

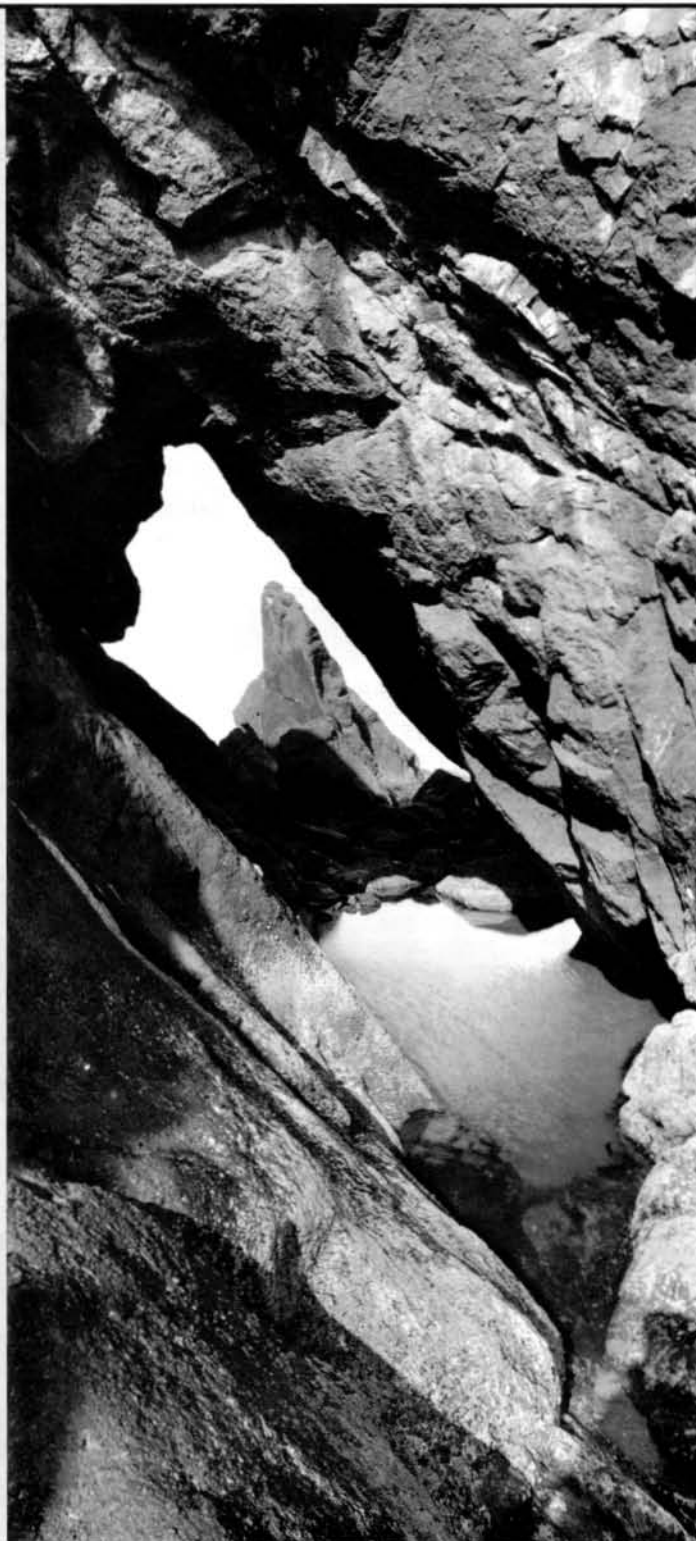
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CHANNELED SCABLAND
FIELD TRIP,
CONCLUSION

and

J.E. ALLEN
ON
EQUILIBRIUM PUNCTUATIONS

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Cover photo

This photograph, entitled "Archway and basalt headland, Lincoln County, taken in 1993," is one of the photos by Terry Toedtemeier to be exhibited in his show "Basalt Exposures" that opens September 24 at Marylhurst College. See related announcement in the right column on this page. Photo courtesy Terry Toedtemeier, copyright 1995.

Governing Board invites participation in the planning for DOGAMI's future

At its July 17, 1995, meeting in Portland, the Governing Board of the Oregon Department of Geology and Mineral Industries (DOGAMI) took its first step in mapping out DOGAMI's mission and goals for the five-year period starting in 1997. The Board announced that it was beginning the planning process, which is expected to take almost a year. Input from the public, other agencies, and industry is invited during that time.

Following its July meeting, the Board met with DOGAMI staff members to review their suggestions for DOGAMI's mission and goals. The next step will be a strategic planning session to be held on Sunday afternoon, September 24, 2:00 p.m. to 6:00 p.m., at the Newport Shilo Inn, 536 SW Elizabeth Street, Conference Room Pacific I, in Newport, OR 97365-5098. Anyone in that area who would like to discuss with the Board DOGAMI's future activities is invited to attend or submit suggestions in writing. The Board will be meeting in other parts of the state during the planning process. The public will be invited to take part in those meetings and to offer suggestions that can be used by the Board.

We in DOGAMI know that our activities affect many aspects of life in Oregon. We hope those of you who have opinions on how we can best serve Oregonians will share their ideas with the Board during this planning process. If you wish to send your written suggestions or ideas, please address them to Angie Karel, Oregon Department of Geology and Mineral Industries, 800 NE Oregon Street #28, Portland, OR 97232-2162. □

Terry Toedtemeier to exhibit basalt photographs at Marylhurst

Terry Toedtemeier, curator of photography at the Portland Art Museum, will exhibit 80 photographs in a show entitled "Basalt Exposures" at Marylhurst College this fall. Toedtemeier, who has a degree in geology, has long been fascinated by the shapes basalt takes in the varied climates of the Pacific Northwest. The black-and-white photographs on display have been taken over the past 15 years as he has toured the area, observing the landforms produced by the erosion-resistant basalt.

According to Toedtemeier, "From the monumental flows of the Columbia Plateau to the Hawaiian-style volcanic rocks of the High Lava and Snake River Plains, this region abounds with a remarkable range of basalt exposures. The photographs reproduced in this show were made in response to the diversity of basalt structures and settings I have found in my travels throughout the region."

The photographs will be on display between noon and 4:00 p.m. on Tuesdays through Saturdays from September 24 through December 9 at the Art Gym on the third floor of the B.P. John Administration Building, Marylhurst College. The college is located 20 minutes south of Portland on Highway 43, just between Lake Oswego and West Linn. The opening reception, which will be held at the Art Gym from 3:00 p.m. to 5:00 p.m. on Sunday, September 24, is also open to the public. □

1995 NWMA convention announced

What is billed as "The western United States' premier international convention and exposition" has been announced by the Northwest Mining Association (NWMA) for December 5 through 8, 1995, in Spokane, Washington, with pre-convention short courses on December 4 and 5. Registration forms and information are available from NWMA, 10 N. Post, Suite 414, Spokane, WA 99201-0772, phone (509) 624-1158, FAX (509) 623-1241. □

Beyond the Channeled Scabland

A field trip to Missoula flood features in the Columbia, Yakima, and Walla Walla valleys of Washington and Oregon—Part 3: Field trip, Days two and three

by James E. O'Connor* and Richard B. Waitt, U.S. Geological Survey, David A. Johnston Cascades Volcano Observatory, 5400 MacArthur Blvd., Vancouver, Washington 98661. With contributions by Gerardo Benito, Centro de Ciencias Medioambientales, Serrano, 115 dpdo, Madrid, Spain 28006; and David Cordero and Scott Burns, Department of Geology, Portland State University, P.O. Box 751, Portland, Oregon 97207

A preliminary version of this field trip guide was prepared for the first annual field conference of the Friends of the Pleistocene, Pacific Northwest Cell, May 13–15, 1994. Parts 1 and 2 of the guide appeared in the May and July 1995 issues of this magazine. This concludes the three-day field trip. References in the text refer to the list of references printed at the end of Part 1 in the May issue, p. 58–60. —ed.

DAY TWO

Day 2 entails driving east 100 mi (160 km) up Columbia River valley into Washington. After passing through Wallula Gap, the trip proceeds into Pasco basin and east up tributary Walla Walla valley, then back west across Pasco basin and up tributary Yakima valley. In these valleys are examined sections of rhythmites deposited by flood waters that backflooded from Pasco basin into these large side valleys. The trip returns to Deschutes State Park via Satus Pass on Highway 97. Much of Day 2 has been described and discussed in Waitt (1980a, 1985b, 1987) and O'Connor and Baker (1992), but new data and arguments will also be had.

Maps: The Dalles, Pendleton, Walla Walla, and Yakima 1°×2° sheets; Hermiston, Pendleton, Walla Walla, Richland, and Toppenish 1:100,000 sheets.

En route to Stop 2.1

Drive the frontage road to Biggs Junction and enter Interstate 84 eastbound. Follow Interstate 84 east, and then Highway 730 to Wallula Junction near the confluence of Walla Walla River with the Columbia. En route we pass through the Umatilla basin, where floodwaters covered a swath as wide as 50 km and an area of about 3,500 km². As discussed in Day 1, between John Day River and just downstream of Wallula Gap, the maximum stage evidence defines a water-surface profile that was nearly flat at an altitude of about 335 m (1,100 ft) for this entire reach of the flood route.

About 43 mi from Biggs Junction, we cross over Willow Creek. In June 1903, a flash flood in a tributary of Willow Creek thundered into the mill town of Heppner, about 50 km upstream, killing 230 people. This has been the most lethal flood ever in the Columbia basin.

Just before crossing the Oregon-Washington border, the basalt cliffs flanking the river become higher as we proceed towards the center of the Horse Heaven Hills anticline. Wallula Gap, a 1,200- to 1,500-m-wide chasm cut through the fold, was a fundamental constriction along the flood route, separating the vast upstream ponded area of the Pasco basin, in earlier times termed "Lake Lewis," from that of the Umatilla basin downstream.

Upon passing through Wallula Gap we enter the vast Pasco basin, where the trunk Columbia River receives three major tributaries: Yakima River from the west and Snake and Walla Walla Rivers from the east. Of these the Snake was one of the major inflow conduits for Missoula flood to Pasco basin, whereas Walla Walla and Yakima were dead ends as flood routes. As immense floodwater hydraulically ponded behind Wallula Gap and Columbia Gorge downriver, it backflooded 240 m (800 ft) deep and more up the Walla Walla and Yakima (Figure 15).

Important to the setting of rhythmic beds upvalley in both Walla Walla and lower Yakima valleys is the fact that a sharp

narrows constricted invading floodwaters. Three specified drive-by views (not actual stops) will point out coarse deposits of floods emerging from these narrows into the broad valley above. The geomorphic setting and features of the Yakima valley narrows is rather more spectacular than those of Walla Walla valley.

Stop 2.1. Narrows of Walla Walla valley

U.S. Highway 12 in lower Walla Walla valley allows a view of the setting of backfloods. Unlike slopes surrounding most of Pasco basin, the narrows of Walla Walla and Yakima valleys are washed clean of regolith. The narrowing, rinsed-off valley sides carved in basalt were the intake for floods that, rising in Pasco basin, backflooded Walla Walla valley. The valley narrows acted as a valve, limiting and regulating the rate at which water could backfill the valley. The nozzlelike geometry also imparted particularly swift currents through the narrows (Figure 15) and just upvalley. The highway avoids the curving course of the canyon, but closer views can be had by the "alternate" return route from Stop 2.3.

Rhythmic flood-slackwater sand-silt beds lying on the floor of the intake to the valley narrows and also immediately downcurrent may seem rather incongruous. The internal stratigraphy of these low-altitude beds is scarcely studied, and so exactly how they correlate to beds at Stops 2.2 and 2.3 is uncertain, but at least part of the answer probably lies in the beds at Stop 2.3.

En route to Stop 2.2

After descending the basalt spur into Walla Walla valley, on the right in the distance along Walla Walla River can be seen a long and tall exposure of rhythmites including coarse gravelly beds. Here the flood currents, after shooting through the valley nozzle, backflooded into the broad valley and dramatically slackened. The eddy and backflood environments were highly important to preserving durable records of floods of all sizes.

Eddy and backflood environment: The main scabland floodways with their great abandoned cataracts, plucked rock basins, and other features are evidence of erosional stream power almost without parallel on Earth. Yet even within these great floodways, currents were somewhat slower in places, allowing coarse debris to accumulate as bouldery bars. These features may be spectacular evidence of huge discharges, but exceedingly high-energy reaches are poor places to expect a continuous sequence of events, for one colossal flood tends to erase evidence of previous ones.

The sediment-charged floodwaters also circulated into hundreds of topographic dead-end tributary valleys like Walla Walla (Figure 15), water driven into the valleys by the deep torrent along the main channel. In each of these dead-end areas, currents in the transitory hydraulic pond had generally far less velocity than the main-channel torrents. Here a waxing and waning sediment-charged flood could deposit almost continuously—and with far less erosion than the high-energy sites in adjacent main channels. A few valleys like the Walla Walla are further influenced by a

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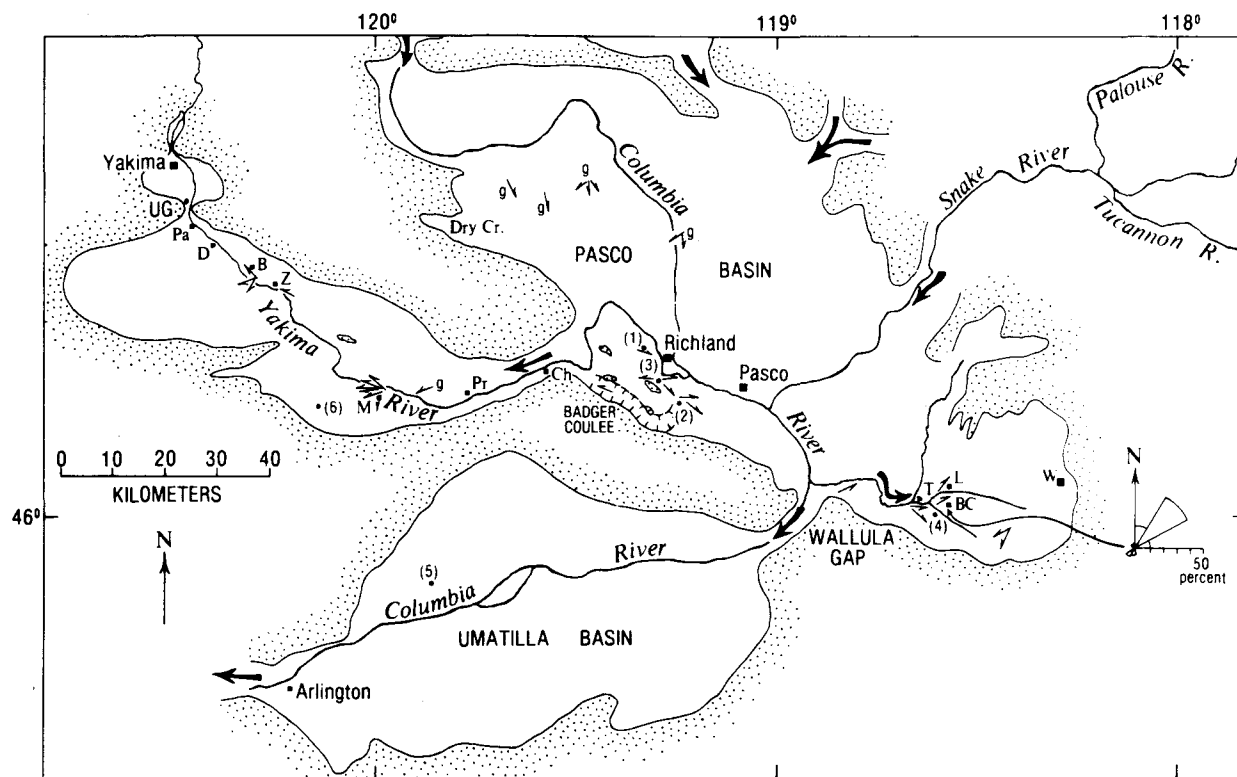


Figure 15. Map of Pasco basin and vicinity, showing area inundated by lake hydraulically ponded to altitude 350 m (1,150 ft). Largest hydraulic lake surface was about at altitude 366 m. Heavy arrows indicate main inflow conduits for Missoula floodwater, the outflow through Wallula Gap, and narrows of large backflooded tributary valleys. Rose diagram (90 measurements at Burlingame canyon) and lighter arrows depict paleocurrent indicators from slackwater sand and silt, or in foreset tractive gravel (g). (1) through (6) are localities of vertebrates within Missoula-flood slackwater facies. B=Buena, BC=Burlingame canyon, Ch=Chandler, D=Donald, L=Lowden, M=Mabton, Pa=Parker, Pr=Prosser, T=Touchet, UG=Union Gap, W=Walla Walla, Z=Zillah. From Waitt, 1980a, Figure 2.

bottleneck above which the valley broadens out five- to twenty-fold. Invading such a valley through the narrows, currents may be swift, but above the nozzle the sediment of a flood can accumulate with little or no disturbance by that flood—or for that matter by later floods of like or larger magnitude.

Bedded sand and silt characterize every backflooded dead-end valley of the flooded system. In Walla Walla valley between Touchet and the city of Walla Walla, several outlier mounds can be seen, some sectioned by road cuts or by Walla Walla River. The thickest, coarsest, most distinctly bedded, and generally best exposed tend to lie in downvalley reaches and at low altitudes. But in every valley studied, including the Walla Walla, they also lap up onto valley sides and gain altitude upvalley along the floor, mantling preflood deposits and topography.

Stop 2.2. Burlingame "canyon"

(Please see Waitt, 1980a, 1985b)

Burlingame "canyon" (informal name) is off South Lowden Road, 200 yards south of an irrigation ditch.

Canyon has steep, unprotected, collapsible walls: Heads up!!

This is private property of the Gardena Irrigation District. Please do not enter without obtaining permission and before signing a written, notarized "hold harmless" agreement. (Please see Ditchmaster at house near irrigation ditch).

Rhythmically bedded deposits in southern Washington have been variously attributed to (1) fluctuations within ordinary lacustrine and fluvial environments (Flint, 1938; Luper, 1944); (2) fluctuating currents within a transient lake during only one or a

few great floods (Bretz and others, 1956; Baker, 1973; Mullineaux and others, 1978; Bjornstad, 1980); and (3) several dozen floods, each of which deposited one graded bed (Waitt, 1980a, 1984, 1985b). By the last hypothesis, floodwater backed up dead-end valleys off the main scabland floodways to form transient ponds in which suspended load settled. Because the side valleys were protected from violent currents, flood-laid strata were not eroded by later floods but became buried and preserved.

Burlingame "canyon," 30 m deep and 500 m long, was mostly cut in 6 days in March 1926, when the 2.3-m³/s flow of the nearby irrigation ditch was crowded by severe wind into a diversion ditch. The canyon exposes one of southern Washington's most complete and accessible stratigraphic sections of slackwater deposits of the late Wisconsin floods from glacial Lake Missoula, the keystone exposure from which the one-graded-bed-per-flood hypothesis emerged (Waitt, 1979, 1980a,b). Yet soon after, these same beds were used to advocate that rhythmic deposits in southern Washington are of but one or a few fantastically pulsating floods (Bjornstad, 1980). The canyon exposes a stratigraphic section of 39 superposed, normally graded beds. Most beds grade upward from sand to silt, concomitant with an upward sequence of sedimentary structures—conspicuous plane laminae to ripple-drift laminae to drapes to obscure plane laminae or massive—crudely comparable to that of distal turbidites (Figure 16; Figure 17, A,B,C). Sparse crystalline, quartzite, and metasedimentary-rock erratics show that the depositing water invaded from the Columbia valley, for Walla Walla valley lies entirely within the Columbia River Basalt Group. Ripple-drift laminae in

the rhythmites climb and dip east-northeast, indicating paleocurrents that flowed generally upvalley.

If the rhythmicity at Burlingame canyon is obvious, the cause is less apparent. The visitor may debate whether many successive

beds were deposited by fluctuating currents during one or two floods (Bjornstad's [1980] view) or whether instead each bed represents a separate flood followed by decades of subaerial exposure (Waitt's view). If the many rhythmites accumulated during one

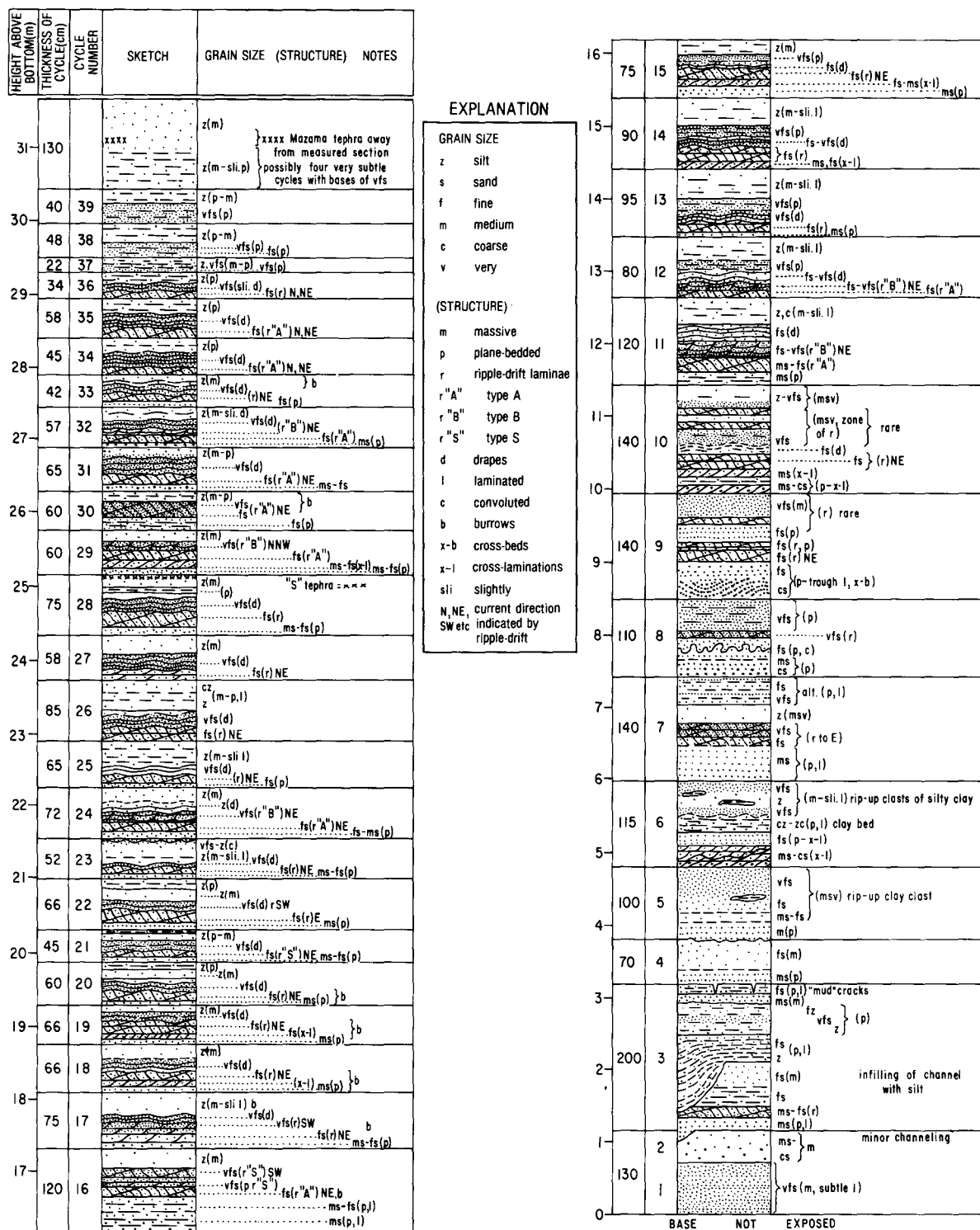


Figure 16. Measured section of 39 rhythmites at northwest end of Burlingame canyon, Walla Walla valley. From Waitt (1980a, Figure 5).

flood, certain conditions would have controlled sedimentation and the character of the deposits: the water would have remained ponded as much as 185 m (600 ft) deep above the top of the exposure, and the accumulating sediment would have had to remain loose and saturated. If on the other hand terrestrial environments intervened for decades between successive floods, other dominating conditions would have influenced the character of deposits: the sediment would become dewatered, eolian processes would be possible, and animals could repopulate the area. Much of the diagnostic evidence, summarized in the next few paragraphs, lies at the contacts between graded beds:

Loess between any two beds indicates that a terrestrial, eolian environment intervened between the floods that deposited the two beds. But the occurrence of loess has been debated, for the water-laid tops of most graded beds are texturally nearly identical to loess, from which the flood-laid sediment was indeed derived.

Channels between rhythmites indicate that erosion interrupted the accumulation of flood sediment. One conspicuous channel exposed near the canyon bottom (beyond allowed limits of this trip) has near-vertical sides: is this likely if the sediment had remained continuously saturated during rapid accumulation?

Slopewash (inferred) partly infills some of the channels. This material is finer and darker (organic coloring?) than is the flood-laid sediment.

Volcanic ash lies within inferred loess atop the 12th rhythmite below the top of section (Figure 16). This characteristic tephra couplet is identified as "set S" from Mount St. Helens, dated at about 13,000 ¹⁴C yr B.P. (Mullineaux and others, 1978; Waitt, 1980a). Both tephra layers are structureless and nearly pure, but the upper part of the thicker ash member is locally contaminated (post-emplacement rainwash and eolian reworking?). Would the very existence or the nearly pure state of the ash be possible had the ash settled through deep, turbid water during a flood episode? Or must the ash instead have settled onto a dry interflood environment—as did the May 18, 1980, Mount St. Helens ash fall across eastern Washington?

Rip-up clasts of the fine material that forms or overlies rhythmite tops may be found low in the section. Rip-up clasts imply that the sediment had dewatered and become coherent before it was reworked by a subsequent current into a new bed.

Rodent burrows filled with reworked flood-laid sediment may be found throughout the entire 30 m of section. Because rodent burrow less than 2 m below the ground surface, the filled burrows imply that rodents repopulated the surface numerous times during the accumulation of this 30 m of sediment.

The striking similarity of graded beds to each other suggests a common origin, not a mixture of two or more different origins.

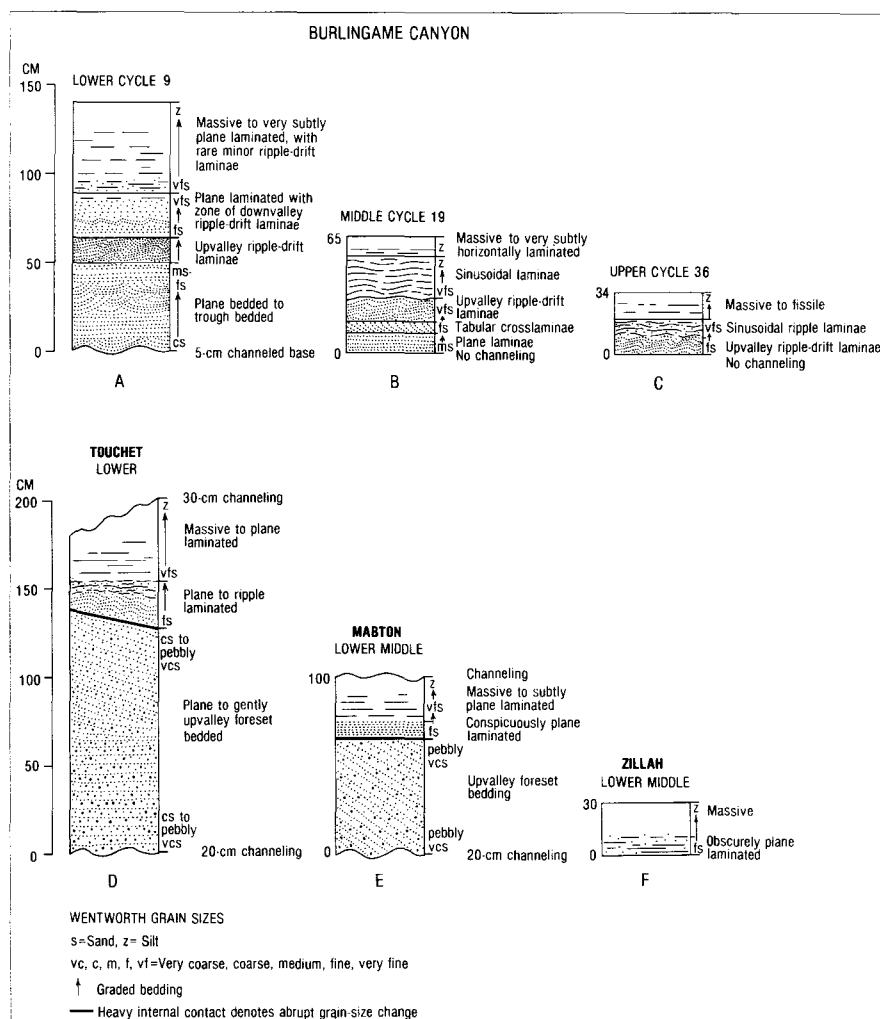


Figure 17. Sketches of typical Missoula-flood rhythmites in southern Washington. A, Burlingame canyon, downsection; B, Burlingame canyon, midsection; C, Burlingame canyon, upsection; D, low in Walla Walla River bluffs southwest of Touchet (stratigraphically ≈ A); E, Mabton, lower midsection (stratigraphically ≈ B); F, Zillah, midsection (stratigraphically ≈ E). From Waitt (1980a, Figure 3).

Thus if several horizons—like that containing the ash couplet—demand a terrestrial environment, then all other nearly identical horizons in this strikingly rhythmic sequence probably also demand a similar origin. But it is difficult to prove a terrestrial episode at the top of each and every rhythmite, especially the thinner and finer ones near the top of section.

An overall pattern is apparent here as in other sections: a **general upsection thinning and fining** of rhythmites, especially in the upper part of the section (Figure 16; Figure 17, A,B,C). This regional characteristic is attributed to the ice dam becoming thinner and therefore glacial Lake Missoula and floods becoming smaller during deglaciation. The bases of the upper 10 or so beds are relatively fine, like those at Zillah (Yakima valley), used as examples of "distal" flood beds in Figure 17 (C and F).

The 30-m section of rhythmic graded beds is capped by about 1 m of loess. The loess is of Holocene age, as can be seen near the southwest end of the canyon where the loess encloses Mazama (Crater Lake) ash whose radiocarbon age is about 6,850 ¹⁴C yr B.P. (Bacon, 1983).

Some have argued even in recent years, albeit without offering new evidence, that multiple major graded-bed rhythmites can be produced during a single flood and that far fewer than 40 separate floods are represented by Burlingame canyon (e.g., Baker and Bunker, 1985, p. 24; Kiver and others, 1991, p. 243). But until these assertions are provided a basis in actual evidence, they are but unsubstantiated speculation. On the other side of the argument, much field evidence has been supplied repeatedly to support the hypothesis that every major, easily countable graded bed here is the deposit of a separate flood.

Waitt (1980a, 1985b) inferred that the rhytmite sections at Burlingame, Touchet, and elsewhere in Walla Walla valley record the very largest scabland-sweeping floods and that the pattern of upsection thinning and fining of rhytmite records that these floods became generally smaller with time. Since about 1985 a competing interpretation has been that the Burlingame and other rhytmite sections represent only a series of late small floods supposedly confined to the Columbia valley and Grand Coulee but not affecting the channeled scablands generally, which were supposedly swept earlier by one great flood (Baker and Bunker, 1985, Baker, 1989a, p. 27; 1989b, p. 54). And yet if these beds do not represent the largest floods, then what does? Walla Walla River is graded to Columbia River now as during the late Wisconsin episode of Missoula flooding. It is geometrically difficult or impossible that there could be much else below the base of this section. Indeed at higher altitude, where the rhytmite lapped up on the valley sides and toward the valley head, rhytmite similar to these directly overlie weathered fan gravel. If the largest Missoula floods are not represented by these rhytmite, then the largest flood(s) of all passed without a trace.

Some recent workers (Busacca and others, 1989, p. 62; Kiver and others, 1991, p. 243) suggest that Burlingame canyon represents only a series of small, late floods that do not correlate with rhytmite in settings such as Snake valley and its tributaries like the Tucannon that clearly were backflooded from floodwater channeled by the Cheney-Palouse tract, though Waitt (1983a,b, 1985a, 1985b) re-

gionally united them. These workers suggest that truly cataclysmic flood(s) represented by the Tucannon rhytmite are middle Wisconsin in age and vastly predate rhytmite in the Walla Walla and Yakima valleys. Yet the Mount St. Helens "set-S" tephra is intercalated within several separate rhytmite sections in Tucannon valley and apparently in Snake valley at Lewiston (Smith, 1993; Waitt, unpublished data), which shows unarguably that most or all rhytmite in Snake valley and its tributaries are contemporaneous with those at Burlingame canyon. In other words, the floods represented by the deposits at Burlingame canyon and those that poured down the Cheney-Palouse tract and the rest of the channeled scabland are identical.

En route to Stop 2.3

Near mile 130 along both sides of road can be seen occasional crystalline erratic cobbles and small boulders culled from the adjacent irrigation ditch during its construction and repair.

At mile 130.7, road south: The sharp-eyed may glimpse the top of a granite ice-rafted erratic in a wheat field east of the road 0.5 mi to the south measuring $2.2 \times 2.3 \times 3.2$ m and weighing some 32 tons. To float this block, a sphere of ice would have to be at least 6.2 m in diameter. The presence of this block near the top of this silt-covered surface suggests that very large ice blocks were carried into Walla Walla valley even during the later several floods represented by the upsection thinner rhytmite.

Rhytmite near Touchet (again). Traction bed-load deposit of beds in the lower midsection is much thicker and coarser (and contains outsized boulders) than in the probably contemporaneous rhytmite at Burlingame canyon (Figure 17, D).

Stop 2.3. Wallula Junction railroad cut

1. Rhythmic deposits: In Columbia valley at the mouth of Walla Walla valley is a coarse flood bar bearing bed-load boulders as large as 1.5 m. Banked against its west side is a deposit of fine sand to silt, and a long railroad cut in it exposes at least 14 couplet beds of fine sand grading up to very fine sand (Figure 18). Con-



Figure 18. Topographic setting of Wallula Gap. To the west of Wallula Gap, outlined area delineates extent of Missoula flood deposits (dashed where approximate). Arrows indicate high-level flood flow. Topographic base from Wallula USGS 7.5' quadrangle.

tacts between beds are notably wavy, partly from depositional relief, partly from erosion by the next overlying bed. Contacts between the fine top of a couplet and the coarser base of the overlying bed are very sharp, whereas the contact between the coarser main bed and the finer top are gradational over as much as a few centimeters. About 14 such couplet beds are easily countable in the tallest parts of the exposures; as many as 21 to 25 have been counted by piecing sections together and by trenching. These beds are texturally identical to fine rhythmic beds near the tops of rhythmite sections or far upvalley. They probably represent as many separate floods.

These beds are generally finer, thinner, and far more lenticular than are rhythmites 2–50 km up the Walla Walla valley in which can be found the Mount St. Helens “set-S” tephra. Nor has the tephra been found here despite almost continuous long exposure. These low-level rhythmites seem to be of floods that left some of the thin and fine rhythmites above the ash at Burlingame canyon; they almost surely include floods that were much smaller and later and not represented at Burlingame and Mabton but coeval with flood beds at the top of Manila Creek section in Sanpoil valley (Atwater, 1986) and the floor of upper Grand Coulee (Atwater, 1987; Waitt and Atwater, 1989).

Ripple-drift laminae dip northeast, indicating northeast paleocurrents away from nearby Wallula Gap. These are evidence of a counterclockwise eddy alongside the main flow that was racing out through Wallula Gap. Because of the slower currents of the eddy, sediment accumulated; whereas in the faster main current just westward the sediment was swept along downvalley with the water.

Opinion about the exposure at the Wallula railroad cut and nearby beds has been repeatedly billed as damaging to the scores-of-cataclysms hypothesis, thus:

“Particularly damaging to the hypothesis that the rhythmites represent ‘periodic, colossal jökulhlaups’ (Waitt, 1985) is the fact that these low-energy deposits commonly occur at sites that would have experienced high velocities and stream power during a cataclysmic flood. A sequence of two dozen or more rhythmites, deposited under low-energy conditions, is preserved at the mouth of Wallula Gap, an environment that would have been subject to phenomenal flow-velocity conditions at the onset of any cataclysmic flood (Bjornstad, 1980).” (Bjornstad and others, 1991, p. 237–238).

Waitt feels that this reiterated claim (e.g., Bjornstad, 1980, p. 75; Baker, 1989c, p. 63–64; Baker and others, 1991, p. 250) is but deductive speculation whose premises fail to include elemental field relations. First, the northeast dip and climb of ripple-drift laminae show that here is the site of an eddy off the main floodway—an eddy that spun counterclockwise along the left side of the main current. While generally water velocities “should” increase as flow approaches and enters the throat of a sharp constriction like Wallula Gap, exceptions are many. Every sharp channel irregularity along every river causes flow separation (eddies); one here in this sharp valley reentrant during great flood is hardly unexpected. Second, the rhythmites at Wallula seem not to contain the “set-S” tephra and probably are the record only of floods late in the sequence, floods perhaps as much as an order of magnitude or more smaller than earlier maximal ones represented by the coarse bar against which the fine rhythmites are banked. The beds at Wallula do not at all “damage” the scores-of-cataclysms hypothesis: they are compatible and support it.

2. Hydrology at Wallula Gap: The evidence of maximum stages and hydrologic studies near Wallula Gap have been described in O’Connor and Baker (1992), of which some aspects will be summarized here. At the entrance to the constriction, cols of divide crossings and a small boulder bar indicate that the maximum flood stage was at least 350 m (1,150 ft) (Figure 18). Loess scarps on both sides of the entrance to the constriction indicate that flow may have been as high as 365–370 m (1,200–1,220 ft).

These values are consistent with the 370–380-m (1,220–1,250-ft) maximum altitude of ice-rafted erratics found in the Pasco basin (Bjornstad and others, 1991). At the downstream end of the constriction, the maximum flood stage was close to 335 m (1,100 ft).

From this evidence it seems that there was very little descent of maximum flood stage through the constriction, at the most only about 30–50 m. This difference was undetectable for Allison (1933), which led him to argue that the ponding in the Pasco basin was not related to hydraulic damming at Wallula Gap but due instead to ponding behind a great ice jam in the Columbia River Gorge. While Allison postulated physical damming by ice jams, hydraulic ponding not only would have had about the same effect but would also allow the assumption of a 30–50-m water-surface drop through Wallula Gap.

That the largest Missoula floods at maximum stage were hydraulically impeded by constrictions downvalley complicates the hydraulic analysis here. The simplest hydraulic situation to evaluate would be if Wallula Gap acted as a free constriction, and discharge from Pasco basin depended solely on the water level in Pasco basin and the geometry of the Wallula Gap constriction—similar to reservoir/weir arrangements that are commonly used to measure discharge. In hydraulic terms, flow would pass through critical depth in the constriction as it funneled out of the Pasco basin, similar to flow conditions in the Columbia River Gorge. This has been the premise for most of the discharge calculations at Wallula Gap. If one assumes critical flow through the constriction and a maximum ponding altitude of 370–385 m (1,220–1,260 ft) in the Pasco basin, the resulting discharge calculates to 13.5–15 million m³/s (Figure 19). Because critical flow through the constriction is the maximum possible flow, this value is the maximum possible discharge through Wallula Gap, given our present knowledge of maximum flood stages in the Pasco basin.

The high-water evidence, however, indicates that at maximum flood stage the constriction at Wallula Gap was partially drowned by backwater effects from constrictions downstream in the Columbia River Gorge; consequently, Wallula Gap did not act as an entirely free constriction. This type of hydraulic situation is more difficult to analyze, because choices of energy-loss coeffi-

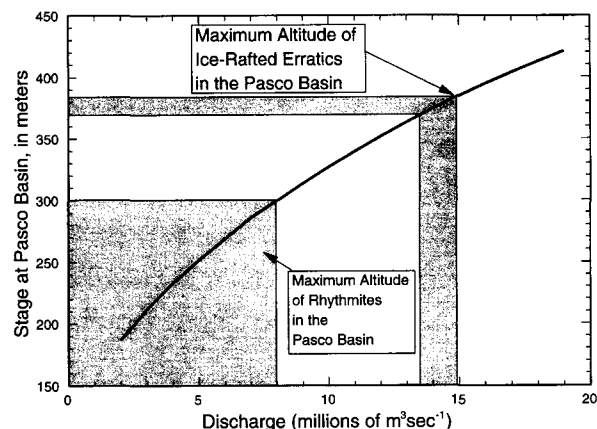


Figure 19. Stage-rating curve for Pasco basin calculated on the basis of assuming critical flow through Wallula Gap. Because critical flow is the maximum possible discharge for a given stage, this curve defines the maximum flow possible for a given ponding level in Pasco basin. Because flow may have been impeded by ponding behind downstream constrictions, the actual discharge associated with a given stage in Pasco basin was probably somewhat less. The maximum altitude of rhythmites is from a 300-m (980-ft) altitude exposure of a deposit at Union Gap that has been described by Allison (1935) (not seen by us) and appears to be composed of several cycles of fining-up deposits.

cients and possible flow unsteadiness introduce much larger uncertainties to the results. Nonetheless, for Wallula Gap we have attempted to calculate a discharge for the profile defined by the highest flood evidence. For these conditions, a discharge of 10 ± 2 million m^3/s is calculated (Figures 20 and 21). The uncertainty values reflect uncertainties introduced by imprecise knowledge of the maximum ponding level in Pasco basin and reasonable ranges of Mannings n values. Because flow was undoubtedly not steady and peak discharge at Wallula Gap was reached probably before maximum stages were achieved downstream, the actual maximum discharge was probably somewhere between the values determined for the critical flow and fully impeded cases. It is also likely that the maximum discharge through Wallula Gap occurred before water levels reached maximum altitudes in Pasco basin.

If one considers that 10 million m^3/s was about the peak discharge at Wallula Gap, a simple hydrograph can be calculated for

the largest flood by assuming a triangular hydrograph and accounting for the $2,184\text{-km}^3$ volume of glacial Lake Missoula at its maximum level. For a peak discharge of 10 million m^3/s , flow duration would have been about 120 hours (five days). Because Pasco basin contained some $1,210\text{ km}^3$ of water at peak stage, the hydrograph must have been somewhat asymmetrical, the waxing phase being <54 hours, the waning period >67 hours (Figure 22). For Wallula Gap and Pasco basin, this would translate into a minimum average rate of water-level rise of about 0.1 m/min . Because the geomorphic evidence downstream indicates a much greater rate of rise (1 m/min), the actual time of the waxing hydrograph was probably much shorter, perhaps just a few hours.

These discharge values relate to the highest evidence of flood features adjacent to Wallula Gap and in Pasco basin. What are the possible discharges associated with evidence of multiple floods? In Pasco basin, the highest described rhythmite sections that clearly represent numerous floods are at about $255\text{--}260\text{ m}$ ($840\text{--}850\text{ ft}$) altitude (Waitt, 1980a, p. 672; 1985b, p. 1285; Bunker, 1980, p. 60). A section at an altitude of 300 m (980 ft) at Union Gap, photographed and briefly described by Allison (1933, p. 682–683) has 15 or more “regularly alternating beds of sand and silt,” perhaps the record of as many floods. If critical (maximum) flow is assumed through Wallula Gap, deposits at 260 m (850 ft) require a discharge of at least 5.5 million m^3/s . A stage of 300 m (980 ft) requires about 8 million m^3/s (Figure 19).

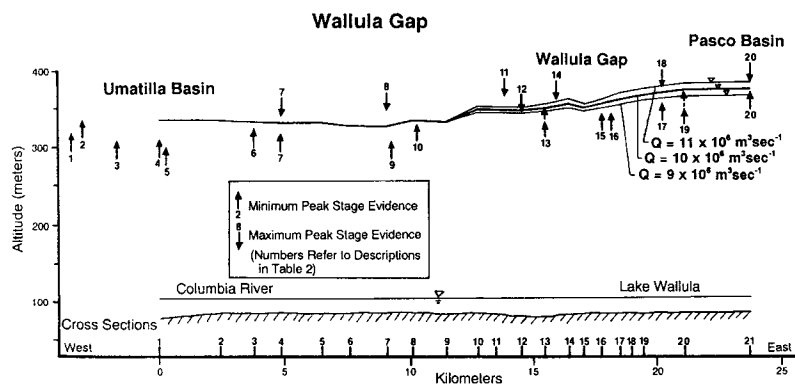


Figure 20. Step-backwater calculated water-surface profiles through Wallula Gap. A 10 million m^3/s discharge results in a calculated profile that matches most of the high-water evidence along the reach and results in a ponding level in Pasco basin consistent with altitudes of the highest ice-rafted erratics. From O'Connor and Baker (1992).

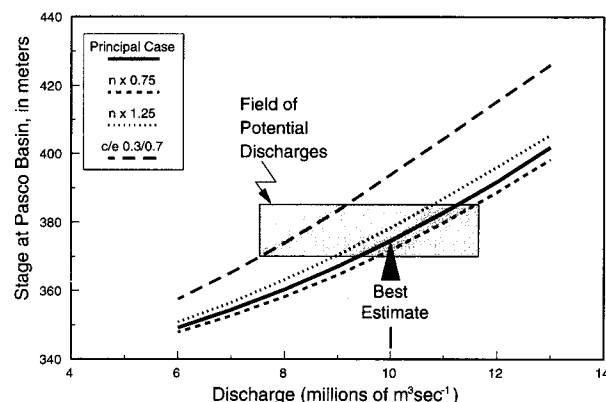


Figure 21. Rating curves for calculated stages in the Pasco basin for different values of energy-loss coefficients and for a ponding level of 335 m in the Umatilla basin. The effects of varying Manning roughness coefficients are minimal. The principal case was calculated with contraction and expansion energy-loss coefficients of 0.0 and 0.5 . Using larger coefficients reduces the discharge required to achieve a 375 m stage in the Pasco basin to about 8 million m^3/s . Considering the high-water evidence identified in this study and the uncertainty of maximum Pasco basin stages and reasonable ranges of the energy-loss coefficients, the maximum Missoula flood discharge through Wallula Gap was between 7.5 and 12 million m^3/s . From O'Connor and Baker, 1992.

En route to Stop 2.4

During each of numerous large floods, Missoula floodwater poured into Pasco basin through several conduits that had diverged from each other at several key divide spillovers in the channeled scabland complex. The three main inflow conduits (north to south) are Columbia River, Esquatzel coulee, and Snake valley (Figure 23). Where currents diverged and slackened, several inconspicuous broad mounds of gravel—flood bars—were deposited (Figure 23) (Bretz, 1928, p. 678–681). Across wide tracts of the Pasco basin the Pleistocene flood deposits are buried (and smaller scale landforms obscured) by late Pleistocene and Holocene (including recent) eolian dune sand $1\text{--}15\text{ m}$ thick.

At the Snake River crossing: Much of Missoula floodwater that descended the Cheney-Palouse scabland tract overflowed from the scablands into the Snake valley $60\text{--}90\text{ km}$ upriver and reentered the Columbia valley here.

Near and east of junction of U.S. 395: Inflow from Esquatzel coulee, which disgorged floodwater collected mostly from the Cheney-Palouse tract via Washtucna coulee but also divergent strands from Quincy basin.

Between the railroad yards west of U.S. Highway 395 and the Columbia River crossing at Richland: Interstate 182 crosses southern part of gravel bar covering 40 km^2 and as much as 45 m above adjacent swales (Figure 23) (Bretz, 1928).

After crossing Columbia and Yakima Rivers, the highway gradually climbs to a line of northwest-trending quaquaversal (doubly plunging) en echelon anticlines that define the regional Olympic-Wallowa Lineament (OWL), probably a dextral shear. On approach to Goose Gap, Badger Mountain is left, Candy Mountain right.

On long, descending road grade: Ridge ahead is Horse Heaven Hills anticline (actually an anticlinorium). Fault scarp along base trends northwest, parallel to OWL. Also on this trend to the northwest is a minor anticline topographically expressed as a line of low hills.

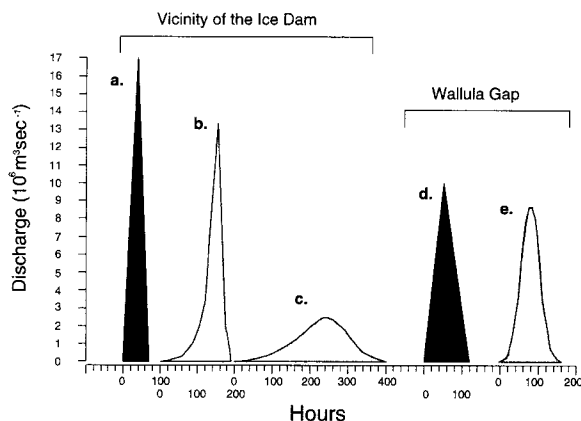


Figure 22. Postulated hydrographs for the largest Missoula flood(s) (assuming complete emptying of Glacial Lake Missoula from its maximum level). All of the hydrographs represent the same total volume ($2,184 \text{ km}^3$). Graphs *a* and *d* are those postulated by O'Connor and Baker (1992) on the basis of maximum discharges near the outlet and at Wallula Gap. Graphs *b* and *c* are those proposed by Clarke and others (1984) as resulting from a jökulhlaup release. Graph *b* represents the extreme case of no "tailwater ponding" (flow impeded by downstream ponding in the Spokane valley) and immediate conveyance of all of the lake water to the breakout location. Case *c* is the more realistic situation of downstream hydraulic conditions affecting the rate of release as well as the delayed response at the breakout point because of the complex lake geometry. Case *e* is the hydrograph proposed for Wallula Gap by Craig (1987).

Stop 2.4. View of Chandler narrows

Bretz (1930, 1969), inferring violent backflooding of lower Yakima valley, focused on spectacular scabland and bars in a valley bottleneck near Chandler, scarcely mentioning the extensive backflood deposits upvalley. Spectacularly rhythmically graded backflood deposits in the lower Yakima valley near Mabton were among the first detailed evidence for scores of separate great Missoula floods (Waitt, 1979; 1980a,b; 1985b). Yet because the top of the Mabton section lies at altitude 215 m (710 ft), some 150 m below the maximum flood level (365 m [1,200 ft]) in Pasco basin at Wallula Gap, some critics have imagined these beds to represent only late, small floods confined to valley floors.

Water rising in Pasco basin by hydraulic ponding streamed into Yakima valley through a structurally determined constriction 6 km long and only 4 km wide (at 305 m [1,000 ft] altitude) at Chandler (Figure 24), where the flood channel is a trench 70 m deep. A cross-valley anticlinal crest is eroded into spectacular scabland ("the badlands") with sharp local relief as much as 60 m extending as high as 135 m above the channel floor, minor scabland extending 65 m higher (Bretz, 1930, p. 413–419; 1969).

At Prosser, 17 km upvalley from Chandler, the valley is 8 km wide, and at Mabton 34 km above Chandler the valley has widened to 24 km—a six-fold increase in width and enormous increase in cross-sectional area (below flood level) between Chandler and Mabton (Figure 25). Scabland and huge boulders along the constriction at Chandler and the absence of any slackwater deposits, show that backfloods here were vigorously erosional. Floodwater sweeping the opposite bedrock upland 60–170 m above Yakima River here deposited "delta bars" into sharp north-south (current-transverse) tributary valleys, filling the east sides of valleys like Snipes Creek 8 km west of here (Figure 24) (Bretz, 1930). At the widening mouth at Prosser, eroded material was also dumped on the valley floor as coarse rubble many meters

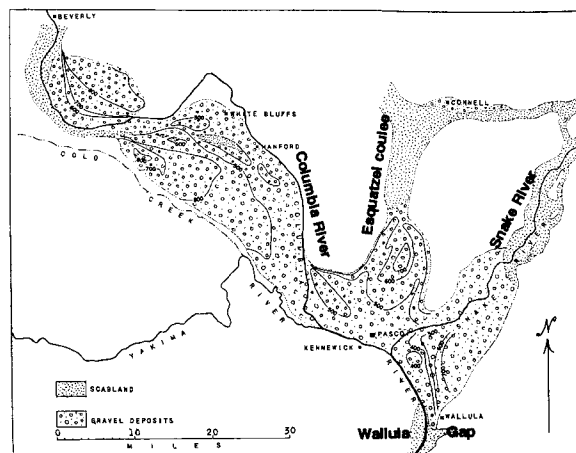


Figure 23. Sketch map of Pasco basin depicting major gravel bars and associated topography (contours on gravel deposits generalized). Route of Day 2 skirts south edge of large pendant bar northwest of Pasco. Note great mound of gravel where floodwater emerged into basin from Esquatzel coulee. Most of inflow from Cheney Palouse was via Snake valley and Esquatzel coulee. From Bretz (1928, Figure 11).

thick, including angular basalt boulders as large as 1 m.

At a distance of 10 km west-northwest upvalley of Prosser, the deposits fine to cobble-pebble gravel deposited in tall foreset beds dipping 25° – 35° upvalley. And 8 km farther upvalley at Mabton the deposit becomes conspicuously rhythmic, and the tractive bases have fined to basaltic fine gravel and coarse sand but with isolated outsized angular basalt clasts as large as 25 cm (Figure 17, E). By 30 km still farther upvalley at Zillah (65 km upvalley from Chandler), the coarse, basaltic tractive bases have dropped out, and arkosic fine sand composes the rhythmic bases (Figure 17, F). This is a contemporaneous facies tract (Waitt, 1980a, p. 660–661) in which thickness and grain size of tractive load systematically decrease upvalley from the Chandler narrows—from boulder gravel to pebble gravel to coarse sand to fine sand. This pattern reflects the enormous increase in cross-sectional area and a consequent order-of-magnitude decrease in current velocity that any one colossal flood expanding into such a broadening valley experienced.

En route to Stop 2.5

At the railroad underpass at Prosser please note coarse, poorly sorted Missoula-flood debris carrying angular basalt boulders as large as 1 m. Largest boulder is on right just past railroad. This material illustrates the coarseness of the transported clasts as floodwater expanded out of the Chandler narrows. These coarse deposits are not overlain by fine slackwater deposits, which apparently could not accumulate here because the currents were far too swift.

A few miles west of the airfield: Here and intermittently for the next few miles are locally derived flood-borne basalt cobbles and boulders recently culled from vineyards. Viewed in the distance are discontinuous outcrops of basalt with skim of flood-borne boulders.

Stop 2.5. Scabland northwest of Byron

Just west of the valley narrows and extending northwest from Byron, a 12-km^2 area of isolated sharp basalt scabland between altitudes 205 and 220 m (670 and 720 ft) has a local relief of 8 m (Figure 26) (briefly noted by Bretz, 1924, p. 145). The scabland

is littered by angular basalt boulders as large as 3 m and is mantled by postflood loess but apparently not by flood-slackwater deposits. Yet just 5 km farther upvalley near Mabton, graded rhythmites are at least 10 m thick at a similar altitude. Floods that deposited the rhythmites at Mabton had just upcurrent eroded a classic scabland! Floods that deposited rhythmites as high as 300 m (980 ft) near Union Gap were at least 70 m deep over this scabland. Neither are the coarse proximal boulder and pebble-gravel deposits at Prosser overlain by any such "low-energy" silt. The coarse deposits at and west of Prosser and the scabland west of Byron are in fact the "high-energy proximal" component of the rhythmite facies demanded by those who would infer that the Yakima valley rhythmites are only of low-altitude, low-energy floods (e.g., Baker, 1991, p. 250).

En route to Stop 2.6

Just after the turn west onto W. Robinson Road, gravel pits on

both sides of the road expose steep west-dipping (up Yakima valley) foreset beds of pebble-cobble gravel subfluvial "delta" shed by great flood(s) off the sharp west edge of the bedrock platform on which we have travelled for the last several miles (Figure 26). The substantial content of subangular to subround nonbasaltic stones is enigmatic but likely derived from a nearby coarse sedimentary interbed between basalt layers. **Private pit, permission required.**

After crossing the bridge over Yakima River, drive slowly to view adjacent scabland on left (Figure 26), which is sparsely littered with flood-borne, locally derived basalt boulders including many 1–2 m in diameter. The scabland is apparently devoid of overlying silt slackwater deposit that would be evidence of feeble floods following scabland-carving floods.

After road ascends to level of scabland, this surface gradually passes west into silt (note hops growing) at about the same altitude as the thick rhythmites at Mabton (Figure 26).

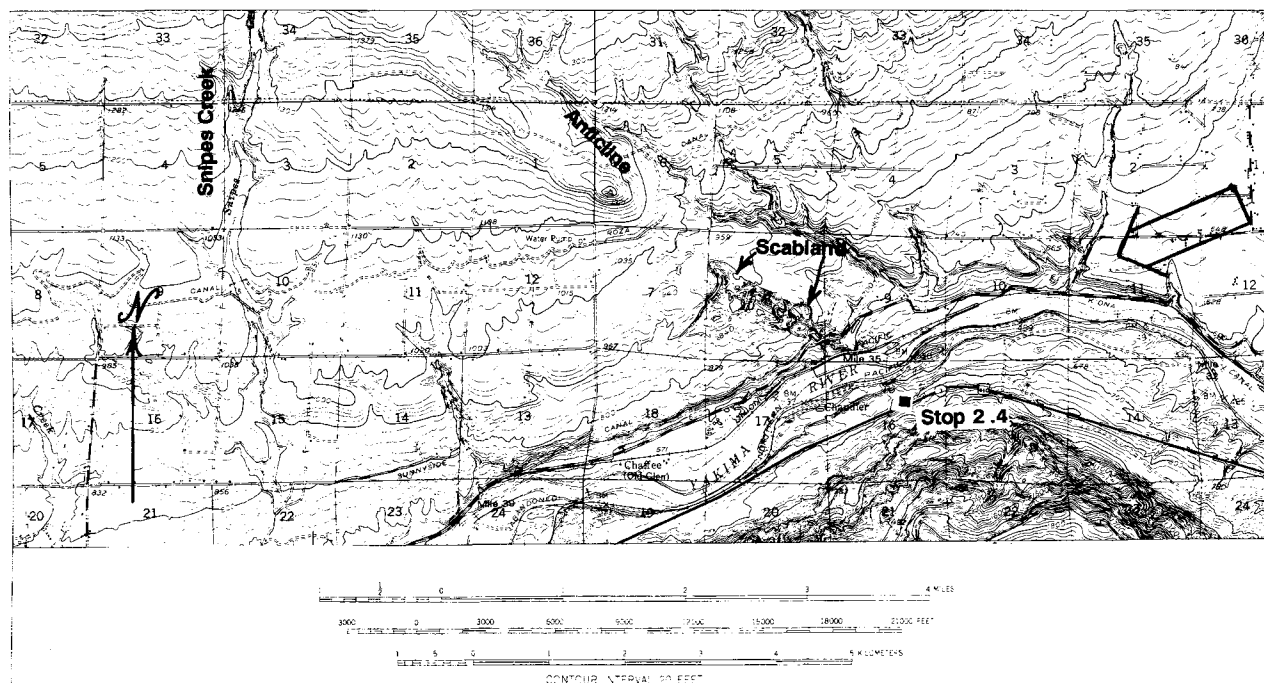


Figure 24. Part of 1:62,500-series USGS Corral Canyon topographic quadrangle, showing area near Chandler; lower Yakima valley, Washington. Map vintage 1951, predating modern highways. The large arrow shows general direction of water movement as stage was rising in the Pasco basin to the east.

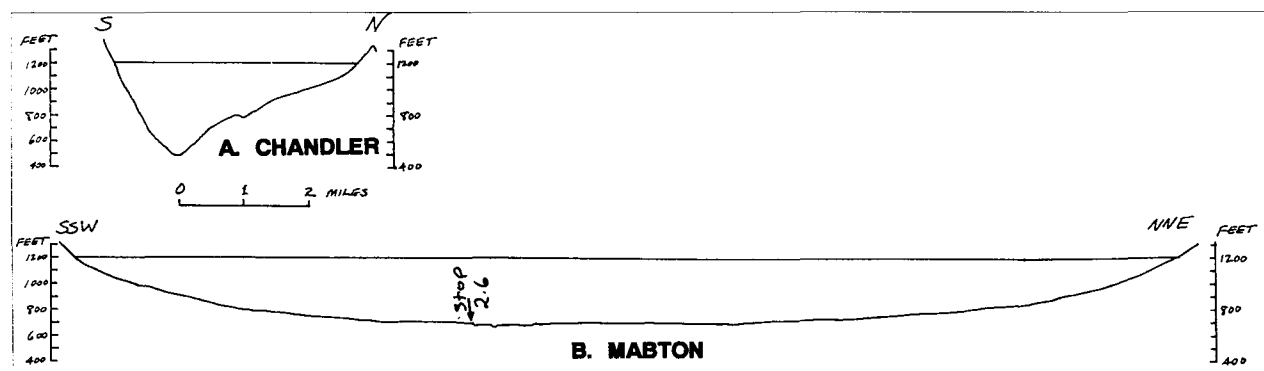


Figure 25. Cross sections of lower Yakima valley showing enlargement by 5.5 to 6 times the width and cross-sectional area between Chandler and Mabton.

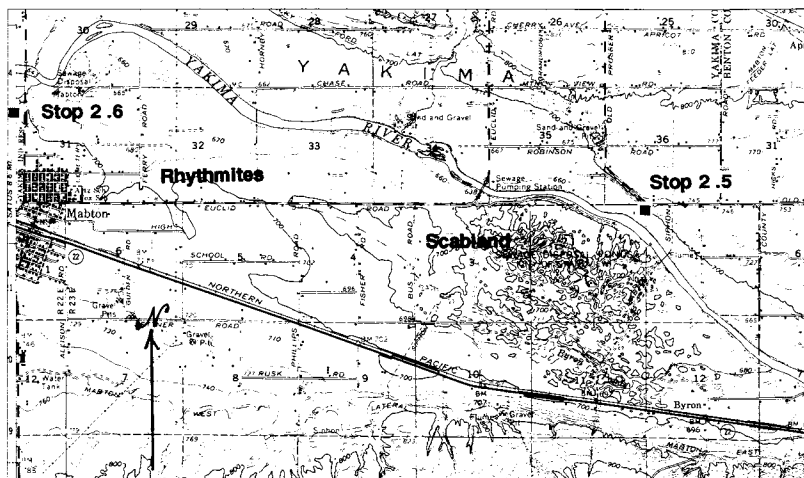


Figure 26. Part of 1:62,500-series USGS Prosser topographic quadrangle, showing area between Prosser and Mabton, lower Yakima valley, Washington. Map vintage 1965, predating modern highways.

Stop 2.6. Mabton

(please see Waitt, 1980a, 1985b)

The section is located in the lower Yakima valley, south-central Washington, 1 mi north of Mabton, along the main road to Sunnyside. Conspicuous exposure is continuous along bluffs defining the south side of Yakima River valley for 200 ft on the west side of the road (former exposures on the east side are now mostly buried). **Please obtain permission from landowner Don Desmaris (through gate on west and up driveway).**

About 25 Missoula backflood rhythmites are exposed but are now far more slumped over and obscured than in the late 1970s. Many features in the succession of graded beds here are similar to those at Burlingame canyon, including upsection thinning and fining of rhythmites and the fact that exactly 11 rhythmites overlie the conspicuous ash couplet. Differences include: (1) paleocurrent indicators are west directed (but that is upvalley here); (2) a coarse bed-load deposit of locally derived basalt forms the base of many rhythmites, especially those low in section (Figure 17, E); (3) the Mount St. Helens "set-S" ash couplet is much thicker, Mabton being about halfway between the volcano and Burlingame canyon; bases of both ash layers are uncontaminated; (4) two additional thin ash laminae lie at top of the rhythmites that overlie and underlie the rhytmite capped by the prominent ash couplet; (5) dunes at the base of several rhythmites are composed partly of freshwater shells; the shells must have been concentrated in an adjacent pond—accumulated there over years or decades before being swept up by an incoming flood. Shells from the base of the second rhytmite below the ash couplet give radiocarbon ages of $14,060 \pm 450$ ^{14}C yr B.P. (USGS-684) and $13,130 \pm 350$ ^{14}C yr B.P. (W-2983).

Yakima valley rhythmic and nonrhythmic "slackwater" deposits locally overlie weathered gravel along the banks of the Yakima River, which is graded to the Columbia now just as during the Pleistocene great-floods episode. If the coarser beds low in the rhytmite sections do not represent the largest scabland floods, then these giant debacles left nothing, for there are no other deposits. Arguments that these represent only late, small floods are fatally inconsistent: numerous allegedly late, low-level floods left rhythmic deposits, yet the largest scabland-sweeping floods deposited nothing. Rather, the rhythmites record all floods: many gigantic near-maximal ones followed by many successively smaller ones.

En route back to Deschutes State Park:

The marvelously rhythmic beds in the Walla Walla and lower Yakima valleys record successive huge backfloods from the Pasco basin. Many of the coarser and thicker rhythmites that underlie the Mount St. Helens "set-S" tephra at Mabton extend upvalley, thinning and fining, as a silt terrace that forms the banks of the Yakima River just below and above Union Gap at altitude 300 m (980 ft), only 65 m below the maximum flood limit at Pasco basin, where backflooding originated. If the barely discernible post-ash rhythmites in the shallow exposures at Donald record floods that barely backflooded that far and high, the much thicker succession of pre-ash rhythmites here and farther upvalley as far as Union Gap record more robust, higher backfloodings. For floodwater to reach the Union Gap sections requires ponding of at least 450 km³ of water behind Wallula Gap. To account for at least 15 graded beds just above Union Gap, this ponding occurred at least 15 separate times.

Near the top of the rhytmite sections, the beds typically become markedly thinner and finer, progressively so upsection. Of the 11 flood beds that overlie the Mount St. Helens "set-S" tephra at Burlingame canyon (altitude 185 m [610 ft]) and at Mabton (215 m [710 ft]), the upper 7 are much thinner and finer than the lower 4 or any other bed downsection. The upper part of rhytmite sections in Yakima valley surely represent progressively smaller floods (Waitt, 1985b, p. 1284). Of 11 relatively thin and fine-grained rhythmites that overlie the ca. 13,100-yr-old Mount St. Helens "set-S" ash at Mabton (altitude 215 m [710 ft]), only 5 overlie the ash farther upvalley at Zillah (altitude 245 m [800 ft]), 4 at Buena (altitude 255 m [840 ft]), and 3 at Donald (265 m [870 ft]). Thus the last 10 or so floods represented at Mabton clearly were successively smaller and ponding not deep enough to flood up to the maximum-flood limit.

The height of the tops of these rhytmite sections above the level of Columbia River at Wallula Gap are: Burlingame canyon, 95 m; Mabton, 125 m; Zillah, 170 m; Buena, 178 m. Floods recorded by the upper seven of the post-ash flood beds exposed at Burlingame and Mabton ponded in Columbia valley as deep as 120–150 m (at Wallula Gap) but apparently not as deep as 170 m. Even a flood ponding to a depth of "only" 125 m (which would flood the top of the Mabton section), while 150 m below the limit of the largest floods, was enormous: behind Wallula Gap, the Pasco basin and the backflooded valleys contained a minimum of 155 km³ of ponded water (Waitt, 1980a; Table 4). Floods capable of such extravagant backflooding out of the Pasco basin could not but have also invaded the channeled scabland.

At U.S. Highway 97 near Toppenish: Fine rhythmites with intercalated Mount St. Helens "set-S" tephra extend at least another 18 km upvalley; the rhythmites at Union Gap are 30 km upvalley.

Approaching Goldendale: Round-stone pebble gravel rich in quartzite clasts is seen in cuts on both sides of road for half a mile. This represents an old (but younger than an underlying 10.5-Ma basalt) course of Columbia River directly across what later became the Horse Heaven and Columbia Hills anticlinorium. The rise of these great anticlines diverted Columbia and Yakima Rivers east to the Pasco basin some time after 10 Ma. A few miles farther, the pebble gravel is overlain and baked by an overlying Simcoe alkali-basalt flow.

Approaching Columbia River, descending off the Columbia Hills anticline: Views of south (Oregon) side of Columbia valley showing basalt benches stripped of regolith as high as about 275 m (900 ft) above the river.

DAY 2 ROAD LOG (mileage is approximate)

Miles

0.0 Deschutes State Park overflow area.
 0.2 Turn right (east) onto old U.S. 30. Miller Island on left, on whose SE side is 1-Ma alkali-basalt lava flow draping down over north valley side from Haystack Butte.
 1.6 Junction with Oregon Hwy. 206.
 4.2 Entering Biggs Junction.
 4.6 Junction with U.S. Hwy. 97. Turn left (north).
 4.7 Ramp to Interstate 84 east. Take it.
 10.1 Rufus.
 12.3 John Day Dam. Aluminum plant across river.
 18.5 Scabland.
 19.8 View ahead of eddy bar at mouth of Philippi Canyon.
 23.3 Exit 123, Philippi Canyon. Stay on I-84.
 37.0 Arlington, Junction with Oregon 19.
 47.0 Willow Creek.
 59.3 Rest area exit.
 61.0 Boardman.
 66.1 Exit 168 to U.S. 730. Take it toward Umatilla.
 73.7 Irrigon.
 81.1 Enter Umatilla.
 82.8 Pass under I-82. Continue east on U.S. 730.
 87.2 Scabland on left.
 92.0 Junction with Oregon 37. Wallula Gap ahead.
 104.6 Walla Walla Grain Growers grain elevators on left.
 107.8 Wallula Gap.
 108.1 Intersection with U.S. 12. Take it east.
 108.4 East arm of U.S. 12 "Y." Proceed east on U.S. 12.
 113.2 Turnoff left onto abandoned segment of old highway parallel to present one. Pull ahead and form single line.
 113.3 **Stop 2.1.** View of narrows of Walla Walla valley. When you leave, continue east on U.S. 12.
 114.8 Intersection with Byrne Road through valley narrows (alternate return route). Stay on U.S. 12, which heads up over basalt spur on north valley side.
 116.0 Road cuts on both sides show very old calcified colluvium draped over a high of bedrock basalt.
 120.1 On right in distance along Walla Walla River is a tall exposure of rhythmites.
 120.5 Entering Touchet.
 125.0 Just upon entering Lowden, turn right onto South Lowden Road at landmark of big isolated mound of bedded slackwater deposit.
 125.3 Cross Walla Walla River.
 126.2 Road intersection. Stay on main road. Ascend Gardena silt "terrace."
 127.3 Just before irrigation ditch, turn right into gravel parking area: **Stop 2.2.** Burlingame canyon.
 127.4 Continue south across irrigation ditch on South Lowden Road and descend off "terrace."
 128.1 T-shaped intersection at Frost Ranch. Turn right.
 129.1 Road intersection. Turn right onto Gardena Road.
 129.5 As road ascends back up onto Gardena silt "terrace," rhythmites are exposed in roadcuts.
 130.0 Occasional crystalline erratic stones culled from irrigation ditch.
 130.7 Road south. Ice-rafted granite erratic, 2.3 m in diameter, in wheat field east of road ½ mi to the south weighs 32 tons.
 132.6 Road intersection. Take sharp turn to right.
 134.0 Touchet, Washington. Stone building on left was bank.
 134.1 At "T" intersection, turn left.
 134.2 At intersection, turn right and cross railroad tracks.
 134.3 Junction with U.S. 12. Turn left onto it westbound.
 134.7 In distance to south is tall rhythmite exposure (again).
 135.3 **Alternate route.** At right curve in Highway 12, turn onto Byrne Road. Follow it about 5 mi through the narrows of Walla Walla valley. Byrne Road rejoins Highway 12 where indicated (mileage 114.8 above) inbound to Walla Walla valley. This alternate route adds about 1 mile to recorded mileage.
 146.5 East limb of U.S. 12 "Y" at Wallula. Continue straight past weigh station on right.
 146.7 Turn right onto west limb of U.S. 12 "Y."
 147.8 Pull to right shoulder, parking as far off pavement as possible: **Stop 2.3.** Wallula rhythmites site is across this road 200 yards or so west, a cut along railroad. *Please beware of traffic while crossing*

road. When you leave, continue on U.S. 12.

147.9 Intersection of U.S. 12 from east. Turn left, continuing west on U.S. 12.
 148.0 Walla Walla River bridge.
 161.3 Bridge over Snake River.
 164.8 U.S. 395 to Spokane. Continue straight. U.S. 12 becomes I-182 here.
 167.4 U.S. 395 south to Kennewick. Continue on I-182.
 173.7 Cross Columbia River.
 174.5 Exit to Richland. Continue west on I-182.
 176.1 Cross Yakima River. We start up Yakima valley, but at first up and over structural high.
 178.0 Line of doubly plunging anticlines defines regional Olympic-Wallowa Lineament (OWL). Badger Mountain left, Candy Mountain right.
 179.1 Goose Gap, a structural sag between anticlines. Get into right lane.
 179.4 Intersection with I-82. Take it (also U.S. 12) west toward Prosser and Yakima.
 184.7 Long descending road grade. Ridge ahead is Horse Heaven Hills anticline with fault scarp along base.
 188.4 Take Exit 93, Yakitat Road.
 188.7 Turn left (south) on Yakitat Road.
 188.9 Turn right (west) at yellow arrow.
 189.4 Power lines.
 190.5 **Stop 2.4.** Chandler narrows. Pull to left (south) shoulder. When you leave, continue west on road.
 194.0 Turn right onto Gibbon Road and cross freeway overpass.
 194.1 Turn left onto I-82 westbound on-ramp.
 195.5 Yakima valley begins to widen out above (upvalley of) Chandler narrows.
 196.8 Road cuts through landslide debris.
 197.2 Road cut on right shows broken-up flows of the Columbia River Basalt Group with slabs of sedimentary interbed in landslide block.
 197.9 Mount Adams ahead.
 199.7 Take Exit 82 to Prosser.
 200.1 At stop, turn left (west) on Wine Country Road (Washington Highways 22 and 221).
 200.5 Enter Prosser. Be prepared for road cut ahead at railroad underpass (no stop).
 201.3 Pass railroad underpass slowly. Coarse, poorly sorted Missoula-flood debris carrying angular basalt boulders.
 201.5 Tenth Street intersection.
 201.8 Intersection with flagpole. Veer right, continuing on Wine Country Road.
 202.0 Yakima River bridge.
 202.4 Small airfield on left.
 202.5 Just beyond airfield, turn left (west) onto Old Inland Empire Highway.
 203.8 For next few miles, flood-borne basalt stones culled from vineyards, then discontinuous basalt outcrops with skim of flood boulders. Mount Adams ahead.
 206.9 Intersection of Old Prosser Road with Canyon Road. Pull off left into clear area just beyond intersection, just before curve in highway:
Stop 2.5. Byron scabland. When you leave, continue on Old Prosser highway around right curve to north.
 208.2 Turn left (west) onto West Robinson Road.
 208.3 Gravel pits exposing upvalley-dipping foreset gravel beds.
 208.8 Hops fields (tall lined poles).
 209.2 Stop sign. Turn left (south) onto S. Euclid.
 209.4 Scabland ahead is a part of that which we viewed from Stop 2.5.
 209.6 Bridge over Yakima River. Road turns west and becomes E. Euclid. Note adjacent scabland.
 209.7 Drive slowly to allow views of adjacent scabland littered with flood boulders but devoid of slackwater silt.
 213.2 Entering Mabton.
 213.9 Stop intersection. Turn right (north) onto Washington 241 (First Avenue).
 214.5 Just after starting downhill, turn left into unmarked driveway through gate. Proceed up driveway.
 214.6 Turn around at house and head back down driveway.
 214.7 Park on drive as far to right as practical (If there are many cars, some may have to park in middle of drive heading up.):
Stop 2.6. Mabton rhythmites. *Private property. Please ask permission of landowner Don Desmaris. Please beware of stock*

- 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 m³/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 gravely 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 ¹⁴C 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 mod-

ern 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. Tephra found within these older flood deposits at this site have not yet been dated or correlated with certainty with tephra 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.

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 Ortle 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 ($1,000 \pm 40$ 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, volcanoclastic, 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

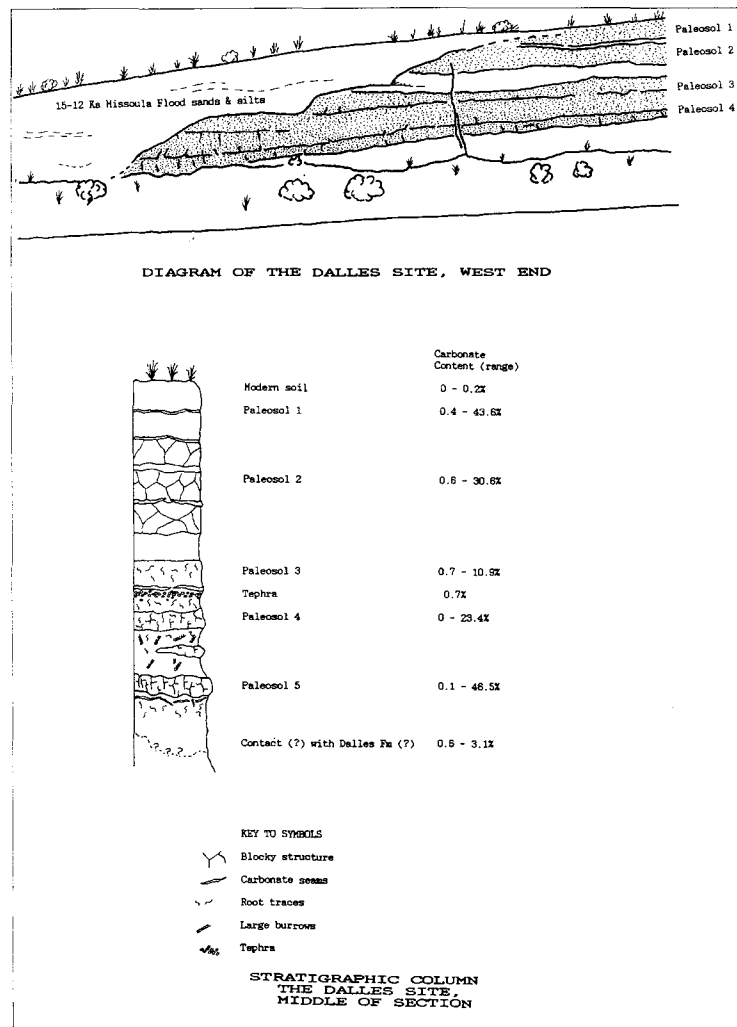


Figure 27. Sketch and stratigraphic column of exposure at Stop 3.2.

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 at 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 \pm 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 $13,695 \pm 95$ ^{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 $14,795 \pm 150$ ^{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-raftered er-

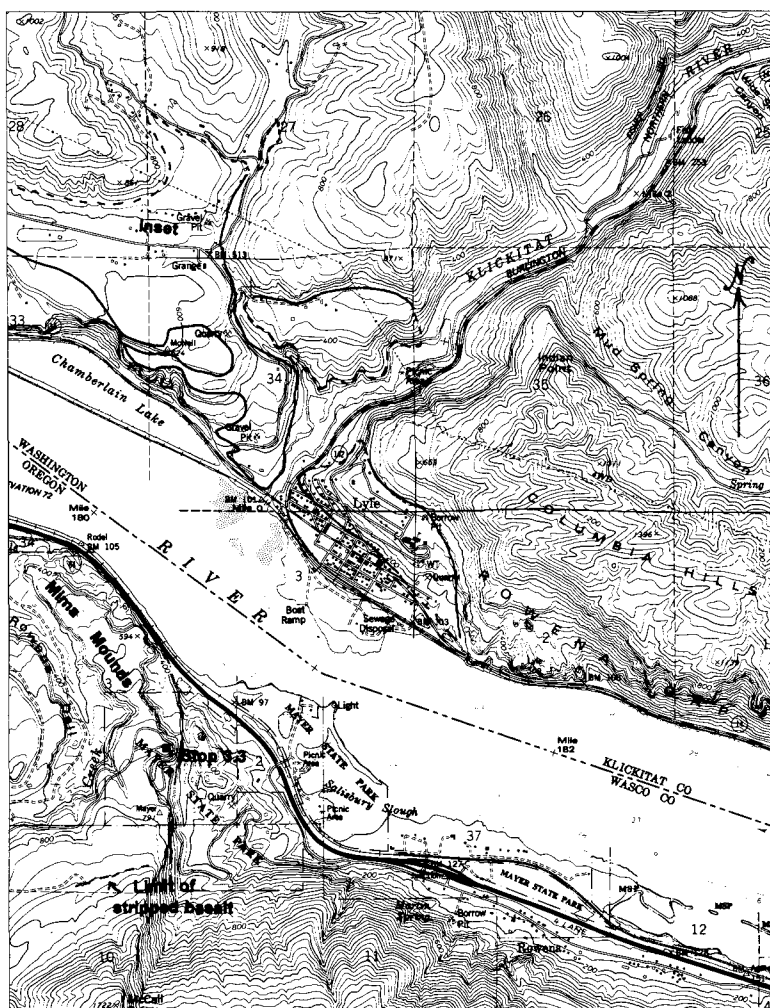


Figure 28. Topographic setting, geomorphic features, and approximate distribution of Missoula flood deposits (outlined by heavy lines) near Lyle. Topographic base from Lyle USGS 7.5' quadrangle. Land sections (numbered) are 1 mile (1.6 km) across.

ratios 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 sur-

faces 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

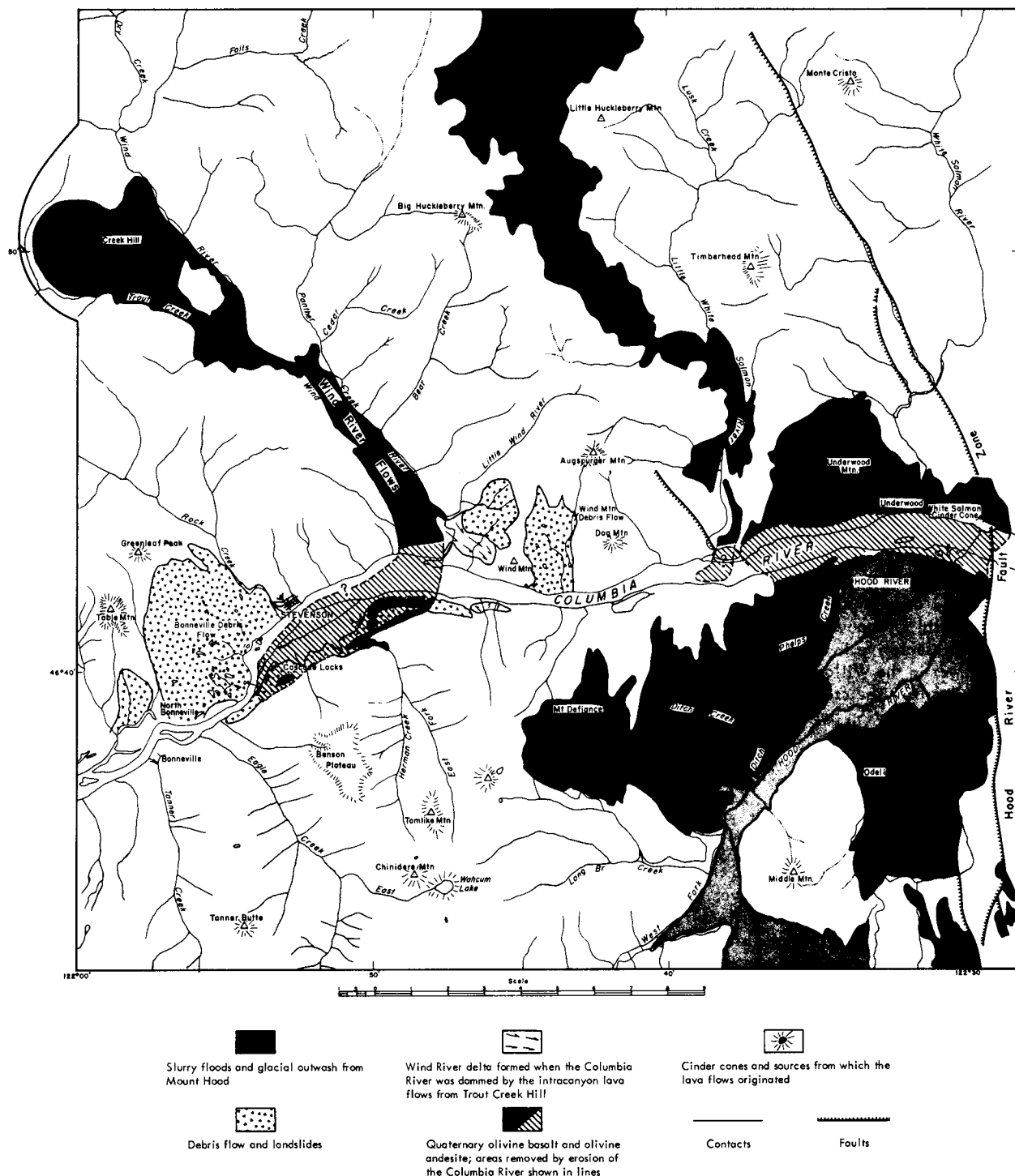


Figure 29. Lava flows and landslides in the Columbia River Gorge, emphasizing flows that may have dammed the Columbia River. From Waters (1973).

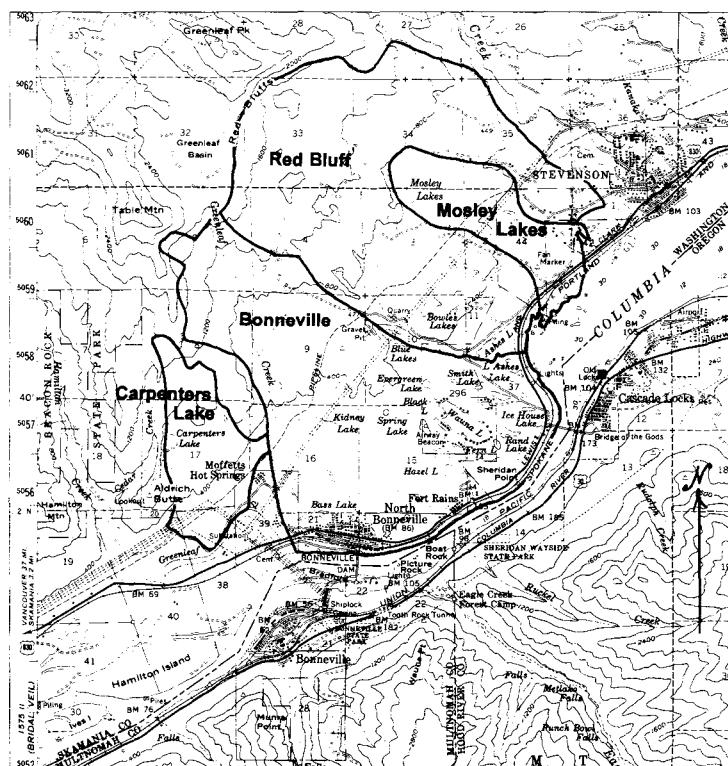


Figure 30. Landslide complex near Cascade Locks. The Bonneville landslide was the most recent one and may have temporarily dammed the Columbia River about 500 years ago. Topographic base is the Bonneville 15' quadrangle. Land sections (numbered) are 1 mi (1.6 km) across. After Minor, 1984.

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 km². 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 ¹⁴C yr B.P. and 700 ± 200 ¹⁴C 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 archaeological investigations and drilling done during construction of the second Bonneville Dam powerhouse. Five wood samples inferred to be in or below land-

slide 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 archaeological 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 archaeological 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, Pettygrewe (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." Pettygrewe (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.

□

Meditations on equilibrium punctuations in Oregon

by John Eliot Allen, Emeritus Professor of Geology, Portland State University, P.O. Box 751, Portland, OR 97207

ABSTRACT

Periodicity of abrupt geologic changes can occur on all scales from days to millions of years. Many examples of landform changes can be illustrated by features in Oregon that have been produced not only by earthquakes and volcanism but also by erosion and glaciation.

INTRODUCTION

Quite recently in this old-timer's life, Eldredge and Gould (1972) proposed that instead of evolving slowly and evenly, life forms remain static for long periods of time and then are "punctuated" by sudden abrupt and obvious change. This revolutionary new idea of "punctuated equilibrium" caused me to rethink several features in Oregon that had puzzled me.

In the 1920s and 1930s, my generation was taught "uniformitarianism": the concept that the past is to be interpreted through what we see going on in the present. Evolution and geologic processes were thought to progress more or less evenly and steadily, except for earthquakes and volcanic activity.

Although William Morris Davis had early (1909) proposed the anthropomorphic periodic stages of "youth, maturity, and old age" in geologic processes, it was not until the 1960s that quantitative geomorphologists (Strahler, 1969, 1971; Leopold and others, 1964) began to demonstrate that periodicity could be important in landform development. At that time, I too began to realize that the idea of a "punctuated equilibrium" can be applied to more than evolution and that landforms can change abruptly instead of slowly and with regularity.

By the 1960s, "absolute" dating methods were supplementing the "relative" determinations of geologic age by fossil and stratigraphic correlation. Today, numerous techniques, including studies of U/Pb and K/Ar ratios, amounts of carbon 14, paleomagnetic reversals, rates of lichen growth, fission tracks of cosmic rays in obsidian, obsidian hydration, and dendrochronology (studies of annual growth of tree rings) are available to be used by geologists to determine periodicities in geology. Now we are even searching for periodicities in earthquakes and volcanic events.

CATASTROPHIC EVENTS

On a large scale, the suggestion by Alvarez and others (1980) of dinosaur extinction caused by a comet impact at the end of the Cretaceous led to another hypothesis of twelve periodic mass extinctions with a periodicity of 26 million years (Raup and Sepkoski, 1984). Their extinction hypothesis was explained by another hypothesis that the earth was periodically bombarded by comets and meteorites pulled out of the "Oort Cloud" by a "Nemesis" passing star.

Atwater (1987), Peterson and Darienzo (1989), and Darienzo and Peterson (1995) recognized that occurrences of tsunami-generated sand layers alternating with peat in the swamp deposits of Oregon and Washington coastal estuaries supply ample evidence of past giant (more than Richter 8) subduction zone earthquakes. More than six of these have occurred at approximately 400-year intervals (actually varying from 200 to 600 years) during the last several thousand years.

EROSION

Erosion is easily the most obvious and yet perhaps the most neglected geologic candidate for recognition of sudden rapid change. Equilibrium in erosion by water is a delicate balance, easily disturbed by changes in any one of a number of variables. The "profile of equilibrium" of a graded stream was emphasized by

Mackin (1948). Erosion and deposition in humid regions, except for areas with large amounts of limestone with characteristic karst topography, are accomplished during heavy periodic rainfalls, floods, and landslides that occur for only a few days a year—or that in arid climates may not occur for many years. The U.S. Army Corps of Engineers has actually calculated the effects of 10-, 50-, and 100-year floods.

A common sight along roads in the residential Portland Hills such as Terwilliger Boulevard are trees that have a distinct bend near their base, which I was taught to attribute to soil creep in which the trees had been tilted downhill by creep and then had straightened themselves up. I no longer think that creep is a continuous slow process; I am sure it occurs almost entirely after periodic rainstorms.

As a long-time student of the Columbia River Gorge (Allen, 1932, 1984), I only recently realized that the narrow, deeply-incised chutes that occupy much of the canyon walls between the main tributary canyons were almost entirely eroded by periodic gully washouts after heavy rains during the last 12,000 years (Holocene). This is evident when every few years after rainstorms the culverts on the scenic highway are blocked with coarse debris and mudflows that may even cover most of the roadway.

Landslides are sudden and effective periodical erosional events, frequently caused in Oregon by rainstorms but also undoubtedly sometimes by earthquakes. During many years of teaching physical geology at Portland State University, while discussing the chapter on mass wasting, I would predict that if Portland had ten days of steady rain, there would be a million dollars worth of damage done by slides in the Portland Hills. In 18 years I never missed.

During the last few years, Oregon highways have been blocked by slides east of Tillamook, on the coast south of Bandon, and at Neahkahnie Mountain north of Nehalem. In the long run, many major landslides in the Pacific Northwest may have been caused by earthquakes. The mud slide that covered a Native American village at the northwest tip of the Olympic Peninsula about 400 years ago and the Cascade or Bonneville landslide that occurred a few hundred years ago may well have been initiated by great earthquakes. Earthquake-generated slides probably dammed Triangle Lake northwest of Eugene and Loon Lake south of Scottsburg. Periodicity of these landslides might be correlated with the evidence of coastal tsunamis.

Oregonians have been justly proud of their crystal-clear mountain streams, never asking how the tree-covered canyons through which the streams flow were cut by erosion. Clear water does not erode (except in limestone), so the canyons must have been deepened primarily during periodic flooding, when the debris supplied from the valley walls by creep and landslide was scoured out. This debris moved downstream during great floods, eventually to be deposited in flood plains, alluvial fans, or deltas.

A longitudinal section of a gravel bar shows that it is entirely composed of "foreset beds" dipping downstream. Only during floods does the gravel bar progress downstream by having debris rolled along its surface and down the sloping front of the bar.

Ice, of course, is another effective and frequently periodic erosional agent. During a particularly hard freeze in 1970, so much ice collected below Multnomah Falls that a miniature glacier more than 500 ft long and 50 ft thick moved down the canyon below the falls and broke the abutments of the highway bridge east of the lodge (Allen, 1984, p. 65).

Multnomah Falls is only one of many waterfalls in the Gorge that drop over cliffs now lying at the back of 100- to 500-ft-wide

amphitheaters that are recessed several hundred feet from the main cliffs produced by the Bretz floods 12,000 years ago. It was only after seeing Multnomah Falls in 1970 after a severe freeze that I could explain this erosion. Freezing winds during periodic extra-cold winters blow the spray back and forth; it freezes in the joints of the brickbat basalt and pops the blocks out.

VOLCANISM

The High Cascade volcanoes suggest periodicity of volcanic activity. Their relative ages can be determined by the degree of glaciation to which they have been subjected. Since most of their rocks are magnetically normal, most of the volcanoes are less than 700,000 years old.

Mount Thielsen, Mount Washington, Three-Fingered Jack, and the North Sister are older than Middle Sister, Mount Hood, Mount Shasta, Mount Adams, and Mount Baker. The youngest are Mount St. Helens, Mount Mazama, South Sister, and Lassen Peak. Detailed studies of Mount St. Helens have shown periodicity. Retallack (1981) has also described thick sections of volcanic ash or tuff of the Clarno, John Day, and Mascall Formations in central Oregon that show numerous periodic (and colorful) fossil soil horizons.

PERIODICITY OF PUNCTUATIONS OF EQUILIBRIUM

Hours to days: Earthquake aftershocks.

Days to months: Earthquakes; rainstorm floods; some small landslides; bent trees.

Years: Minor faulting earthquakes; annual floods; small landslides; gully washouts; gravel bar progression.

Decades: Major faulting earthquakes; 10-year floods; numerous landslides; volcanic debris flows; glacial flash floods or "jökulhlaups"; "El Nino" climatic changes.

Hundreds of years: Subduction-zone earthquakes; great landslides; hundred-year floods; glacial bursts; volcanic activity; climatic change.

Thousands of years: Glacial intervals (Little Ice Age); climatic change; paleosoils.

Millions of years: Extinctions; "Nemesis" (comet impacts?); great basaltic floods; new species.

REFERENCES CITED

- Allen, J.E., 1932, Contributions to the structure, stratigraphy, and petrography of the lower Columbia River Gorge: Eugene, Oreg., University of Oregon master's thesis, 96 p.
- , 1984, The magnificent gateway, a layman's guide to the geology of the Columbia River Gorge: Portland, Oreg., Timber Press, 144 p.
- Alvarez, L.W., Alvarez, W.A., Asaro, F., and Michael, H.V., 1980, Extraterrestrial cause for the Cretaceous-Tertiary extinction: *Science*, v. 208, no. 4448, p. 1095.
- Atwater, B.F., 1987, Evidence for great Holocene earthquakes along the outer coast of Washington State: *Science*, v. 236, p. 942–944.
- Daríenzo, M.E., and Peterson, C.D., 1995, Magnitude and frequency of subduction-zone earthquakes along the Oregon coast in the past 3,000 years: *Oregon Geology*, v. 57, no. 1, p. 3–12.
- Davis, W.M., 1909, Geographical essays: Ginn and Co., Boston (reprinted in 1954 by Dover Publications, New York), 777 p.
- Eldredge, N., and Gould, S.J., 1972, Punctuated equilibria: an alternative to phyletic gradualism, in Schopf, T.J.M., ed., *Models in paleobiology*: San Francisco, Freeman, Cooper, and Co., p. 82–115.
- Leopold, L.B., Wohlman, N.G., and Miller, J.P., 1964, Fluvial processes in geomorphology: San Francisco, W.H. Freeman and Co., 522 p.
- Mackin, J.H., 1948, Concept of the graded stream: *Geological Society of America Bulletin*, v. 59, p. 463–512.
- Peterson, C.D., and Daríenzo, M.E., 1989, Episodic abrupt tectonic subsidence recorded in late Holocene deposits of the South Slough syncline: An on-land expression of the shelf fold-belt deformation from the southern Cascadia margin [abs.]: *Geological Society of America, Abstracts with Programs*, v. 21, no. 5, p. 129.

Raup, D.M., and Sepkoski, J.J., Jr., 1984, Periodicity of extinctions in the geologic past: *National Academy of Science Proceedings*, v. 81, p. 801–805.

Retallack, G., 1981, Fossil soils: indicators of ancient terrestrial environments, in Niklas, K.J., ed., *Paleobotany, paleoecology, and evolution*: New York, Praeger Publishers, v. 1, p. 55–102.

Strahler, A.N., 1969, *Physical geography*: New York, John Wiley and Sons, 733 p.

———, 1971, *The earth sciences* (2d ed.): New York, Harper and Row, 824 p.

Editor's footnote

Recent research may have added another candidate to the phenomena affected by "punctuation": geomagnetic field reversals, i.e., the periodic reversals of the polarity of the Earth, when north became south and vice versa. In an article of the April 20, 1995, issue of *Nature* (v. 374, p. 687–692), R.S. Coe, M. Prévot, and P. Camps describe their study of lava flows at Steens Mountain in Harney County. Their findings suggest that, at times, the geomagnetic field was changing direction so rapidly that the effect was recorded in some individual flows while they were cooling. The calculated speed of 3° per day is on the order of 1,000 times faster than previously observed variation rates. The authors conclude "that rapid jumps of field direction occur many times during reversal of polarity." Their final assessment states: "This is not to suppose that geomagnetic reversals take place much more quickly than the several thousand years currently supposed, but rather to suggest that polarity transitions may be punctuated by episodes of extraordinarily rapid field change." □

Camp Carson mine in Union County successfully reclaimed

Federal and state agencies and a La Grande-based construction firm worked cooperatively this summer to clean up and stabilize an abandoned placer mine site at Camp Carson along Tanner Gulch Creek in the Wallowa-Whitman National Forest. The site is approximately 20 mi south of La Grande. The project was completed in July and will protect critical salmon habitat in the upper Grande Ronde River. Cooperating agencies included the USDA Forest Service (USFS), who contributed \$45,000 to the project; the Bonneville Power Administration, who contributed \$20,000; and the State of Oregon Watershed Health Program, whose contribution of \$45,000 was administered by the Oregon Department of Geology and Mineral Industries (DOGAMI).

Gold mining at the Camp Carson mine site, one of the largest hydraulic placer gold mines in Union County, began in 1872. The site was mined intermittently over a period of many years, with the most intense mining taking place in 1893 and 1894. Recently, gravel that had been placed on the edge of a steep hillside over Tanner Gulch Creek began washing down into the creek. From there the sediment was carried into the upper Grande Ronde River, where it began affecting critical salmon-spawning habitat. In addition, deep cracks forming at the top of the hill indicated that a massive landslide was likely to occur.

The USFS, with technical help from DOGAMI, designed a reclamation plan to rehabilitate the site and prevent further damage to the fish habitat. The actual reclamation work was done during July under contract by Mi-Trac Construction Company of La Grande. Mi-Trac controlled sediment runoff at the site, stabilized the steep slope that was threatening to slide into the creek, recontoured the site so that vegetation could grow on the hillside, dewatered the landslide, and built structures to contain any sediment that might come off the site in the future.

The work was supervised by the USFS working with DOGAMI. According to Ben Mundie, reclamationist from DOGAMI's Mined Land Reclamation Program, "Because the reclamation was completed quickly and successfully, critical salmon-spawning habitat in the upper Grande Ronde River has now been protected." □

DOGAMI PUBLICATIONS

Released July 27, 1995:

Relative Earthquake Hazard Map of the Beaverton Quadrangle, Washington County, Oregon, by M.A. Mabey, I.P. Madin, and D.B. Meier. Geological Map Series map GMS-90, 1 map, 6 p. text, \$10.

Relative Earthquake Hazard Map of the Lake Oswego Quadrangle, Clackamas, Multnomah, and Washington Counties, Oregon, by M.A. Mabey, I.P. Madin, and D.B. Meier. Geological Map Series map GMS-91, 1 map, 6 p. text, \$10.

Relative Earthquake Hazard Map of the Gladstone Quadrangle, Clackamas and Multnomah Counties, Oregon, by M.A. Mabey, I.P. Madin, and D.B. Meier. Geological Map Series map GMS-92, 1 map, 5 p. text, \$10.

Each of these relative earthquake hazard maps outlines areas that are most susceptible to damage from earthquakes. These maps are particularly useful in a time of limited resources, for they provide a good indication of where earthquake mitigation efforts should be focused. Also shown on each map sheet, which is approximately 27 by 40 in., are three smaller maps that show relative liquefaction, ground-motion amplification, and slope instability hazards that were combined to develop the large relative hazard maps. The scale of each larger relative hazard map is 1:24,000; the smaller maps are at a scale of 1:55,000.

The three maps are part of a series of maps produced by a DOGAMI/Metro partnership in a study partially funded by the Federal Emergency Management Agency. The first map in this series was published by Metro as the *Relative Earthquake Hazard Map of the Portland Quadrangle*, with supporting data maps published by DOGAMI as GMS-79. The *Relative Earthquake Hazard Map of the Mount Tabor Quadrangle* was published earlier this year by DOGAMI as GMS-89. Through the same grant, Metro has also developed an inventory of buildings, critical facilities, and lifelines in the Portland metropolitan area for assessing seismic risk. Similar relative earthquake hazard maps of the Vancouver, Washington, area were prepared jointly with the Washington Division of Geology and Earth Resources and have already been released to the public as that agency's map GM-42.

These maps are available from all the usual DOGAMI publication outlets in Baker City, Grants Pass, and Portland (see addresses below) and also from the Metro Data Resource Center, 600 NE Grand Avenue, Portland, OR 97232, phone (503) 797-1742, FAX (503) 797-1909.

Released September 1, 1995:

Geologic Map of the Charleston Quadrangle, Coos County, Oregon, by Ian P. Madin, Galan W. McNelly, and Harvey M. Kelsey. Geological Map Series map GMS-94, 1 map, 8 p. text, \$8.

The Charleston 7½-minute quadrangle covers the area around Barview, Charleston, and South Slough, just south of the city of Coos Bay in Coos County. The new map was developed with particular emphasis on the geologic structure of the area, to provide basic geologic information about potential earthquake hazards in coastal Oregon. Such information can be used by private citizens as well as local and state government in making well-informed decisions on land use, earthquake-hazard mitigation, and emergency planning. The project was funded by the U.S. Geological Survey and the National Earthquake Hazard Reduction Program.

The full-color geologic map is at a scale of 1:24,000 (one inch on the map corresponding to 2,000 ft on the ground) and is accompanied by three geologic cross sections. In addition to showing the distribution of various geologic units, the map shows complex folding and faulting and identifies numerous faults that have been active in geologically recent time and may be active in the future. The map area includes the first Quaternary thrust fault in western

Oregon, the Winchester fault, that has been confirmed by the digging of trenches, up to 150 feet long and 15 feet deep, across the fault.

The map also provides the most up-to-date depiction of the geology responsible for the spectacular scenery along this stretch of the Oregon coast and the geologic framework for the formation of South Slough, an estuary whose importance was recognized by the creation of the South Slough National Estuarine Reserve.

The eight-page text that accompanies the map contains rock-unit explanations, an extensive discussion of geologic structure, and brief descriptions of geologic history, resources, and hazards.

Mist Gas Field map, rev. 1995, with 1993-1994 production figures. DOGAMI Open-File Report O-95-1, 1 map, 9 p., \$8.

Production figures of earlier years (1979-1992) are available as Open-File Report O-94-6 for \$5.

Released September 15, 1995:

An Economic Analysis of Construction Aggregate Markets and the Results of a Long-Term Forecasting Model for Oregon, by DOGAMI mineral economist Robert M. Whelan. DOGAMI Special Paper 27, 123 p., \$15.

Between 2001 and 2050, about 2.8 billion tons of aggregate will be needed by Oregon's economy. Recycling will satisfy about 200 million tons (about 7 percent) of that demand. The remaining 2.6 billion tons will have to come from mines and quarries. Five counties—Multnomah, Washington, Clackamas, Lane, and Marion—will account for half of the state's aggregate consumption. About 16 percent of the aggregate will be used for housing. Infrastructure will take up 19 percent of the total. Most of the rest will be used for nonresidential buildings and roads. This forecast is based on the assumption that Oregon's population growth rate will slow to 1.01 percent per year, while consumption will rise 0.53 percent per year, so that the overall per capita aggregate consumption will actually decline.

These are some of the results of the study that represents the first complete analysis of aggregate consumption in Oregon ever done. It answers many important questions that apply not only to Oregon but to other states as well.

The report is based on a large-scale economic model with extensive amounts of data. It explains how urbanization, population growth, and personal income affect aggregate consumption and why this study goes beyond the method of using per capita consumption as a basis of forecasting. It examines such issues as shipping costs, recycling, differences in road-aggregate needs between rural and urban counties, and the risks of regional monopolies. The second part of the report presents individual consumption forecasts, divided by end uses, for every county in the state.

The new publications are now available over the counter, by mail, FAX, or phone from the Nature of the Northwest Information Center, Suite 177, State Office Building, 800 NE Oregon Street #5, Portland, Oregon 97232-2109, phone (503) 872-2750, FAX (503) 731-4066; and the DOGAMI field offices: 1831 First Street, Baker City, OR 97814, phone (503) 523-3133, FAX (503) 523-9088; and 5375 Monument Drive, Grants Pass, OR 97526, phone (503) 476-2496, FAX (503) 474-3158. Orders may be charged to Visa or Mastercard. Orders under \$50 require prepayment except for credit-card orders. □

October 11 to be National Landslide Awareness Day

On that day, the Association of Engineering Geologists (AEG) will hold special public forums in 22 AEG sections across the country to share the landslide information known to engineering geology professionals with the general public. For more information, contact Jerome V. DeGraff, Fresno, California, phone (209) 297-0706 or FAX (209) 294-4809. □

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