road from the south. Large exposure of Fairbanks bar in the gravel pit on the north side of the road.

23.9 Turn left on Old Moody Road (one-lane gravel road).

24.5 View left to surface of Fairbanks bar. Hills and swales on bar surface are giant crescentic current dunes.

24.7 Fairbanks Gap.

25.3 View down to the Columbia River (Lake Celilo), 180 m below.

27.1 **Stop 1.2,** Celilo overlook. Pull off as far as possible on right side of road. Watch for traffic on narrow road. When you leave, continue east on Old Moody Road.

27.8 Traveling across high-altitude basin-and-butte scabland surface.

29.3 Ranch on right.

29.9 Begin descent into Deschutes River valley.

30.5 Oregon Department of Transportation gravel pit.

30.9 Pass under Burlington Northern railroad.

31.2 Heritage Landing (restrooms).

31.4 Stop sign at junction with Oregon 206/US 30. Turn right (east).

31.6 Cross over Deschutes River.

31.8 Turnoff to Deschutes River State Park camping area.

33.2 Junction with Oregon 206. Continue east on US 30.

35.8 Enter Biggs Junction.

36.2 Four-way stop. Turn left onto US 97.

36.3 Turn right and enter I-84 eastbound.

43.9 John Day Dam.

46.1 Cross John Day River.

54.9 Exit I-84 at Philippi Canyon (Exit 123)

55.2 Stop sign. Turn right onto Philippi Canyon Road.

57.0 Top of large eddy bar deposited in east side of Philippi Canyon.

57.1 Pavement ends. Turn right onto Philippi Lane (private road).

57.7 View down into John Day valley and large bar.

57.8 Pass under power lines.

58.9 **Stop 1.3,** Columbia River overview. When you leave, continue west on Philippi Lane.

60.0 Exposure of the Alkali Canyon Formation and old soils in road cut on right.

60.6 Divide crossing (sec. 35, T. 3 N., R. 18 E.)

60.7 Turn around.

64.2 Junction of Philippi Lane with Philippi Canyon Roa (signed as Quinton Lane and Heritage Road). Turn rigl (south).

64.4 **Stop 1.4,** Scabland of the "Narrows" divide crossin Park on right side of road and hike about 500 m southwe to the knob of basalt with the power line standard fo views of the divide crossings between the John Day an Columbia Rivers. When you leave, continue south an then east, following Philippi Canyon Road up Philipp Canyon.

64.4 Small eddy bar.

69.1 **Stop 1.5,** Ice-rafted erratics (next to first utility pole or north side of road). Park on right side of road. When you leave, continue west.

69.3 Junction with Hoag Road. Pavement begins. Proceed straight ahead.

71.1 Turn right (south) onto Blalock Canyon road. (Turn left to rejoin I-84.)

72.6 Pavement changes to gravel.

74.2 Bear left, continuing on Blalock Canyon Road.

75.9 Pass under power lines.

76.5 Exposure of the Alkali Canyon Formation.

76.8 Descent into Alkali Canyon, crest of small eddy bar on left.

77.0 Left at Y, join Alkali Canyon Road eastbound.

79.8 Junction with road to chemical waste dump on left.

80.7 Railroad crossing.

84.2 Junction with Oregon 19. Turn left (north) toward Arlington.

85.4 **Stop 1.6,** rhythmically bedded sand and silt. Park on left side of highway. Watch for traffic. When you leave, continue north on Oregon 19.

86.6 View of delta front from upland channels to the east.

87.5 **Stop 1.7,** delta from upland channels to east. (Just past junction with Eightmile Road.) Park in gravel area on right side of highway. When you leave, continue north on Oregon 19 toward Arlington.

89.3 Exposure of several rhythmites on left (east) side of highway.

90.3 Exposure on right side of road of two gravel units, capped by rhythmites.

91.2 Railroad crossing. Follow signs to I-84 westbound.

91.6 Enter I-84 westbound.

124.5 Exit I-84 at Biggs Junction (exit 104).

124.7 Stop sign. Turn left onto US 97.

124.8 Four-way stop. Turn right onto old US 30.

129.2 Turn left into Deschutes State Park camping area.

End of Day 1.
To be continued
in next issue

fences, which are "hot." Close any fence you open. When you leave, turn right (south) back toward Mabton on Washington 241.

215.3 Entering Mabton.

215.5 Veer right, staying on main road through town.

215.7 Railroad crossing.

215.8 Intersection. Turn right onto Washington 22 toward Toppenish and Yakima.

217.0 Views ahead of Mount Adams volcano (left) and Mount Rainier volcano (right).

221.2 Nice stone house on left.

229.9 Conspicuous landslide off Toppenish Ridge anticline.

233.7 Cutoff left to U.S. 97. Continue on highway.

234.9 Stop light at Toppenish. Turn left onto U.S. 97.

237.8 Youthful small stream valleys cut north flank of Toppenish Ridge anticline.

239.7 Begin ascent of Toppenish Ridge anticline.

242.8 Crest of Toppenish Ridge anticline. Roadcuts expose Columbia River Basalt Group.

244.0 Simcoe volcanic field (Pliocene), a shield of alkali basalt.

269.4 Satus Pass.

276.2 Alkali basalt of Simcoe volcanic field on right.

277.9 Round-stone pebble gravel rich in quartzite clasts in cuts on both sides of road here and for next half mile. This represents an old (but younger than an underlying 10.5-Ma basalt) course of Columbia River directly across what since has become the Horse Heaven and Columbia Hills anticlinorium. The rise of these great anticlines diverted the Columbia and Yakima Rivers east to Pasco basin some time after 10 Ma.

278.7 Baked base of Pliocene alkali-basalt flow.

279.5 More quartzitic pebble gravel.

282.0 More cuts in alkali basalt.

282.5 Baked substrate beneath alkali-basalt flow.

283.5 Intersection with highway to Goldendale. Continue south on U.S. 97 across Klickitat valley. Mount Adams to west.

289.0 Volcano viewpoint (Mount Hood, Adams, Rainier).

290.0 Begin descent to Columbia valley off Columbia Hills anticline.

292.0 Here and for next 1.5 mi views of scabland benches on south side of Columbia valley, stripping by flood as high as 900 ft above river.

293.7 At intersection turn left, continuing on U.S. 97 south.

294.0 At intersection turn left, continuing on U.S. 97.

294.4 Turn right, continuing on U.S. 97.

296.5 Center of bridge over Columbia River.

297.0 After crossing I-84, turn right into Biggs (old U.S. 30). Deschutes State Park campground is 4.5 mi to west.

End of Day 2.

DAY THREE

Day 3 includes stops looking at a variety of features, including Missoula flood deposits, older soils that may relate to pre-late Wisconsin episodes of Missoula flooding, and recent landslides. The road log ends at Cascade Locks near the west end of the Columbia River Gorge. The route crosses the Columbia River to the Washington side, then follows Washington Highway 14 until crossing back to Oregon at The Dalles. From The Dalles, continue west, driving part of the historic Columbia River Scenic Highway, ending at Cascade Locks. Maps: The Dalles 1°×2° sheet; Hood River and Goldendale 1:100,000 sheets.

En route to Stop 3.1

Proceed east to Biggs Junction, enter U.S. Highway 97 northbound, and cross the Columbia River. Ascend U.S. 97, past replica "stonehenge" on the knob to the east, to Washington Highway 14 and turn left (west). Proceed about ¼ mi west, pull over, and park on the large gravel area south of Highway 14 near its junction with the northbound continuation of U.S. 97.

Stop 3.1. Maryhill gravel bar

Private property! Please obtain permission before entering.

This is a high longitudinal bar, 1 km long with a crest at an altitude of 255 m (840 ft). A gravel pit provides a three-dimensional exposure of west-dipping foresets of alternating sand and gravel containing clasts as large as 30–40 cm. The top of the section is only locally exposed.

This high coarse deposit contains evidence of subaerial exposure between several of the depositional units. The tops of some foresets are composed of concentrations of cobbles with a silty matrix, zones that appear armored and have a slightly browner cast. The silt matrix is inferred to be the result of postdeposition loess that migrated down into interstices at the top of the gravel bar. The contacts with overlying gravel are commonly unconformable, the cobbly lag having been partly eroded in the course of subsequent deposition. There are about six of these units separated by contacts like this, indicating that at least six floods were capable of transporting gravel at this elevation. According to our modeling results, a discharge of at least 6 million m^3/s would be required to inundate this bar. This is the highest discharge value we have yet been able to associate with evidence of multiple floods in the lower Columbia Valley.

Within many of these depositional units separated by the contacts described above are several foresets with no evidence of depositional hiatus. These foresets may reflect flow pulses or gravelly bed forms moving over the surface during a single flood. A charcoal sample from the lowest stratigraphic unit exposed in the east wall yielded a radiocarbon date of 32,630±610 ^{14}C yr B.P.

En route to Stop 3.2

Continue west on Highway 14, traveling along a bench immediately south of the tight, southward verging, overturned anticline and thrust fault that forms the Columbia Hills to the north. Several landslides and thick colluvial and alluvial-fan deposits have been shed south off of this structure. About 2 mi from Stop 3.2, we pass Maryhill Museum, containing an eclectic collection of European and American art, Native American artifacts, and the former crown jewels of Romania. Maryhill Museum was originally a residence of Sam Hill, who started building it in 1914, apparently to fulfill a desire to live in a castle like those he had seen along the Rhine River.

About 1.25 mi past the museum, Highway 14 crosses steeply dipping lava flows from Haystack Butte. Continue west, having good views of the extensive butte-and-basin scabland across the Columbia River just downstream of the Deschutes River confluence. Road cuts show alluvial fan and landslide deposits from the Columbia Hills. Continue through Wishram Heights and on toward the wide, open synclinal valley of The Dalles. Prominent trimlines are carved into the alluvial fans at several levels, the highest ones consistently at altitude 290±10 m (960±40 ft). There are good views of the Fairbanks Gap and Petersburg divide crossings on the south side of the river. In good lighting, a pronounced trimline can be seen on the southwest flank of Sevenmile Hill on the far (west) side of The Dalles.

The course of the Columbia River follows structural lows. From The Dalles eastward to the John Day confluence, the path of the river largely follows the Dalles-Umatilla syncline, flanked on the north by the Columbia Hills anticline. The wide valley of The Dalles is a large synclinal valley. The rapids and holes of "The Dalles of the Columbia" corresponded with the area where the river intercepts resistant basalt units that dip gently to the southwest into the syncline.

Turn left (south) onto U.S. 197, crossing alternating areas of gravel and scabland. Continue across the Columbia River, follow U.S. 197 south across Interstate 84. On the east side of the road is a nice exposure of pillow basalts. The next stop is about 1.25 mi southeast of I-84 on U.S. 197.

Stop 3.2. Late Wisconsin rhythmites and pre-late Wisconsin rhythmites(?)

(By David Cordero and Scott Burns)

Site stratigraphy: The oldest unit in the immediate study area is the Dalles Formation, well exposed in the next roadcut northwest of this stop. Resting unconformably on the Dalles Formation are fine sand and silt beds, which we believe to be ancient Missoula flood deposits, slackwater facies, possibly interbedded with loess (Figure 27). Unlike the composition of the Dalles Formation, mica is a common mineral in these younger deposits, indicating a Columbia River source. The presence of sparse pebbles of varied lithology, including some granitic, is the strongest evidence for the fluvial, instead of eolian, origin of these deposits. The deposits contain five well-developed paleosols with strong carbonate horizons and extensive bioturbation (Figure 27). They are in turn unconformably overlain by late Wisconsin Missoula flood deposits, also fine sand and silt. Scattered pebbles, again in groups, serve as evidence for flood origin. The late Wisconsin deposits appear massive at first glance, but actually consist of several rhythmites deposited by separate late Wisconsin floods. Thin, discontinuous layers of coarse basaltic sand can be traced at several levels within the "massive silt." At the top of the section is latest Pleistocene loess on which the modern soil is developing.

Significance of the site: Besides the Missoula flood deposits of latest Pleistocene age, deposits we attribute to much older Missoula flood events are preserved here. Evidence for the antiquity of these latter deposits are the well-developed paleosols they contain. Each paleosol contains a Bk or K horizon ranging in carbonate development from Stage II to Stage IV, in contrast to the modern soil, developed on the most recent flood deposits and loess, which contains virtually no carbonate and has been forming for close to 10,000 years. Each of the five paleosols must consequently represent a much longer period of soil formation—much more than 10,000 years—during which carbonate could be concentrated in the soil. Thus several floods must have occurred, before the 15- to 12-ka period of late Pleistocene jökulhlaups began, and long periods of time occurred between each of these ancient floods.

We are not the first to suggest the occurrence of pre-late Wisconsin Missoula floods. Bretz and others (1956), Baker (1978), and McDonald and Busacca (1988) are among those who have recognized evidence of older episodes of catastrophic flooding. Tephras found within these older flood deposits at this site have not yet been dated or correlated with certainty with tephras of known age. The most abundant tephra at the site has a chemistry most closely resembling the Dibekulewe tephra of Morrison and Davis (1984), a 400-ka fine ash of unknown source found in western Nevada. As the tephra here is fairly coarse, this correlation, if correct, may help to reveal the source of this ash.

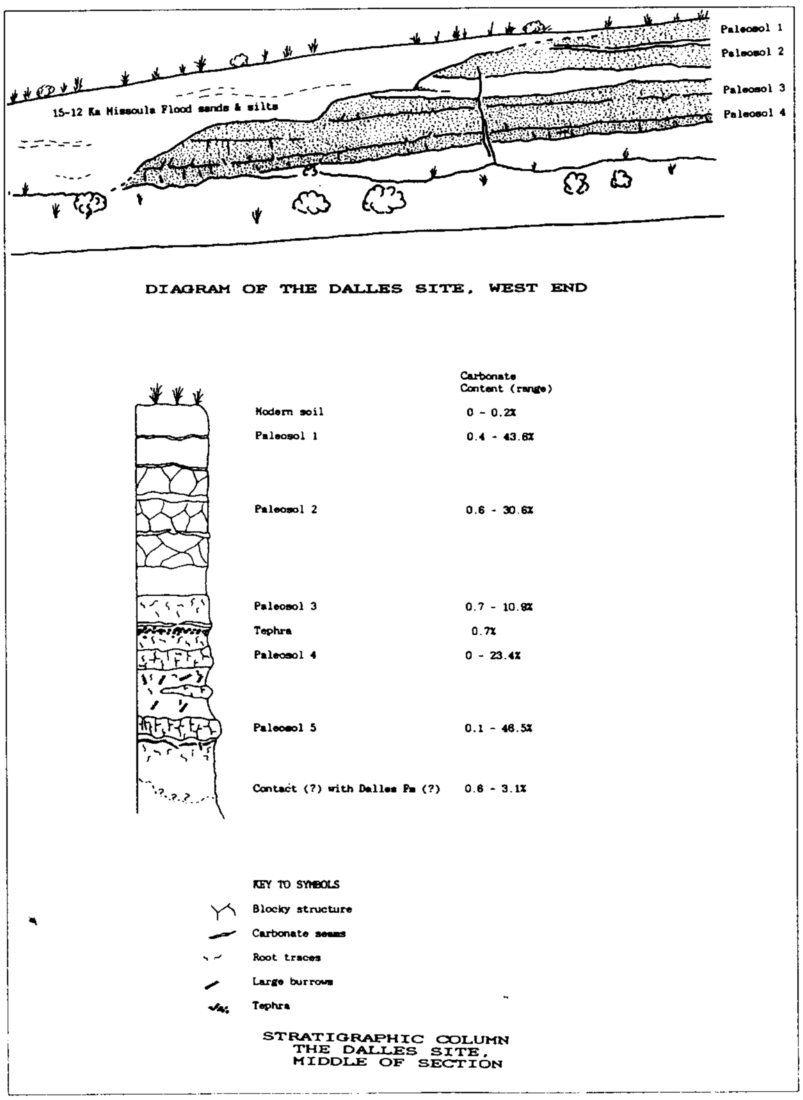


Figure 27. Sketch and stratigraphic column of exposure at Stop 3.2.

En route to Stop 3.3

Proceed back to Interstate 84 and head west, passing through The Dalles. The Columbia River takes a broad sweep to the south and then north, as it leaves the structural basin and crosses the Columbia Hills anticline that trends southwest across the river's path. Capping the Columbia River Basalt Group locally is the Dalles Formation, which dips down to form the bluffs south of the city. Some recently active landslides with movement as great as 5 cm/yr have affected the eastern portion of The Dalles (Rosenfield, 1992).

Past The Dalles, where the highway and river turn north, is butte-and-basin scabland at highway level. To the west is the rising flank of Sevenmile Hill and Crates Point, defining the south limb of the Columbia Hills anticline (also called the Ortley Anticline) where it has been breached by the Columbia River. A prominent trimline has been etched into the hill slope, below which floods stripped loess from the top of the Columbia River Basalt Group. This trimline is at 315±12 m (1,000±40 ft) at the southwest end of the slope and descends to 290±12 m (960±40 ft) at the Rowena Gap constriction near Crates Point. Small granitic erratics lie as high as 285±12 m (940±40 ft) at Crates Point.

The Columbia River Gorge National Scenic Area, managed by the U.S. Forest Service, extends as far east as the Deschutes River confluence. The true physiographic gorge is between The Dalles and Portland, where the Columbia River crosses the Cascade Range. The core of the range has been uplifted several hundred meters during the late Neogene, raising the Columbia River Basalt Group and exposing older Tertiary volcanic, volcaniclastic, and sedimentary rocks below. These uplifted rocks, locally faulted and folded, are capped by the products of numerous small late Tertiary and Quaternary volcanoes.

Pass through Rowena Gap and exit Interstate 84 at Rowena (Exit 76). From here, proceed east on a segment of the historic Columbia River Scenic Highway. The scenic highway, the first successful highway to cross the Cascade Range, was constructed between 1913 and 1915, largely by the inspiration of Sam Hill. It was essential to Hill and Chief Engineer Samuel Lancaster that the road harmonize with the beauty of the Gorge. It was also important that the highway serve as a functional crossing of the Cascade Range: the engineering specifications dictated a minimum width of 24 ft, a maximum grade of 5 percent, and a minimum curve radius of 100 ft. The result was graceful sets of curves, separated by viaducts, bridges, and tunnels, all faced with natural stone worked by European masons, as the road clung to the cliffs on the Oregon side of the river.

Stop 3.3. Rowena Crest

Across the river, a large pendant-eddy bar was deposited downstream of a basalt salient at the downstream end of Rowena Gap. This bar underlies most of the town of Lyle (Figure 28) and originally extended across the present mouth of the Klickitat River. Similar pendant bars flank expansions downstream from each constriction in the Gorge.

Stratigraphy in exposures of eddy deposits northwest and across the Klickitat River from Lyle, near the 513-ft benchmark, indicate that several floods achieved stages of 180 m (600 ft). In particular, an exposure in the gravel pit north of the bench mark exposes at least seven sets of east-dipping foresets of granule gravel to coarse sand. These sets of foresets are capped by pebbly lags that have silty matrices. We interpret these silt-gravel horizons to be the result of loess deposition between separate Missoula floods. Some of the foreset sets are unconformably overlain by as much as 25 cm of steeply dipping loose sand and gravel that may be scree deposited between floods. This gravel deposit is apparently inset against a slightly higher (to altitude of 195 m [640 ft]) and coarser unit to the north (Figure 28) that apparently represents an older and larger flood. The minimum discharge required to inundate an altitude of 180 m (590 ft) is about 4 million m^3/s, which indicates that there have been a least eight floods to surpass that discharge, with at least one that was perhaps substantially larger.

The surface on which we stand at an elevation of 220 m (720 ft) has been stripped of its preflood cover. Locally, such stripped basalt surfaces and trimlines are evident to about 290±12 m (960±40 ft)—an altitude about 25 m lower than maximum flood stage near The Dalles.

En route to Stop 3.4

Continue west on the historic highway, passing Rowena Dell and dropping into the town of Mosier, which lies in a synclinal valley. Like the bars at Petersburg and Fairbanks, flow spilling over a divide between the Columbia River and Mosier Creek deposited a large delta composed of southwest-dipping foresets of cobble-pebble gravel and sand. A discharge of at least 2.5 million m^3/s was required for flow to overtop the divide. Similar to the delta at Petersburg, several depositional units are separated by erosional unconformities, perhaps evidence of multiple flows. One exposure shows at least seven such units. The second unit from the top contained a piece of dung(?) that yielded a radiocarbon date of 13,695±95 ^{14}C yr B.P., indicating that at least two flows subsequent to this date were capable of transporting gravel over this divide.

West of the town of Mosier, a large eddy bar was deposited on the west flank of the Mosier syncline. The bar is composed of well-sorted sand and fine gravel deposited in east-dipping foresets. We infer that this sediment was part of the suspended load of the flood, deposited in a large recirculation zone; that zone developed as a part of the flow was diverted into the topographic low that follows the southwest-trending axis of the Mosier syncline. Exposures in this bar do not show the sweeping unconformities or zones of loess-impregnated sand that can be seen in lower altitude eddy bars, which suggests that perhaps flood flow was only large enough to emplace this deposit. The altitude of this deposit requires a discharge in excess of 4.5 million m^3/s to be overtopped. A piece of charcoal contained in the deposit has a radiocarbon age of 14,795±150 ^{14}C yr B.P., which perhaps indicates that this deposit was emplaced relatively early in the flood sequence.

Return to Interstate 84 at Mosier and follow it to Cascade Locks. We first pass through Bingen Gap, a constriction formed by the river's passage through the Bingen anticline. The town of White Salmon is built upon a large pendant bar in the lee of the downstream end of Bingen Gap on the north side of the river. One of the larger bars in the Columbia River Gorge, White Salmon bar (Bretz, 1925) rests on a basalt platform, is about 2 km long, and ascends from 120 m (400 ft) at its apex to almost 240 m (800 ft) at its downstream end.

The Hood River valley was inundated by backwater from the Missoula floods. Newcomb (1969, p. 6) reported "fine-grained lacustrine deposits" as high as altitude 245 m (800 ft), probably slackwater deposits of Missoula floods. The highest ice-rafted er-

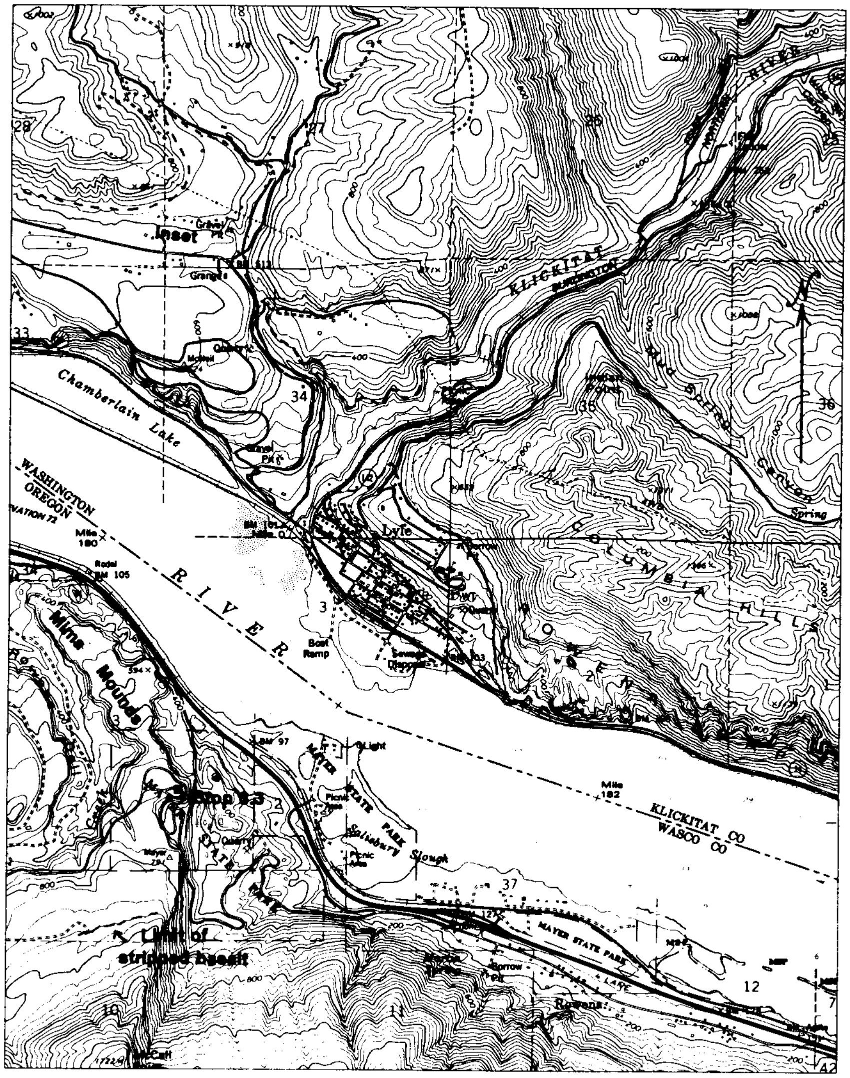


Figure 28. Topographic setting, geomorphic features, and approximate distribution of Missoula flood deposits (outlined by heavy lines) near Lyle. Topographic base from Lyle USGS 7.5′ quadrangle. Land sections (numbered) are 1 mile (1.6 km) across.

ratics in the Hood River valley are between altitudes of 255 and 270 m (840–880 ft). If this was the maximum stage achieved by the largest flood, the water surface dropped substantially through Bingen Gap.

The best examples of polished, fluted, and scoured basalt surfaces known in the Columbia River Gorge are in the gardens of the Columbia River Gorge Hotel, a 1921 structure listed on the National Historic Register.

Between Hood River and the downstream end of the Gorge below Crown Point, we find little conclusive evidence of maximum

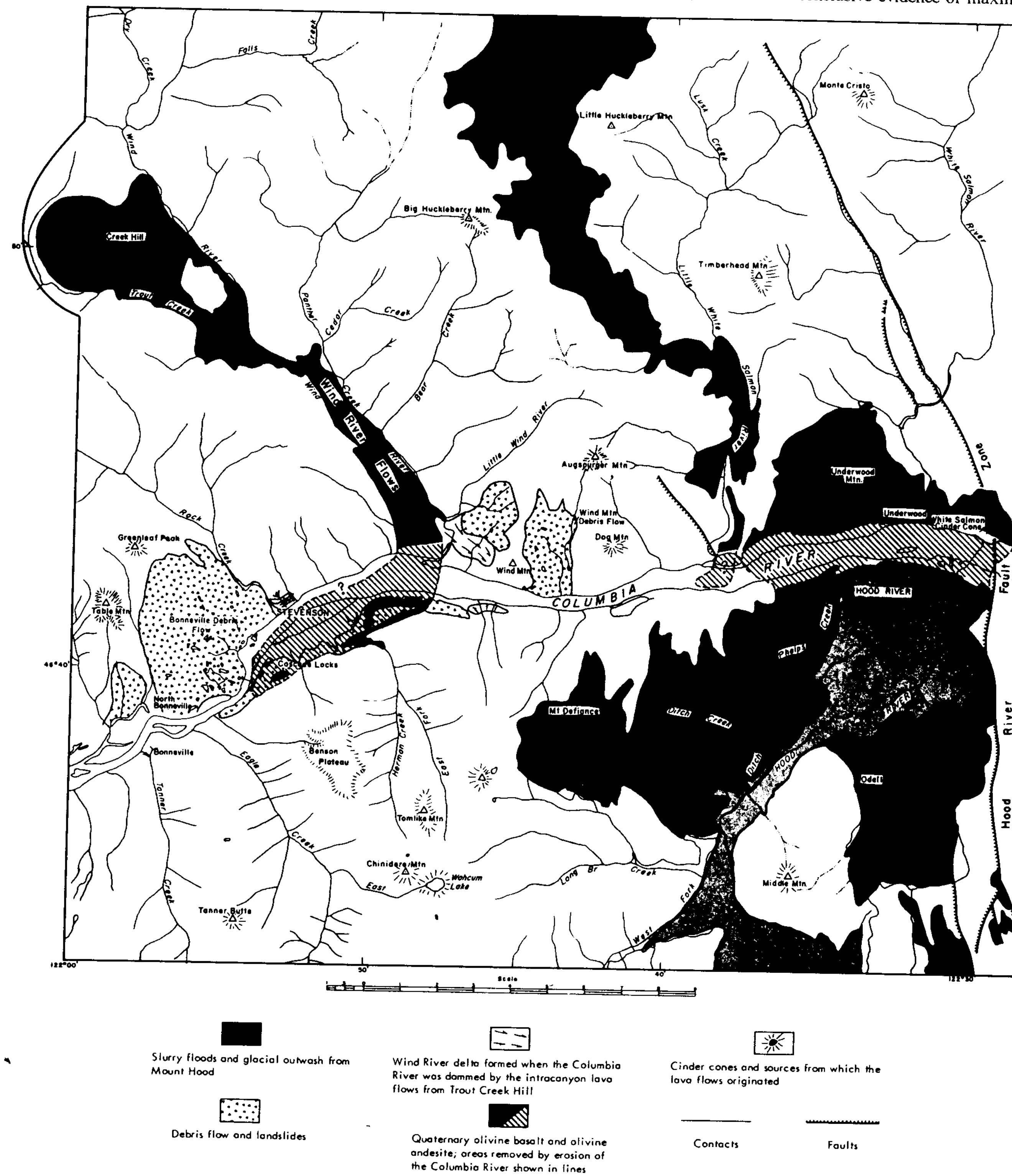


Figure 29. Lava flows and landslides in the Columbia River Gorge, emphasizing flows that may have dammed the Columbia River. From Waters (1973).

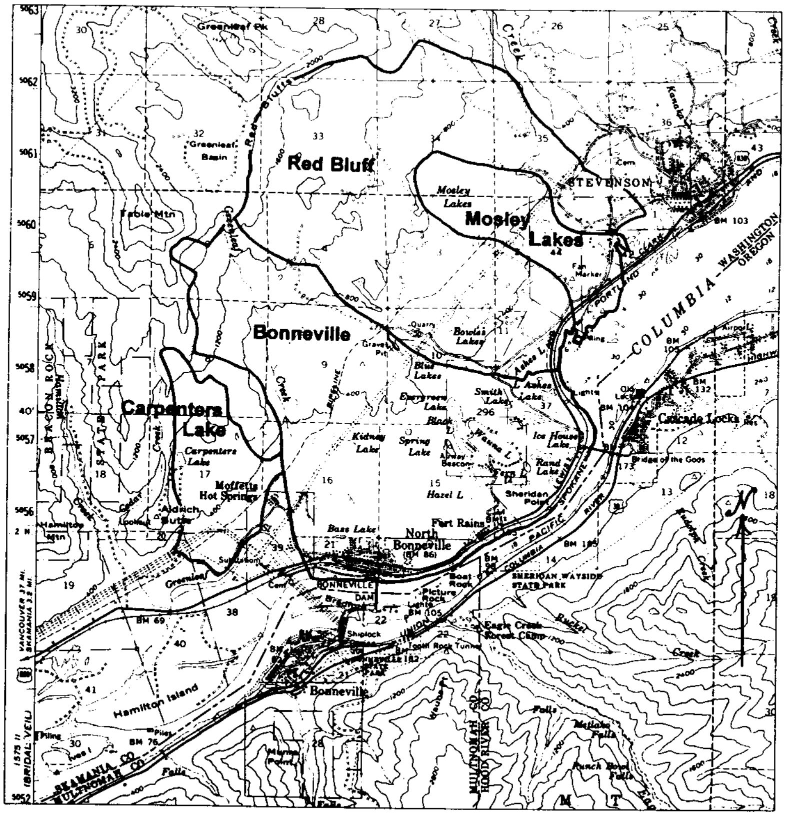


Figure 30. Landslide complex near Cascade Locks. The Bonneville landslide was the most recent one and may have temporarily dammed the Columbia River about 500 years ago. Topographic base is the Bonneville 15′ quadrangle. Land sections (numbered) are 1 mi (1.6 km) across. After Minor, 1984.

flood stage. The combination of dense vegetation and abundant mass wasting hinder the search. It is clear that by Portland, however, the maximum water surface descended to 120 m (400 ft) (Allison, 1935), indicating an average gradient of 0.003. Most of the drop probably occurred near Crown Point, at the downstream end of the Columbia River Gorge.

For several kilometers downstream of Hood River, the valley of the Columbia River is particularly constricted, generally narrower than 2 km. About 5 km downstream of Viento State Park, the Columbia River is encroached upon by the Wind River landslide, one of several recent or presently active landslides in the Columbia River Gorge (Figure 29). The upper part of the Wind River landslide moves as fast as 15 m/yr (Allen, 1984).

Downstream of the Wind River landslide, the Columbia River valley funnels between the twin granodiorite intrusions of Shellrock and Wind Mountains. Shellrock Mountain, with its constant raveling of platy rubble at a repose angle of 42°, was a major obstacle to early road building through the Gorge. On the north side of the river, between Wind Mountain and Wind River, a large pendant bar was deposited in the lee of Wind Mountain as flow expanded out of the constriction. This bar is about 2 km long and 125 m high.

The broad, flat surface west of Wind River and under the town of Carson is underlain by basalt flows: several lava flows that originated from Trout Creek Hill (Figure 29) and moved down the Wind River valley about 340±75 ka (Korosec, 1987), temporarily damming the Columbia River to a depth of at least 45 m (Waters, 1973). The evidence that these basalt flows and related fluvial deposits fill valleys that were entrenched to near-present grades, along with the local presence of pre-flood Columbia River gravel near the present margins of the Gorge, indicate that the Missoula floods did not substantially widen or deepen the Columbia River Gorge. The famous waterfalls of the Columbia River Gorge were probably not formed by the passage of the Missoula floods, though they were probably somewhat enhanced by erosion of talus and other unconsolidated deposits from their bases. The falls exist more likely because of the layered heterogeneities within the south-dipping Columbia River Basalt Group.

Exit Interstate 84 at Cascade Locks and proceed to Cascade Locks Marine Park.

Stop 3.4. Bonneville landslide

Cascade Locks and Canal were completed in 1896, permitting steamboat navigation between the coast and The Dalles. Previously, the Columbia River dropped 10–15 m within about 400 m in a set of rapids called the "Cascades of the Columbia," the namesake of the Cascade Range. The rapids as well as most of the Cascade Locks and Canal were drowned after completion of Bonneville Dam in 1938.

These rapids were the remnants of the toe of the Bonneville (or "Cascade") landslide complex that probably once completely crossed the Columbia River. The landslide complex consists of four separate mass movements (Wise, 1962; Minor, 1984); the largest ones, the Red Bluff and Bonneville landslides, head from the 500-m escarpment that runs southeast at the flanks of Table Mountain and Greenleaf Peak (Figure 30). The total area of landslide debris is about 35 km^2. The Bonneville landslide has most recently affected the Columbia River, pushing it to the south side of the valley and constricting it to a width of less than 400 m.

According to Waters (1973, p. 147), the cause for most of the landslides along the north side of the river in the Gorge is a thick clay saprolite developed on zeolitized rocks of the Ohanapecosh Formation. Rainwater, penetrating the joints of the Columbia River Basalt Group and the sand and gravel of the underlying Eagle Creek Formation, is concentrated at the saprolite layer capping the Ohanapecosh Formation, raising the pore pressure and converting the saprolite to slippery clay. The contact at the top of the Ohanapecosh Formation slopes 2°–10° south toward the Columbia River, acting as a "well-greased skidboard" upon which the Bonneville landslide and others within the Gorge have slid.

The Bonneville landslide gave rise to the Native American legend of the "Bridge of the Gods." Oral histories of the region, summarized by Lawrence and Lawrence (1958, p. 33), indicate that the Native Americans "could cross the river without getting their feet wet" and that "the falls are not ancient, and that their fathers voyaged without obstruction in their canoes as far as The Dalles". The Natives also said "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 these rapids first made their appearance."

Early explorers noted large stands of partially submerged tree stumps between Cascade Rapids and The Dalles. The origin of this "submerged forest" was controversial among explorers, settlers, and geologists (Lawrence and Lawrence, 1958), but eventually it became clear that they resulted from the permanent 10- to 15-m rise in river level after formation and incision of the Bonneville landslide dam. Lawrence and Lawrence (1958), on the basis of radiocarbon ages of 670±300 ^{14}C yr B.P. and 700±200 ^{14}C yr B.P. for two submerged stumps, concluded that the landslide occurred about A.D. 1100.

Since then, there has been additional dating, summarized by Minor (1984), in connection with archaeologic investigations and drilling done during construction of the second Bonneville Dam powerhouse. Five wood samples inferred to be in or below landslide debris near the site of the second powerhouse yielded radiocarbon ages of 5550±90 to 400±70 ^{14}C yr B.P. Radiocarbon dates on 26 samples of material found at five archaeologic sites on landslide debris near Bonneville Dam range from modern to 740±100 ^{14}C yr B.P.

We have converted all of the dates reported by Minor (1984) to calendar years with CALIB 3.0.3, a calibration program distributed by the Quaternary Isotope Laboratory at the University of Washington (Stuiver and Reimer, 1993).

The following assumptions were made in the calibration and interpretation of the results:

1. The stratigraphic context of all the samples was correctly reported, and furthermore (a) there was no contamination of pre-landslide samples with modern or recent carbon, and (b) there was no old carbon in the post-landslide samples. It is, however, possible that old wood was used at archaeological sites.

2. All dates were corrected for ^{13}C activity. Violation of this assumption would not make a significant difference on the wood samples from trees that predated the landslide, but it could make a substantial difference for the material (unknown to us) dated at the archaeologic sites.

3. A lab error multiplier factor of 2, as recommended for nonhigh-precision dates. This yields larger but more realistic calendar-year ranges for the samples.

Results:

1. Considering 1σ uncertainty in calendar-year age for each sample, the ranges of stratigraphically bracketing samples indicate that the landslide postdates A.D. 1409 and predates A.D. 1410.

2. Considering 2σ uncertainty in calendar-year age for each sample, the ranges of stratigraphically bracketing samples indicate that the landslide occurred after A.D. 1300, and before A.D. 1650.

3. Considering 2σ uncertainty in calendar-year age for each sample and the age of a tree growing on the landslide that apparently postdates the landslide (Lawrence and Lawrence, 1958), the landslide occurred between A.D. 1300 and A.D. 1562.

These results place the landslide a few hundred years later than previously thought. This is primarily due to a 400±70 yr B.P. radiocarbon date obtained on wood from Columbia River sediment below the landslide. This date was regarded as anomalously recent in Minor's (1984) report and was not included in that report's age derivation.

It is interesting to speculate about what might have happened when the landslide dam was overtopped. In view of the morphology of the landslide at Cascade Locks, the river may have been dammed to an elevation of 75 m (240 ft), and water may have been impounded as far upstream as Arlington. Breaching may have been catastrophic; the whaleback forms of Bradford, Robins, Hamilton, and Ives Islands, just downstream from the landslide suggest flood-formed features. A flood from the Bonneville landslide is accepted by archeologists studying the lower Columbia valley. For example, Pettygrew (1981, p. 121) inferred that "the flood destroyed many aboriginal settlements; it also may have caused major changes in the topography of river channels and land surfaces. As a consequence, villages may have been reestablished at new sites, in response to shifted salmon migration routes and alterations in the river and slough channels used for transportation." Pettygrew (1981, p. 122) stated that there was only one known site that shows evidence of occupation before and after the flood, and at this site there was a thick layer of "sterile" [artifact-free] silt deposited above strata containing organic material that yielded a radiocarbon date of 850±180 ^{14}C yr B.P.

In the Sandy River drainage 30 km downstream, Tom Pierson and Jim O'Connor (USGS-Vancouver, unpublished data) have found Columbia River sand deposited more than 30 m higher than any historic Columbia River flood stage. These deposits are substantially higher than conceivable stages of snowmelt- or rainfall-runoff floods and may have resulted from breaching of the Bonneville landslide. Samples of charcoal immediately below this sand at Dabney County Park and Oxbow State Park yielded dates of 520±110 and 440±60 ^{14}C yr B.P. The more precise date equates to a 1σ range of A.D. 1405–1635 and a 2σ range of A.D. 1300–1953. If this sand was indeed deposited by a flood from the failed landslide dam, then breaching of this dam was probably closer to 500 years ago rather than the 800–900 years ago generally cited.

DAY 3 ROAD LOG (mileage is approximate)

Miles	
0.0	Deschutes State Park overflow area.
0.2	Turn right (east) onto Oregon 206 (old U.S. 30).
1.6	Junction with Oregon 206 southbound, continue east on U.S. 30.
4.2	Entering Biggs Junction.
4.6	Junction with U.S. 97. Turn left (north).
4.9	Bridge over Columbia River.
7.1	Junction with Washington 14, turn left (west).
7.5	Junction with U.S. 97 (north), continue west on Washington 14.
7.8	Stop sign at junction with U.S. 97. Pull into large gravel area on left (south) side of Washington 14: **Stop 3.1.** Maryhill Bar ***(Private property!)*** When you leave, continue west on Washington 14.
9.9	Maryhill Museum on left.
11.0	Enter Columbia River Gorge National Scenic Area.
11.2	In next 1.4 mi, pass through outcrops of 0.9-Ma basalt from Haystack Butte.
13.0	Flood-transported boulders of basalt from Haystack Butte.
15.0	Celilo Falls overlook, good view of scabland across river.
15.9	Wishram Heights.
17.2	Good view to south of Fairbanks Gap divide crossing.
19.8	View to south of Petersburg divide crossing.
20.7	View of Columbia River following axis of The Dalles syncline.
22.1	Basin-and-butte scabland.
23.6	Turnoff to Horsethief State Park (restrooms available).
25.2	Junction with U.S. 197. Turn left (south).
28.0	Cross Columbia River, note scabland in channel.
28.4	Fishing platforms on right.
28.6	Pass over I-84.
28.9	Stop sign and junction with U.S. 30. Turn left to continue south on U.S. 197.
30.2	Road cut through the Dalles Formation.
30.3	**Stop 3.2.** Pre-late Wisconsin loess and flood(?) stratigraphy. Park on gravel area on right (west) side of road. When you leave, turn around ***(Watch for traffic!)*** and return north on U.S. 197.
31.7	Junction with U.S. 30, bear right.
32.0	Enter I-84 westbound.
34.2	View of trimline about halfway up Sevenmile Hill.
37.7	Enter Rowena Gap, cut through the Columbia Hills anticline.
42.3	Exit I-84 at Rowena (Exit 76).
42.5	Stop sign, turn left.
42.6	Bear left onto frontage road.
42.7	Two right turns to end up heading west on old U.S. 30.
43.4	Bear left toward Rowena Crest.
45.3	Turn left at Rowena Crest overview.
45.5	**Stop 3.3.** Rowena Crest. Park on right. When you leave, continue west on old U.S. 30.
45.6	Left onto old U.S. 30.
47.8	Gravel bar.
51.6	Enter Mosier.
51.8	Cross Mosier Creek.
52.3	Cross I-84 and enter westbound.
56.4	Rest area.
58.2	Hood River.
60.4	Columbia Gorge Hotel on right.
63.6	Mitchell Point.
69.2	Wind River landslide on north side of Columbia River.
69.9	Shellrock Mountain, on south side; Wind Mountain on north side of Columbia River. Both are granodiorite stocks.
77.2	Exit I-84 at Cascade Locks (Exit 44), continue west on U.S. 30.
78.3	Turn right at Marine Park, continue west under the railroad.
78.6	**Stop 3.4.** Bonneville Landslide at Cascade Locks.

End of trip. □