UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GUIDEBOOK TO QUATERNARY GEOLOGY OF THE COLUMBIA, WENATCHEE, PESHASTIN, AND UPPER YAKIMA VALLEYS, WEST-CENTRAL WASHINGTON

By

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Open-file Report

77-753

Prepared for Geological Society of America
1977 Annual Meeting (Seattle), Field Trip no. 13,
10-11 November, 1977

This report is preliminary
and has not been edited or
reviewed for conformity with
Geological Survey standards
and nomenclature.

GLACIATION OF YAKIMA, PESHASTIN, AND WENATCHEE VALLEYS--DISCUSSION

South of Chelan Valley (Fig. 1) the eastern Cascades record episodic alpine glaciation alternating with intervals of weathering and development of soil. The most complete and best preserved sequence is in the upper Yakima Valley (Porter, 1976); other glacial sequences reside in the Wenatchee Valley near Leavenworth (Page, 1939; Porter, 1969), in Peshastin Valley (Hopkins, 1966), in Entiat Valley, and elsewhere in the region. Having examined these glacial sequences, I agree with some of the earlier mapping but have augmented the history of the younger drift sheets and have modified the local correlation of the older drifts (Table 1).

The Yakima Valley records three episodes of alpine glaciation separated by long intervals of soil development. The relative positions of moraines and of attendant outwash terraces are the primary means distinguishing the three drift sheets (Table 1; Porter, 1976; Waitt, in press). Distinction between the drifts, and subdivision of the youngest drift, are independently supported by weathering rinds on clasts of basalt, by relative degrees of soil development, and by other weathering criteria (Porter 1975, 1976). Traveling down the Yakima Valley and up the lower Teanaway and Swauk valleys, one passes the moraines and heads of outwash terraces that define the four members of the Lakedale (youngest) Drift and the two members of the Kittitas Drift; at a distance can be seen the terminal moraine of the Lookout Mountain Ranch (oldest) Drift (Waitt, in press). Table 1 lists the approximate distances of the moraines from Snoqualmie Summit and correlates the bodies of drift in several valleys.

Terraces in the Yakima Valley above Ellensburg follow a pattern typical of alpine-glacial sequences. Each set of moraines leads abruptly downvalley into an outwash terrace whose gradient decreases downvalley; from the moraines the several terraces can be readily traced many miles downvalley, in which direcion they converge with each other and with the modern valley floor; weathering of stones and soil development are progressively greater on progressively higher surfaces, giving independent evidence of the relative antiquity of the higher terraces; soils on terraces above the Lakedale outwash have thick argillic B horizons; some of the terraces are thickly mantled with loess, beneath the Lakedale addition of which is the widely preserved argillic B horizon of the pre-late Wisconsin paleosol; Quaternary lacustrine deposits do not occur beyond the downvalley glacial limit.

The Wenatchee Valley, the next trunk valley that drains the eastern Cascades north of the Yakima, has a morainal record of three glaciations comparable to the three glaciations Yakima Valley (Table 1). Many of the most voluminous tributary glaciers of the Icicle Creek glacier headed on the Cascade crest and on the western segment of the Stuart Range, the same general part of the Cascades that nourished the Yakima Valley glaciers. Yet the characteristics of Wenatchee Valley terraces beyond the drift limit could hardly be more different than those in Yakima Valley. Terraces graded to the Leavenworth (last glacial) and Mountain Home (penultimate glacial) moraines near Leavenworth cannot be confidently traced more than a mile or two beyond the glacial limits; the terraces diverge downvalley from each other and from the modern floodplain; weathering and soils are almost universally weak, at least below the Peshastin Creek confluence, the higher terraces showing the same paucity of soil as the lower; loess is rare and nowhere overlies a paleosol; lacustrine sediments occur in abundance downvalley of the glacial limit.

The differences between the terrace sequences in the Yakima and Wenatchee valleys indicate that fundamentally unlike processes governed the late Quaternary development of the two valleys. The chief difference between the two valleys is in the degree of isolation from the many exceptional events that took place in and along the Columbia River valley. The glacial limit in the Yakima Valley is isolated from the confluence of the Columbia by a tortuous steep-walled canyon and by 80 miles of river and 1400 feet of altitude. A mere 18 miles distance and 500 feet in altitude along an unobstructed wide valley separates the glacial limit in the Wenatchee Valley from the Columbia. Late Wisconsin floods as deep as 1000 ft, great landslide-dammed lakes, and other extraordinary events along the Columbia evidently have so profoundly affected the lower Wenatchee as to obliterate most of the proglacial record the valley otherwise should contain.

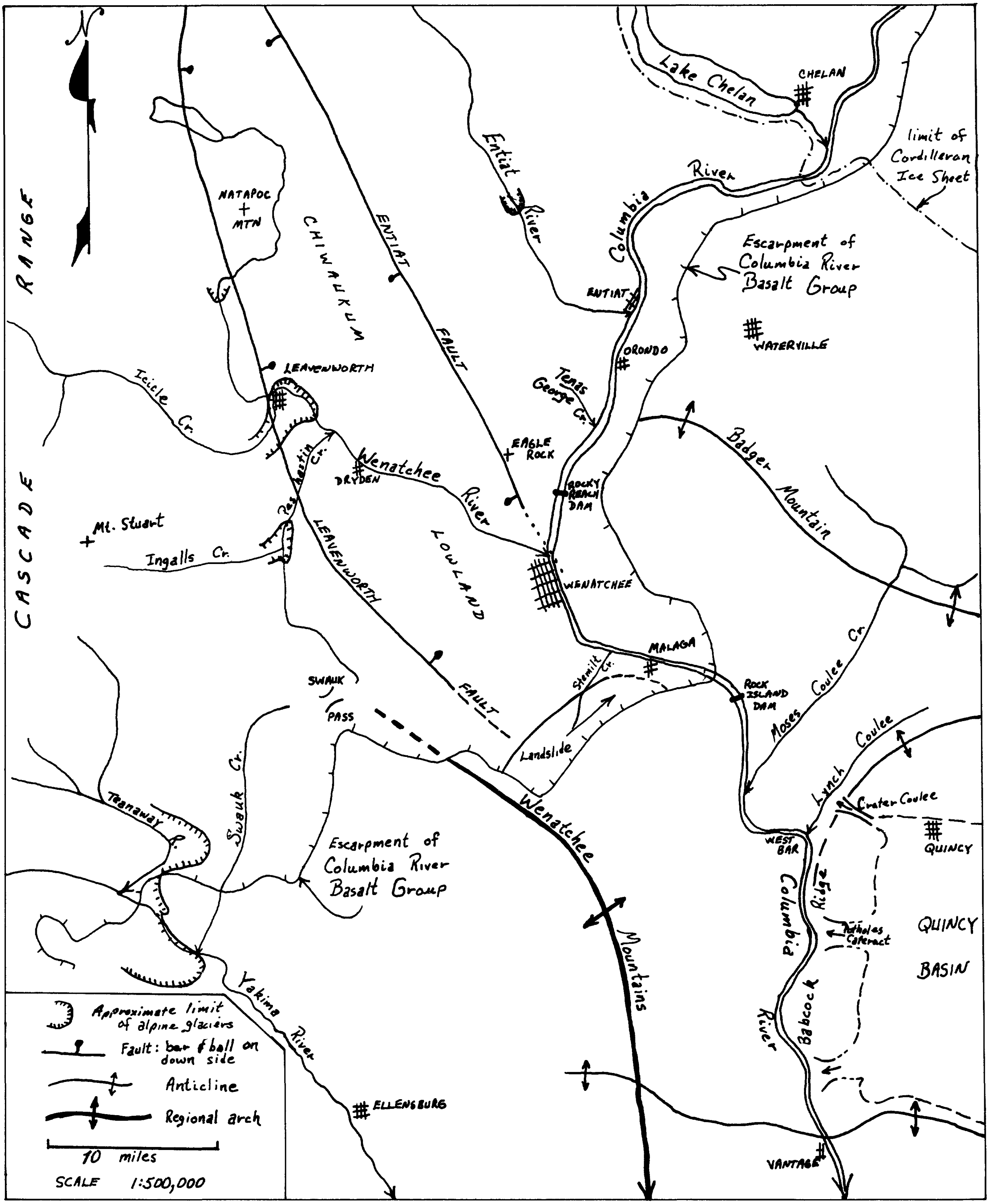

Figure 1.-- Columbia River and its tributaries, central Washington

TABLE 1.--CORRELATION OF SURFICIAL DEPOSITS IN EASTERN-CASCADE VALLEYS

approx. Age BP		Upper Yakima Valley (Porter, 1976; Waitt in press)		Peshastin Valley (Modified from Hopkins, 1966		Wenatchee Valley (Page, 1939; Porter, 1969; This paper)	Columbia Valley (Waitt)
11,500	Lakedale Drift	Hyak Member (2)*	Leavenworth Drift	Inner member	Leavenworth Drift	V (Rat Creek moraines)	Late flood deposits (2?)
							Spokane Flood deposits
14,000		Domerie Member (10)				IV	Vashon Drift
15,000 ?							Moses Coulee flood deposits
		Ronald Member (27)				III, II	
18,000		Bullfrog Member (30)		Outer member		I	Malaga landslide
W E A T H E R I N G A N D S O I L S							
130.000 to ?	Kittitas Drift	Indian John Member (38)		Older drift		Intermediate drift (Peshastin Till of Page (1939); to become Mountain Home Drift)	Early flood deposits
140,000		Swauk Prairie Member (44)					
W E A T H E R I N G A N D S O I L S							
700,000 to ? 850,000		Lookout Mountain Ranch Drift (45)		-------------		Oldest drift (to become Boundary Butte Drift)	
E R O S I O N							
3.7 m.y.		Thorp Gravel				High gravel deposits	

* (27) distance in miles downvalley of Snoqualmie Pass of glacier limits in upper Yakima Valley.

ROAD LOG--SWAUK PASS TO WATERVILLE

mileage	
0.0	Swauk Pass. U.S. Hwy 97 descends northward along Tronson and Peshastin valleys, whose headwaters are carved in steeply upturned Eocene strata (formerly included in the Swauk Formaton).
12.2	On left is a landslide that years ago destroyed part of highway.
12.3	Ruby Creek confluence. On the right is the (penultimate) drift from Ingalls Creek valley overlies bedrock. Bedrock in this segment of valley are metamorphic rocks that surround the Mount Stuart batholith, all forming the crystalline-rock upland block southwest of the Leavenworth Fault (Fig. 1).
13.4	On left, at mouth of Ingalls Creek valley, poorly sorted muddy gravel containing 1-2 m boulders is till. Pedogenic oxidation extends only 1 m deep and soil includes no argillic B horizon; most boulders at the surface are fresh. This is drift of late Wisconsin age, correlated with Leavenworth drift in the Wenatchee Valley.
14.0	On left is a stream cut through a Holocene fan emanating from Hansel Creek. The 5-cm-thick white layer 2 m below surface of fan is Mazama tephra, aged 6700 years BP.
15.0	Ridge on right (above sign for Blewett Pass Lodge) is a lateral moraine of the penultimate glaciation. The moraine abuts a bedrock knoll on its downvalley end.
15.3	Cross the Leavenworth fault from the crystalline-rock block to the downthrown sedimentary-rock block that underlies the Chiwaukum lowland. Ahead on both sides are upturned light-colored upper Eocene strata that compose most of the bedrock of the lowland.
21.0	Enter Wenatchee River valley, developed in the southeast-trending lowland of the erosionally weak sedimentary rocks infaulted between the crystalline-rock blocks. Exposures ahead are upturned upper Eocene sandstone.
21.3	Intersection of U.S. Hwy 2: turn right. This point is about 2.5 mi downvalley of the limit of the Icicle Creek glacier during the last two or more glaciations.
23.0	Turn left into Dryden.
23.2	Stop sign: turn right onto Main Street.

23.3 Turn left onto Depot Road. Cross railroad tracks and park on left.

STOP 1: Exposure on opposite side of Wenatchee River shows upturned Eocene strata that underly 12 m of gravel having a reddish paleosol, which underlies 15 m of thinly bedded fine sand and silt that has but a very weak soil.

Whereas Leavenworth drift is oxidized 1 m deep to a brown, lacks an argillic B horizon, and contains unweathered granitic stones. The gravel opposite is oxidized several meters deep to a reddish brown, has a well-developed argillic B horizon, and contains granitic boulders that are partly to greatly weathered. The gravel must be at least as old as early Wisconsin, and perhaps represents the penultimate global glaciation of 0.13 to 0.14 m.y. BP (Emiliani and Shackleton, 1974; Hays and others, 1976), or some older glaciation.

The overlying sand and silt, which has but thin brown non-argillic soil, represents a late-Wisconsin ponding in Wenatchee Valley to an altitude of at least 1100 ft. Porter (1969), who found granodiorite erratics presumed to have been ice-rafted upvalley from the Columbia, suggested that this deposit represents hydraulic ponding during catastrophic flooding of Columbia Valley.

I am a trifle suspicious about the erratics, which I have found only as "float" on a part of the slope that is littered with diverse artifacts cast away from the orchard above. Those parts of the sand and silt that are well exposed have not revealed dropstones in situ. The deposit, displays mostly downvalley-dipping crosslaminations and either abuts or grades upvalley into silt that contains dropstones of the Mount Stuart Granodiorite that were rafted downvalley into a lake ponded at least to altitude 1320 ft. A brief hydraulic pond is unlikely to effect the downvalley rafting of erratics from contemporaneous valley glaciers; the body of silt upvalley from here therefore suggests a lake that was physically ponded (by landslide?) in Columbia Valley, a lake in which glacier ice in the Leavenworth area (and in Columbia Valley?) terminated.

Late Wisconsin deposits of bedded silt further down-valley occur at various altitudes and in more than one stratigraphic position. Some are definitely associated with ice-rafted stones; others definitely are not. While the meaning of some of these deposits remains obscure, they clearly relate to events in the Columbia River valley, rather than to the episodic growth and wane of glaciers in the Wenatchee valley.

Return to U.S. Hwy 2 through Dryden.

23.6 Turn left onto U.S. Hwy 2.

23.8 In middleground on left is a conspicuous gently sloping surface 400 ft above the highest outwash terrace and 500 ft above the modern Wenatchee River. The surface is underlain by deeply weathered Wenatchee River gravel that overlies an erosion surface beveled across upturned Eocene strata. The surface ends abruptly against a concave-valleyward scarp carved in the same Eocene strata, which evidently is the outer curve of an ancient meander loop of the Wenatchee River. Since abondoning the surface the Wenatchee River has incised 500 ft.

24.2 Bridge over the Wenatchee River. Terrace to the right is underlain by Wenatchee River gravel that, unlike the deposit at Dryden, lacks an argillic B horizon. This and similar terrace remnants downvalley have late Wisconsin soils but are much too high (30 to 70 m above the Wenatchee River) to be outwash from the Leavenworth (last glacial) or the Mountain Home (penultimate glacial) moraines upvalley. The cause of these high but young Wenatchee River gravel deposits seems to be aggradation due to late Wisconsin ponding or aggradation in the Columbia Valley.

25.0 Ahead is an example of local superposition of the Wenatchee River. The highway follows the natural valley, which is filled with barely weathered gravel forming the terrace. During incision of the gravel, a meander against the southern side of the valley evidently discovered a buried bedrock spur, into which the river remains entrenched.

26.0 Flat end of spur on right is underlain by Wenatchee River gravel atop a beveled bedrock surface--another remnant of the surface discussed at mileage 23.8. The soil on this surface includes a thick argillic B horizon.

26.3 Late Wisconsin terraces on both sides of valley.

28.3 Town of Cashmere. The site in the 1860's of a Catholic mission to the Indians in the region.

29.0 Bald, flattish knoll on right and ahead is capped by a diamicton of angular clasts of basalt, whose source evidently is the Columbia River Basalt Group that caps the Wenatchee Mountains 9 mi to the south. The diamicton overlies greatly weathered Wenatchee River gravel, which in turn overlies a beveled bedrock platform. These deposits represent a mudflow that descended Mission Creek (the valley immediately west of the knoll) and spilled out onto the ancient floor of the Wenatchee River valley. The river has incised 800 ft since abandoning the ancient surface.

30.0 On the left the bald summit at about 10:00 is capped by a diamicton of angular clasts of pyroxene-andesite porphyry as large as 3x4x5 m and derived from Eagle Rock, the crags on the skyline at about 9:00 (Whetten and Waitt, in press). Wenatchee River gravel is found on this ridge within 800 ft altitude of the summit and is overlain by the diamicton of pyroxene-andesite clasts. Herein is another example of a sidestream debris-flow that descended to the ancient floor of the Wenatchee Valley. The ancient topography has been completely inverted as the Wenatchee River incised 1700 ft below its highest gravel, and 2500 ft below the summit-capping diamicton.

An analagous relation is found atop Natapoc Mountain (25 mi farther upvalley) about 2000 ft above the valley floor. The Wenatchee Valley thus preserves a fragmentary record of the last 2000 ft of incision of the master stream and its tributaries.

31.3 Above the wide floodplain on the right rise two late Wisconsin terraces composed of Wenatchee River gravel, neither of which contains much-weathered stones nor displays an argillic soil. Atop the upper gravel terrace is a third terrace of silt whose thin-bedded rhythmites individually grade upward from fine sand to clay. The clay layers signify a long-lived physically, not a briefly hydraulically, dammed lake in the lower Wenatchee and Columbia valleys (see Quincy-Wenatchee log, mileage 21.0). Unlike the deposit at 1100 ft at Dryden (Stop 1), this deposit of maximum altitude 920 ft contains no ice-rafted stones.

33.4 To the left at about 8:00 is Eagle Rock atop the upthrown crystalline-rock block northeast of the Entiat fault, and the diamicton-capped summit within the Chiwaukum lowland. Eagle Rock is now separated from the diamicton by Warm Springs Canyon. Since deposition of the diamicton, and during the inversion of the original topography, Warm Springs Canyon developed headward as a subsequent stream along the trace of the Entiat fault.

34.4 Knoll on left consists largely of Eocene bedrock, but is capped with weathered Wenatchee River gravel. The river has downcut 340 ft since depositing the gravel, inverting the former topography.

34.5 Excellent view left up lower Warm Springs Canyon, whose headward growth along the trace of the Entiat fault separated the diamicton on the summit southwest of the canyon from its source on Eagle Rock. Lower Warm Springs Canyon and the adjacent floor of Wenatchee Valley contain a diamicton with angular boulders as large as 1.5 m,* some of them derived from Eagle Rock, from which powerful debris flows apparently still occasionally descend.

*Unless otherwise specified, all dimensions on stones given in this report indicate the _intermediate_ diameter.

34.8 Roadcut through terrace exposes two layers of Wenatchee River gravel, each overlain by massive to laminated silt and fine sand. Both gravel layers and the intervening fine sediments are virtually unweathered. They include no paleosols and the surficial loess has but a very weak soil, indicating a late Wisconsin age of the entire deposit. The upper gravel is 200 ft above the modern river and therefore clearly is not outwash from the Leavenworth moraines. Evidently this deposit represents one or more episodes of aggradation of the Wenatchee River, responding to late Wisconsin aggradation or ponding of the Columbia River.

35.8 Enter northern outskirts of Wenatchee , the "apple capital of the world," a town spawned by land speculation attendant to the building of the Great Northern Railway in 1892.

View ahead of eastern side of Columbia Valley. Skyline is western edge of the Columbia River Basalt Group; hummocky surface (in wheat) below is very old landslide complex, deposited on a surface beveled in the Oligocene Wenatchee formation of Gresens (1976); gentle slope (in orchards) farther to the right at lower altitude is the upvalley end of a giant bar deposited by one or more great late Wisconsin floods that swept down the Columbia.

Across the river at 1:00 a high fill terrace of the Columbia River gravel is capped with 2 m of caliche, indicating antiquity.

36.2 Turn right, continuing east on U.S. Hwy to Spokane.

37.1 Turn right, continuing east on U.S. Hwy 2.

37.3 Barely weathered boulder of basalt at base of scarp of caliche-capped terrace discussed at mileage 35.8. Its intermediate diameter is 95 ft and it rests 350 ft above the river. The most promising explanation of this boulder is ice-rafting. The minimum diameter of a sphere of clean ice required to float the boulder is 350 ft.

37.6 The Columbia River, "the old Oregon that now hears far other sounds than 'his own dashings', the River of the West, the Thegayo, the Rio de los Reyes, the Estrachos, the Rio de Aguilar, the many-named river which unites all parts of the Pacific Northwest." The party of David Thompson, partner of the North West Company, passed here on 7 July 1811, during his vain downriver dash to claim the lower Columbia for Britain and to preempt fur-trading rights from the Astorians. Exposures to the right on the east side of river is downvalley limit of Swakane Biotite Gneiss, which is a boundary significant to Stop 7 on the Quincy-Wenatchee log.

38.4 Turn left, continuing east on U.S. Hwy 2 to Spokane.

38.6 Variegated gently dipping strata on the right are the Oligocene Wenatchee formation of Gresens (1976), which unconformably overlies the Eocene strata in the Chiwaukum lowland and nonconformably overlies the pre-Tertiary Swakane Biotite Gneiss northeast of the Entiat Fault (Tabor and others, 1977). Swakane Biotite Gneiss forms the bold western side of the Columbia Valley ahead and to the left. Crossing the Columbia, we crossed the trace of the Entiat Fault: we are now on the upthrown block northeast of the Chiwaukum lowland. That the Wenatchee formation (of Gresens) is at similar altitudes on both sides of the fault indicates that the southeastern end of the fault has not moved appreciably since the Oligocene Epoch.

39.2 Swakane Biotite Gneiss, exposed on the right, forms both walls of the Columbia canyon upvalley.

42.6 Rocky Reach Dam: a Chelan County PUD project completed in 1961. The lake behind the dam bears the name Entiat, curiously an Indian word meaning "rapid water." The dam occupies a constricted segment of the valley carved in Swakane Biotite Gneiss. The valley here is about 1 mi wide, whereas near Wenatchee is more than 5 mi wide. The variable width of the valley affected the hydraulics of catastrophic floods that poured down the valley. The narrow, cliffy Rocky Reach segment was erosional and supplied most of the giant boulders strewn downvalley into the wide depositional segment near Wenatchee.

44.5 The Columbia divides at Turtle Rock. The bottom topography of the near channel includes elongate closed depressions, suggesting that it was deepened by floodwater, whose passage the large boulders at the downvalley end of the island reveal. Turtle Rock probably is the much-eroded remnant of a landslide from the eastern side of the valley.

45.0 The mouth of Tenas George Creek on the western side of the valley is obstructed by a bar of barely weathered pebble gravel. The surface of the bar, 600 ft above the Columbia River, is ornamented with well-formed asymmetric east-trending current dunes spaced about 20 m, whose steeper slopes face north. The paleocurrent was thus normal to the trend of Tenas George valley but parallel to, albeit up, the Columbia Valley. The gravel, whose provenance is from the upvalley Columbia, is a bar deposited by the clockwise upvalley swirl of an eddy alongside an enormous flood that swept down the Columbia Valley.

45.9 On the left are unweathered 2 m boulders of Swakane Biotite Gneiss resting 160 ft above the Columbia River. As will be argued at Stop 7 on the Quincy-Wenatchee log, these boulders are the bedload gravel of a great flood down the Columbia .

49.7 At flashing yellow light bear right, continuing east on Hwy 2.

49.8 Town of Orondo: a steamboat and ferry landing during the golden era of river travel. Begin ascent to Waterville Plateau.

54.3 Approximate base of Columbia River Basalt Group, which here overlies a weathered surface beveled in gneiss. The contact is mostly obscured throughout the region by extensive landsliding caused by failure of weakly lithified sedimentary strata interbedded with and underlying the basalt.

56.7 Edge of the Waterville Plateau. As seen in roadcuts, basalt is mantled with several meters of loess, which evidently blew up from the Columbia and which provides a surficial deposit suitable for dry wheat farming.

57.7 Gently rolling unglaciated surface of the Waterville Plateau. Ridge to the south is Badger Mountain, an anticline. In the region underlain by the Columbia River Basalt Group, the anticlines define ridges, the synclines valleys. Topography is thus a crude guide to structure contours on the basalt. The vast majority of the drainage on the Columbia River Basalt Group is positioned in structural lows.

59.6 Town of Waterville: prior to railroad spurs on the plateau and dams on the river, the town was the principal collection and distribution point between farms on the Waterville Plateau and the riverboat facilities at Orondo.

END OF LOG

COLUMBIA RIVER VALLEY--DISCUSSION

The Columbia River valley owes its deranged position to two geologic events. Miocene eruption of the Columbia River Basalt Group displaced the ancestral Columbia River northwestward to the margin of the flows in north-central Washington; the post-Miocene growth of the Wenatchee Mountains and other anticlines diverted the river from the basalt margin to a position across the basalt in south-central Washington.

During the Pleistocene Epoch the Cordilleran ice sheet advanced over the northern parts of the valley, most extensively during the Fraser (late Wisconsin) Glaciation. Catastrophic failure of the Pend Oreille lobe of ice that ponded glacial Lake Missoula released immense that floods excavated the great coulees in the Channeled Scabland and deposited enormous volumes of gravel in low areas like Quincy and Pasco Basins, and also in great bars in the Scabland and in the Columbia and Snake River valleys.

The number of Lake Missoula floods through eastern Washington is unknown. J Harlen Bretz in his early (1923-1932) papers argued for a single great flood, but later (1956-1969) inferred many floods, most of them late Wisconsin in age. Baker (1973), however, inferred that most of the late Wisconsin deposits in the Channeled Scabland resulted from a single great flood, but allowed, as did Bretz and others (1956) and Bretz (1969), that the Columbia Valley conveyed catastrophic floods both before and after the last Scabland flooding. In the Columbia Valley, however, I reduce the required number of late Wisconsin floods by at least two. The current trend in central Washington is thus towards Bretz' early perception of a great late Wisconsin flood, which I designate with Bretz' early name: Spokane Flood.

The age of the Spokane Flood is in debate. Through broad interregional correlation, Richmond and others (1965) inferred the last great flooding of the Scabland to have been during the "early Pinedale", which all recent students of the Scabland have taken to mean 18,000 years ago or earlier. In the northwestern glaciated ("Great Bend") segment of the Columbia Valley, however, ice-rafted erratics and upvalley-dipping crossbeds in gravel reveal a down-Columbia flood as deep as 1400 ft, a depth that can only be identified with Bretz' Spokane Flood (Waitt, 1972a, 1972b). The flood clearly predates the eruption of Glacier Peak (12,000 to 12,750) years BP); but, prevailing opinion to the contrary, postdates the maximum stand of the ice sheet (ca. 14,000 BP). This thesis not only advocates the relative youth of the Spokane Flood, but it contradicts the traditional view that it was the blockage of the Columbia Valley by the Okanogan lobe that caused Lake Missoula floodwater to overflow across the Scabland (e.g., Bretz, 1932, 1969; Baker, 1973).

The evidence of 1972 was from only a few briefly studied localities. In 1976-1977 I mapped ice-rafted erratics, giant current dunes, enormous expansion and eddy bars of gravel derived upvalley, and bedload-transported boulders as large as 12 m--evidence indicating that the Spokane Flood flowed 1000 ft deep down the Entiat-Vantage segment of the Columbia (Waitt, 1977). On the Quincy-Wenatchee leg of the field trip, which shows some of this new evidence, I argue the case that the Spokane Flood occurred 13,000 to 13,500 years ago and that it flowed down the Columbia Valley unobstructed by an Okanogan Lobe.

Quaternary deposits and landforms in the Wenatchee-Rock Island Dam segment of the Columbia Valley testify to several other extraordinary events: damming of the river by landslide, damming by a pre-Spokane catastrophic-flood bar that emanated from Moses Coulee, ponding of the Columbia and some of its tributaties by Spokane Flood bars, and evidently erosion and deposition by relatively small catastrophic floods. These and other events, still imperfectly understood, are relatively dated by the relation of their effects to deposits and landforms of the Spokane Flood.

ROAD LOG--QUINCY TO WENATCHEE

mileage

0.0 Intersection of Washington Hwys 28 and 281 in Quincy, Washington. Take Hwy 28 westward, toward Wenatchee .

1.2 Ridge on skyline to the west (ahead) is the Wenatchee Mountains, the grandest of the anticlines in central Washington that warp the Columbia River Basalt Group. The ridge, over a mile above the eastern rim of Quincy Basin, is the fundamental structure that in late Miocene time evidently diverted the Columbia River from the basalt-margin position that the river still follows north of Wenatchee, to its course across the basalt in southern Washington.

2.5 Begin descent into Crater Coulee, the northernmost of three channels wherethrough Spokane Floodwater escaped Quincy Basin westward into the Columbia (Fig. 1).

3.1 Cross Crater Coulee. On right is a lake-filled depression scoured into basalt, evidently by Spokane Floodwater escaping Quincy Basin. To the southeast (left) the coulee merges with the floor of Quincy Basin. In excavations for irrigation canals of the Columbia Basin Project, George Neff (oral commun., 1976; see also Bretz, 1969, p. 529, and Baker, 1973, p. 8-9) discovered two superposed fans of basaltic gravel that distend basinward from the head of the coulee and from the head of the Potholes cataract farther south. The gravel in both units fines, and crossbeds dip, southeastwardly--indicating two episodes of flooding <u>into</u> Quincy Basin via Crater Coulee and Potholes Cataract.

From Neff's descriptions of the degree of calcification of the upper unit (thin coatings on stones; no plates) it seems to me that the upper basaltic gravel in western Quincy Basin is no more weathered than flood gravel in Columbia Valley and in the Scabland. Whereas previous workers (Bretz and others, 1956; Bretz, 1969; Baker 1973) attributed the upper gravel to a pre-Spokane flood, I infer that it was the initial surge of the Spokane Flood. Spokane Floodwater from Quincy Basin indubitably discharged down the coulee toward the Columbia; yet first it surged into Quincy Basin <u>up</u> Crater Coulee.

The flow of floodwater in western Quincy may have been reversed by rapid excavation of the upper Grand Coulee. Were the upper coulee completed by headward retreat of a great cataract (Bretz, 1932) <u>during</u> the Spokane Flood, discharge into Quincy Basin would have abruptly and dramatically increased--enough so to reverse eastward inflow to westward outflow.

4.8 Crest of Babcock Ridge. The ridge was above the ≃1400 ft limit of Spokane Floodwater, and thus obstructed floodwater entering Quincy Basin from, and escaping the basin to, the Columbia.

6.4 Enter lower Lynch Coulee. Floodwater escaping Quincy Basin down Crater Coulee descended Lynch Coulee to the Columbia.

6.9 Park on shoulder at end of white rail, on eastern side of Lynch Coulee.
STOP 1: On the western wall of the coulee about 100 ft upvalley from the culvert beneath the highway are two bodies of gravel. The lower pebble gravel, which contains about 2 percent of rounded nonbasaltic stones of Columbia provenance, has foreset bedding dipping up Lynch Coulee. The upper cobble gravel, consisting entirely of angular clasts up to 0.8 m of basalt and of sedimentary interbeds, has foreset beds dipping downcoulee. This exposure shows that floodwater first surged upcoulee from the Columbia, but later delivered floodwater downcoulee to the Columbia. There is no evidence of weathering at the top of the lower gravel, suggesting that both units are similar in age, if not contemporaneous. The lower unit evidently is continuous with the flood bar in Columbia Valley at Stop 2. Both units probably derived from the Spokane Flood, which arrived here first via the Columbia, later via Quincy Basin.

7.5 Turn left onto Crescent Bar road.

8.4 Turn left into gravel pit.
STOP 2: Pit exposes small-pebble gravel with foreset beds that dip northward, from Columbia Valley. The gravel contains about 4 percent rounded, nonbasaltic stones of diverse lithologies of up-Columbia provenance. This is the the top of a generally fining-upward deposit 300 ft thick with northeast-dipping foresets and of up-Columbia provenance throughout. The gravel coarsens downvalley and at lower altitudes to a large-pebble gravel; it fines upvalley to a coarse sand. Despite the up-Columbia provenance of its stones, this gravel records an upvalley flow. I interpret this deposit as the result of a huge oval counterclockwise eddy that formed in this northern alcove when the main flood current flowed several hundred feet deep downvalley over West Bar (across the river).

The gravel is overlain by 2 m of thin-bedded granule gravel, coarse sand, and laminated fine sand and silt indicating temporary slackwater deposition, perhaps in the lake hydraulically ponded behind Wallula Gap. Near the base of the finer unit are three discontinuous thin layers of tephra, that are common in sediment of this type elsewhere in south-central Washington and which have been attributed to Mount St. Helens Set S tephra (Mullineaux and others, 1977). Dated at Mount St Helens at 13,000 BP, this tephra perhaps also dates the Spokane Flood. Insofar as the hydraulic pond necessarily was short-lived (one week?), the presence of a single layer of tephra is extraordinary. The presence of three tephra layers raises the interesting speculaton that the immediate transfer of 5 x 10^{15} kg of Spokane Floodwater to central Washington triggered the 13,000 BP eruption of Mount St. Helens.

Across the river is West Bar, whose giant asymmetric transverse dunes in cobble gravel indicate downvalley flow of floodwater. Were the dunes of West Bar shaped by the Spokane Flood, it flowed downvalley, not upvalley as as traditional theory requires.

The low-altitude bar riverward of the dune-marked surface of West Bar is sparsely littered with large boulders and has a moat along its inner margin. This and analogous features elsewhere in the valley might be taken as evidence of a late flood down the valley. Because the Spokane Flood swept down the Columbia, however, its entire waning flow also coursed the valley. Here as elsewhere it is difficult to distinguish the effects of a discrete late flood from the effects of the waning flow of the Spokane Flood.

Return to Highway 28.

9.2 Intersection of Hwy 28, turn left and continue westward.

9.7 The road descending to the left is on the original grade of James J. Hill's Great Northern Railway, pushed through central Washington in summer and autumn of 1892.

10.3 Coarse sand in roadcuts is the upvalley-fining tail of the gravel unit seen at Stop 2. Crossbeds in this sand dip upvalley.

10.5 Cuts along the Burlington Northern tracks and along the original Great Northern grade show that the sand unit extends at least 1 mi farther upvalley. On the right, the westward-accreting sand delta obstructed the tributary and now keeps the stream to the western side of its valley.

12.3 Highway descends to the upper surface of a huge bar that spilled from Moses Coulee into Columbia Valley during a pre-Spokane Flood.

13.5 The cliff to the east (right) shows north-dipping foreset beds in basaltic palagonite. This is one of the classic localities where R. E Fuller argued his case for aqueous chilling of flows within the Columbia River Basalt Group.

14.0 Descend to the lower surface of the Moses Coulee bar. Bretz (1930, 1969), Bretz and others (1956), and Hanson (1970) inferred that the bar was wholly the result of a flood out of Moses Coulee that thence surged upvalley toward Wenatchee and downvalley toward Pasco Basin. Indeed the basaltic composition of the gravel indicates a Moses Coulee, not Columbia, provenance. The summit of the bar (ahead), which stands in the middle of the Columbia Valley, is almost at the same 960 ft altitude as the upper surface of the bar whence we are now descending, and probably is close to the original surface of the bar built by the flood out of Moses Coulee. The depositional surface that descends gradually downvalley from the summit to the lower surface of the bar evidently is a fan from a huge flood--the Spokane Flood--that swept down the Columbia sometime after the Moses Coulee flood.

15.8 Cross Moses Coulee Creek. Most of the coulee floor is outwash that grades from the moraines in the upper part of the coulee.

16.4 Excellent view to the right up lower Moses Coulee, showing magnificently floodwater-truncated spurs and hanging tributaries. We are now traveling on an original surface of the bar that is but slightly modified by later events.

17.2 Pull to right shoulder.
STOP 3 (in bus): We have descended to a surface distinctly below the original surface of the bar, which is the near-horizontal surface at the top of the low scarp on the left. Crossbeds in railroad cuts near the river show that indeed the earlier flood down Moses Coulee surged up this segment of the Columbia. The surface on which we are now parked, however, is embellished with giant transverse dunes whose lee slopes evidently face downvalley. I attribute the erosion of the original bar and the giant current dunes to the Spokane Flood.

From the dune area ahead a depositional surface descends through the flood-eroded moat against the valley wall to the right, and thence distends as a fan into and up Moses Coulee. The deposit fines from cobble gravel in the dune area to granule gravel at the toe of the fan in lower Moses Coulee, indicating that the last great flood to have swept this bar flowed continuously down the Columbia and up Moses Coulee.

18.0 Giant current dunes, most of them irregularly shaped. Aerial photographs show that those most resembling transverse current dunes have asymmetric cross profiles with the steeper slopes facing downvalley.

18.8 Cuts through the giant current dunes reveal cobble gravel, whose basaltic composition led previous workers to suppose that all of the bar resulted from the Moses Coulee flood. The Spokane Flood, apparently contributing little or no new material to the bar, merely reworked gravel deposited by the earlier Moses Coulee flood.

19.2 Flat surface in reentrant atop bar is underlain by several meters of thinly bedded silt, sand, and rare granule gravel. This deposit indicates that an episode of ponding ended or followed the sweep of the Spokane Flood.

19.4 Surface of the Rock Island bar across the river is conspicuosly ornamented with giant transverse current dunes normal to the trend of the valley and with steeper slopes facing downvalley. Unlike the surface of the Moses Coulee bar, the gravel atop the Rock Island bar includes stones from the upper Columbia.

20.0 Large boulders of locally derived basalt litter the riverward slope of the Rock Island bar. These are bedload, gravel, not ice-rafted stones.

20.5 Rock Island Dam was the earliest of the great concrete impediments to the river. Around the nearly drowned islands above the dam (formed by the basal Columbia River Basalt Group dipping beneath the river bed) were one of the worst (best?) rapids on the Columbia. The upriver-bound Astorian Northwester, and Hudson's Bay fur traders portaged here. Steamboats on the upper Columbia at the turn of the century offered service only above these rapids. Two steamers made unscheduled stops on the rapids in 1905-1906, lending credence to later arguments favoring a dam and lock at the site. The project eventually was completed in 1933--without the lock.

21.0 Pull to right shoulder
<u>STOP 4</u> (in bus): Exposure across river shows 37 m of gently upvalley-dipping basaltic small-pebble to granule gravel, overlain by 14 m of thinly bedded silt, in turn overlain by 4 to 8 m of boulder gravel of diverse lithology and sporting the giant current dunes. The lower gravel is the toe of the great fan built upvalley by the Moses Coulee flood, a fan that evidently dammed the Columbia Valley. The overlying silt is sediment that accumulated in the lake behind that dam--perhaps the same lake evinced by rhythmites in lower Wenatchee Valley (Swauk Pass - Waterville log, mileage 31.3). The capping gravel records the downvalley sweep of the Spokane Flood. Whereas the largest clast in the lower gravel is about 15 cm, boulders in the upper gravel are as large as 1.5 m.

22.7 View ahead is of the downvalley end of the huge flood bar viewed from north of Wenatchee yesterday. (Swauk Pass - Waterville log, mileage 35.8). The summit of the bar is 750 ft above the natural grade of the Columbia. Ahead and to the left is the Great Northern Railway bridge completed in 1893, when it was considered one of the finest cantilever bridges in the country.

24.5 Across the river is an enormous landslide derived largely from the cliffs of basalt above. Blocks of basalt in and north (this side) of the Columbia indicate that the landslide may have blocked the Columbia River. This is the slide alluded to in the Swauk Pass - Waterville log (Stop 1) that may have been responsible for an episode of physical ponding represented by silt bodies in the Wenatchee Valley near Dryden.

26.0 Blocks of basalt on the northern (near) side of the river perhaps are part of the huge landslide, whose toe is much eroded by floodwater.

26.6 The surface of bar across river is embellished with giant current dunes whose lee slopes face downvalley. As at West Bar, the rippled bar is truncated riverward by a scarp overlooking a low-altitude bar lacking dunes. The lower bar is littered with boulders of Swakane Biotite Gneiss as large as 2.5 m. The two surfaces are analogous to those at West Bar; and it is equally unclear here whether the lower surfaces (or both surfaces?) resulted from the waning flow of the Spokane Flood or from a discrete, later, smaller catastrophic flood.

Both surfaces are developed on the eroded toe of the great landslide, indicating that the landslide predates the flood(s).

28.4 Turn right onto South Nile Avenue.

28.5 At stop sign continue straight ahead and up winding road.

28.8 Stop at upper of two pits, 0.1 mi beyond the bend in road at the ditch crossing.

STOP 5: Gravel pit exposes 60 ft of foreset-bedded cobble gravel, mostly rounded stones of diverse lithologies. Stones in this gravel can be traced to bedrock sources in such upvalley Columbia tributaries as the Wenatchee and Methow valleys. Downriver the Columbia flows entirely in the Columbia River Basalt Group, obviously an impossible source of these mixed lithologies. Scattered throughout the depth of this exposure are boulders of Swakane Biotite Gneiss and of hornblende quartz diorite up to 1.5 m in intermediate diameter. The pit reveals two sets of crossbeds, the upper about 40 ft high. The crossbeds dip southeastwardly and downvalley. The large crossbeds and the boulders derived from upvalley indicate that this sequence was deposited rapidly by a flood moving down the Columbia valley. A light brown pedogenic oxidation extends only 1 m or less below the surface; nor does the soil here or elsewhere on the bar display a pedogenic B or platy calcic horizon. This deposit is late Wisconsin in age.

The view across the valley shows the huge landslide that underlies flood-deposited bars. Unweathered angular, apparently ice-rafted erratics on this landslide as high as 800 ft above the river evidently were borne by the flood that deposited the bedload gravel exposed in this gravel pit. The erratics further indicate the preflood age of the landslide.

Most of the ice-rafted boulders are light-colored megacrystic (K-feldspar) granite that have not been previously tracked to a known bedrock source. The Okanogan lobe of Cordilleran ice has long been suspected of generating late flood down the Columbia (Waters, 1933), but drift from that lobe on Waterville Pleateau does not contain this granite. Although that drift contains many non-basaltic lithologies that should have been ice-rafted had the Okanogan lobe generated the flood, those lithologies are not among the ice-rafted stones at high altitude in the Wenatchee area.

The unweathered, angular megacrystic granite boulders that occur 1000 ft above the Columbia River near Wenatchee occur as an inconspicuous minor constituent of the pebble fraction of Columbia River gravel; they are identical to most of the erratic boulders I have sampled in the southwestern part of Quincy Basin--boulders that traditionally have been attributed to ice-rafting by the Spokane Flood; they are also identical to angular, evidently ice-rafted boulders at the head of the Scabland on the northern rim of the Columbia Plateau west of Spokane; they occur as bedload gravel along the path of the flood northeast of Spokane; and they occur in drift and in bedrock north, west, and southwest of Lake Pend Oreille. There is no question that the great flood down this segment of the Columbia emanated from glacial Lake Missoula.

Although the boulders in Wenatchee and in Quincy Basin have traveled over 200 mi from their source, most show no evidence of abrasion; many are unmodified joint blocks. Clearly they were floated to their resting places encased in ice. That the boulders near Wenatchee occur to a higher altitude (1590 ft) than those in Quincy Basin (1385 ft) independently reveals the same pattern of flooding as indicated by the bedload gravel: the Spokane Flood flowed down the Entiat-Vantage segment of the Columbia .

At the mouth of Stemilt Creek is a conspicuous fan-terrace of basaltic gravel derived from Stemilt Creek. The surface of the terrace, whose riverward edge is over 300 ft above the Columbia, is unmodified by floods. This and other tributary-mouth fan-terraces in this segment of the Columbia indicate a significant episode of ponding after the sweep of the Spokane Flood. The enigmatic terraces of late Wisconsin mainstream gravel (and bedded silt?) in the lower Wenatchee Valley (Swauk Pass - Waterville log, mileages 23.3 to 34.8) may also be related to this interval of ponding. There is no apparent nonflood cause for ponding in the Columbia of sufficient duration to have caused as much aggradation as at the mouth of Stemilt Creek. The suggestion is that at least one of the flood bars, probably including the one we are now standing on, blocked the river at the conclusion of of the Spokane Flood. The general lack of lake sediment at low altitudes and the presence of bars ornamented with giant current dunes below the altitude of the Stemilt fan-terrace suggest that such low-altitude flood deposits as at West Bar and across the river at Malaga resulted from a late, small catastrophic flood that postdated the Spokane Flood.

Continue on South Nile Avenue.

28.9 Uppermost gravel pit shows only 0.8 m of pedogenic oxidation and no argillic B or platey calcic horizon. Boulders in this pit are as large as 1.5 m. Top of exposure is 450 ft above the river. This is clearly a youthful flood deposit.

29.1 Turn right onto 8th Avenue SE. Roller-coaster road is obliquely across giant current dunes that are thickly mantled with loess.

30.1 Turn left onto S. Union Avenue. Road crosses giant current dunes obliquely.

30.9 Turn left onto 2nd Ave. SE.

31.0 Crest of giant transverse current dune.

31.05 STOP 6 (in bus): Trough between dunes. The steeper face of the dune ahead slopes 15^{o}; the gentler slope of the dune behind is 4^{o}. The lee slopes of these giant current dunes face southeast and downvalley, nearly parallel to the large crosbeds exposed in the gravel pit at Stop 5. This locality if 650 ft above the Columbia; to the southeast this deposit of bedload gravel rises gradually to 750 ft above the river. This huge bar of nearly unweathered (unsoiled?) gravel, whose internal structure and surface morphology each indicate southeast-flowing floodwater, give evidence of a huge late Wisconsin flood down the Columbia River valley. The only known late Wisconsin flood of sufficient depth to have effected this deposit is the Spokane Flood that swept the Channeled Scabland. Evidence of this same flood is found at least as far upvalley as the confluence of the Methow River, in the glaciated segment of valley. The Spokane Flood therefore swept down the formerly glaciated segment of valley sometime after 14,000 years BP, when the ice sheet reached its terminal position athwart the Columbia .

31.1 Crest of giant current dune. Dunes are thus spaced approximately 0.1 mi. The mean spacing for the field is 215 m, which is 1.5 times the maximum spacing reported by Baker (1973) for the Scabland current dunes.

31.3 Turn right onto South Roland Avenue.

31.5 Turn left onto Grant Road. Next 0.8 mi is across obsure giant current dunes.

31.7 On the right skyline the Columbia River Basalt Group forms the prominent escarpment, below which an ancient landslide complex derived from the basalt is thickly mantled with loess. On this deposit unweathered ice-rafted angular boulders of megacrystic granite occur to altitude 1590 ft, indicating that the surface of the flood responsible for the dunes on this bar was 300 ft above the maximum altitude of the bar, and over 1000 ft deep along the main channel of the Columbia--almost 1.5 times the maximum depth of flooding (at Dry Falls) in the Scabland.

32.5 Begin descent of slope that leads upward from the Columbia. This entire slope from 200 to 500 ft above the river is dimpled with giant current dunes formed by floodwater that ascended this slope southeastwardly. Unlike the long widely spaced transverse dunes at the top of this bar (mileage 31.0), those on this slope are short, are more closely spaced, and are cuspate in plan.

32.8 Exposure to the right shows unweathered pebble gravel of diverse lithologies composing the dune. The dunes are mantled with about 1.5 m of loess that displays but a weakly developed soil.

34.6 Turn right at light onto N. Main Street (no sign). Follow to end of road.

35.7 Intersection of Washington Hwy 28. Turn left and pull to right lane.

36.2 Just beyond old bridge pull off on right shoulder.
STOP 7: Completed in 1908, this was the first highway bridge across the Columbia River in the United States. In addition to wagons, it carried the first water for irrigation east of the river. It was replaced in 1950 by the highway bridge one-half mi to the south, but still carries an irrigation pipe.

Large boulders occur up to at least 150 ft above river level. Most of them are of Swakane Biotite Gneiss, which crops out in the constricted Rocky Reach segment 5 to 10 mi upvalley (Swauk Pass - Waterville log, mileage 42.6). At least 15 boulders in this field have intermediate diameters exceeding 5 m; the largest boulder, overlooking the river 0.1 mi below the bridge, is 15 x 10 x >7 m--as large as or larger than the largest boulders reported from the Channeled Scabland. The rounded boulders of hornblende quartz diorite, which are up to 2 m in intermediate diameter, derived from near Entiat, 17 mi upvalley. An exposure of upturned Eocene strata at the base of the riverward scarp clearly indicates that all of the Swakane Biotite Gneiss at this site indeed is boulders. Because the boulders in this field are but mildly weathered, and because glaciers in Columbia Valley terminated upvalley of the upvalley limit of Swakane Biotite Gneiss, these boulders could not have been carried by ice. Clearly they are the bedload deposit of a great flood.

Continue south on Hwy 28.

36.3 Bear right, staying on Hwy 28 to Quincy.

36.5 Underpass beneath the 1950 bridge.

36.6 Boulders in cloverleaf and extending beyond sight to the south are continuation of the same boulder field as at Stop 7. Largest boulder riverward of Eddie May's Inn is an angular block of Swakane Biotite Gneiss with an intermediate diameter of 5.5 m.

Pull to far left lane.

36.9 At stoplight turn left toward Pangborn Field.

37.0 Turn left onto N. Main Street (again); follow to Hwy 28.

37.4 View ahead of Eagle Rock and diamicton-capped summit, discussed in the Swauk Pass - Waterville log.

38.1 Intersection Washington Hwy 28. Turn right.

39.2 Ahead and to the right is the 95 ft boulder of basalt discussed at mileage 35.8 on the Swauk Pass - Waterville log. It perhaps was ice rafted. Terrace behind boulder is capped with 2 m of caliche, and therefore seems to be much older than the boulder. The gravel of the terrace, which displays tall downvalley-dipping forsets, is the only known representative in this segment of the Columbia of the "older flood deposits" of Table 1.

41.4 Intersection of U.S. Hwy 2. Turn left, toward Seattle.

END OF LOG.

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