Evidence for dozens of stupendous floods from Glacial Lake Missoula in eastern Washington, Idaho, and Montana

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LOCATION AND ACCESS

Burlingame Canyon (Fig. 1). Walla Walla valley, southeast Washington about 2.5 mi (4 km) south of Lowden. Lat. 46°01′ N.; Long. 118°36′ W. SW¼SW¼Sec.5,T.6N.,R.34E. (SW¼ of Lowden, Washington 7½-minute Quadrangle). Drive on U.S. 12 to Lowden, 11 mi (17.7 km) west from Walla Walla, 18 mi (29 km) east from Wallula Junction at U.S. 395. From Lowden, drive south for 0.25 mi (0.4 km) to intersection; turn south (right) on road to Gardena, and drive south another 2.4 mi (3.9 km) to house on right just beyond crossing of irrigation ditch. Burlingame 'canyon' is another 0.1 mi (0.16 km) along road and 200 ft (60 m) west of road. (Please do not try to park or walk in the clear, vaguely fenced area between road and head of canyon; this is man-made in-ground nesting for pollinating bees.)

PLEASE OBTAIN PERMISSION FROM DITCHMASTER at house on west side of road just south of irrigation ditch. Burlingame 'canyon' is on private land; the area is hazardous to the unwary, for vertical 100-ft-high (30 m) walls are unprotected at top by fence and are formed in collapsible silt: BE CAREFUL. Access is a slope at head (northeast end) of canyon.

Manila Creek, Sanpoil valley (Fig. 1). Section located in Manila Creek valley, western tributary of lower Sanpoil River (arm of Lake Franklin D. Roosevelt behind Grand Coulee Dam), north-central Washington. NE¼SW¼Sec.18,T.29N.,R.33E. (near southwest corner of USGS Keller 15-minute Quadrangle). On Washington 21, drive about 4.8 mi (7.7 km) north from ferry landing or Lake FDR or 5.5 mi (8.8 km) south from town of Keller to intersection of *old* Manila Creek Road (not new road, which joins Washington 21 about 0.3 mi (0.5 km) farther north). Turn west on old Manila Creek Road and drive about 1 mi (1.6 km) to prominent tall exposure on conspicuously bedded deposits on north (right) side of road (Arrieta Locality; see Fig. 4). Park here; higher parts of stratigraphic section are exposed 0.2 mi (0.3 km) up road (Switchback Locality, Fig. 4).

SIGNIFICANCE OF SITES

Glacial Lake Missoula, Montana, was dammed by the Cordilleran ice sheet during each of several Pleistocene glaciations, most recently 15,500 to 13,000 yr B.P. during the late Wisconsin. The lake, whose volume was as much as 600 mi^3 (2,500 km^3), discharged through the ice dam as stupendous floods, which carved the Channeled Scabland of Washington and followed the Columbia River valley west to the Pacific Ocean (Fig. 1). Between 1923 and 1932, J Harlen Bretz published a series of imaginative papers on the Channeled Scabland that describe large-scale erosional and depositional landforms wholly alien to rivers of ordinary discharge. Bretz's unorthodox hypothesis of gigantic floods through Washington seemed outrageous to many and was contested for decades (e.g., Flint, 1938). But at length, after unarguable field evidence—such as giant current dunes—became known and the source of water identified, stupendous flood became an acceptable explanation (Bretz and others, 1956). Later the idea received quantitative legitimacy (Baker, 1973), and the colossal scale of landforms was made plain by space-age imagery (Baker and Nummedal, 1978).

Rhythmically bedded deposits in southern Washington have been variously attributed to: (1) fluctuations within ordinary lacustrine and fluvial environments (Flint, 1938; Lupher, 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); and (3) several dozen floods, each of which deposited one graded bed (Waitt, 1980, 1985). 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.

Varved lake sediment separates successive flood-laid beds at many localities in northern Washington. The numbers of varves indicate durations of 6 decades to a few years—generally becoming fewer upsection—between successive floods (Waitt, 1984, 1985; Atwater, 1984, 1986). The bottom sediment of glacial Lake Missoula is also varved; it constitutes dozens of fining-upward sequences, each the record of a gradually deepening then swiftly emptying lake (Chambers, 1971; Waitt, 1980). Figure 2 shows the inferred relation of Lake Missoula's bottom deposits to the interbedded lake and catastrophic-flood deposits in northern Idaho and Washington and to the flood-laid beds in southern Washington. The behavior of repeated discharge every few decades or years suggests that glacial Lake Missoula emptied due to the hydraulic instability that causes glacier-outburst floods (jökulhlaups) from present-day glaciers in Iceland and elsewhere (Waitt, 1985).

The Lake Missoula floods swept some 500 mi (800 km) from the ice dam to the sea; the lake itself was 186 mi (300 km) long (Fig. 1). No one locality gives all the needed data to prove the floods were numerous. The sites below are among the most informative of hundreds scattered about a vast area between western Montana and southern Washington.

This guide contains brief descriptions of four sites in the area of the Cordilleran Section and two sites in the area of the Rocky Mountain Section that have been more completely described in publication. Each of these gives different information, though three are more important than others. The essence of the data and its interpretation can be had from the sections at Burlingame

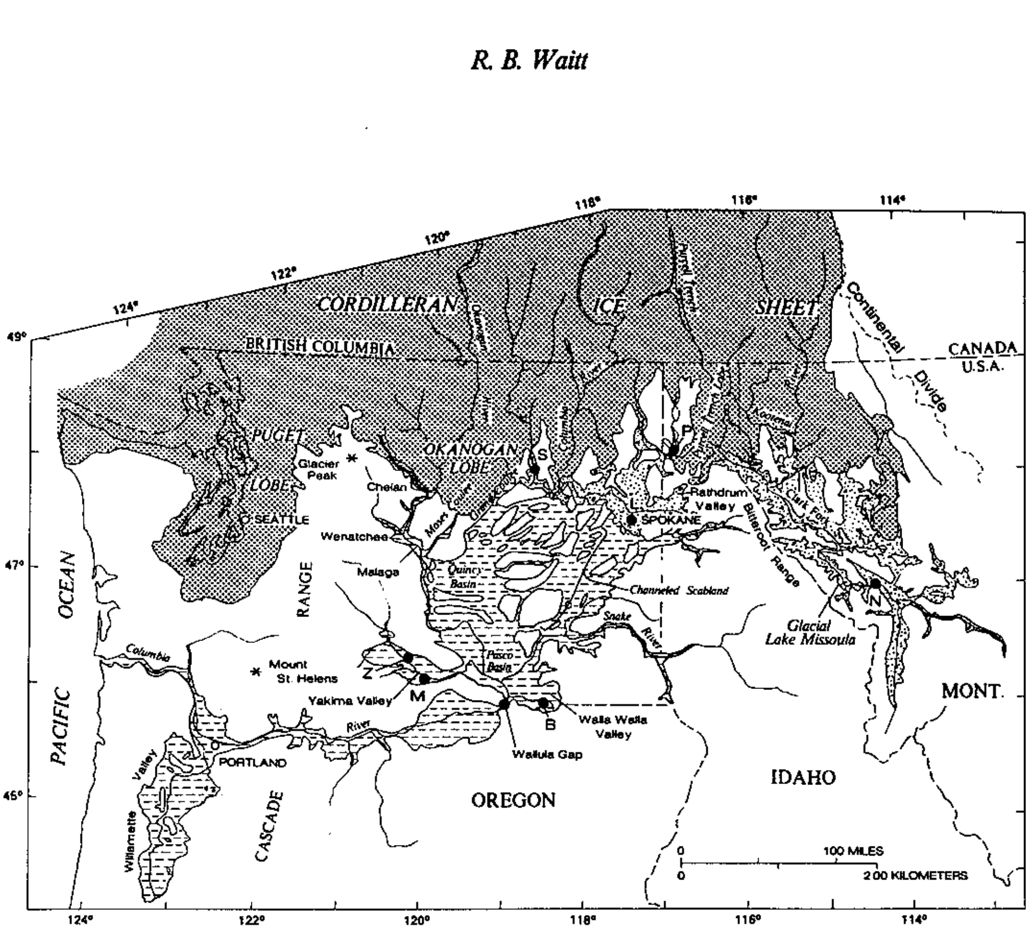

Figure 1. Map of Columbia River valley and tributaries. Irregular small-dot pattern shows maximum area of glacial Lake Missoula east of Purcell Trench ice lobe and maximum extent of glacial Lake Columbia east of Okanogan lobe. Dashed-lined pattern shows area that, in addition to these lakes, was swept by the Missoula floods. Late Wisconsin Cordilleran ice sheet margin (heavy-dot pattern) is from Waitt and Thorson (1983, Fig. 3-1). Large dots indicate sites of bedded flood sediment mentioned in text or figures: B, Burlingame canyon; L, Latah Creek; M, Mabton; N, Ninemile Creek; P, Priest valley; S, Sanpoil valley; Z, Zillah. From Waitt (1985, fig. 1).

Canyon (southern Washington), Manila Creek (Sanpoil Valley, northern Washington), and Ninemile Creek (northwestern Montana; Fig. 1).

SITE INFORMATION

Burlingame Canyon. (Waitt, 1980, 1985). Burlingame 'canyon', cut in the 1930s by wastewater from the nearby irrigation ditch, exposes southern Washington's most complete stratigraphic section of slackwater deposits of the late Wisconsin floods from Lake Missoula. Burlingame canyon is the keystone exposure from which the one-graded-bed-per-flood hypothesis was erected (Waitt, 1980). (But to the contrary, these same beds have been used to advocate that rhythmic deposits in southern Washington are deposits of one or a few pulsating floods [Bjornstad, 1980].) The canyons exposes a rhythmic stratigraphic section of 39 normally graded beds. Most beds have an upward sequence of sedimentary structures—conspicuous plane laminae, to ripple-drift laminae, to drapes, to obscure plane laminae, to ripple-drift laminae, to drapes, to obscure plane laminae or massive—crudely comparable to that of distal turbidites (Fig. Sparse crystalline, quartzite, and metasedimentary-rock errat show that the depositing water invaded from the Columbia Ri valley, for the Walla Walla valley is formed entirely within Columbia River Basalt Group; ripple-drift laminae in rhythmites indicate that paleocurrents generally flowed eastw (*up*valley).

The visitor to Burlingame canyon may debate whet many successive beds were deposited by fluctuating currents d ing one flood (Bjornstad's view) or whether instead each b represents a separate flood (Waitt's view). If on the one hand many rhythmites accumulated during one flood, certain con tions would have controlled sedimentation and the character the deposits: the water would have remained ponded as much 650 ft (200 m) deep above the top of exposure, and the accun lating sediment would have had to remain loose and saturated on the other hand terrestrial environments intervened for deca between successive floods, other dominating conditions wo have influenced the character of deposits: the sediment wo have become dewatered, and animals would have repopula

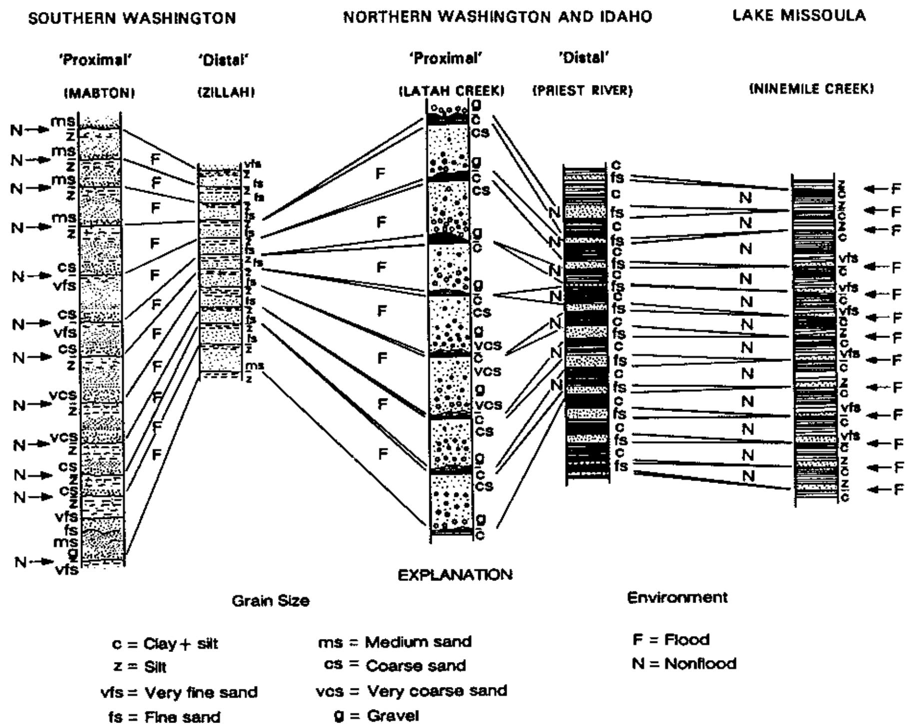

Figure 2. Inferred relations between rhythmites in southern Washington, northern Washington and Idaho, and western Montana (Lake Missoula). From Waitt (1985, Fig. 17). See Figure 1 for section locations.

the area. Much of the diagnostic evidence lies at 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 an erosional process of some sort interrupted the accumulation of flood sediment. One conspicuous channel exposed near the canyon bottom 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 overlies the eleventh rhythmite below top of section (Fig. 3). This characteristic ash couplet is identified as "set S" from Mount St. Helens, dated at about 13,000 yr B.P. (Mullineaux and others, 1978; Waitt, 1980). Both ash layers are structureless and nearly uncontaminated. Is this possible had the ash settled through deep, turbid water during a flood episode? Or does it instead suggest that the ash settled in a terrestrial interflood environment?

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 sediments had dewatered and become coherent before they were reworked by a succeeding current into a new bed.

Rodent burrows filled with reworked flood-laid sediment may be found throughout the entire 100 ft (30 m) of section. Because rodents burrow less than 6 ft (2 m) below the ground surface, the filled burrows imply that rodents repopulated the surface numerous times during the accumulation of this 100 ft (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. Thus if any one horizon—such as that containing the ash couplet—demands a terrestrial environment, then all other nearly identical horizons in the sequence suggest, if not demand, a similar origin. But it is difficult to *prove* a terrestrial episode at the top of each and every rhythmite.

A general upsection thinning and fining of rhythmites is apparent, especially in the upper third of the section. This regional characteristic is attributed to the ice dam becoming thinner, and therefore glacial Lake Missoula and floods therefrom becoming smaller, during deglaciation.

The bases of the upper 10 or so beds are relatively fine. These beds are similar to those at Zillah used as examples of 'distal' flood beds on Figure 2.

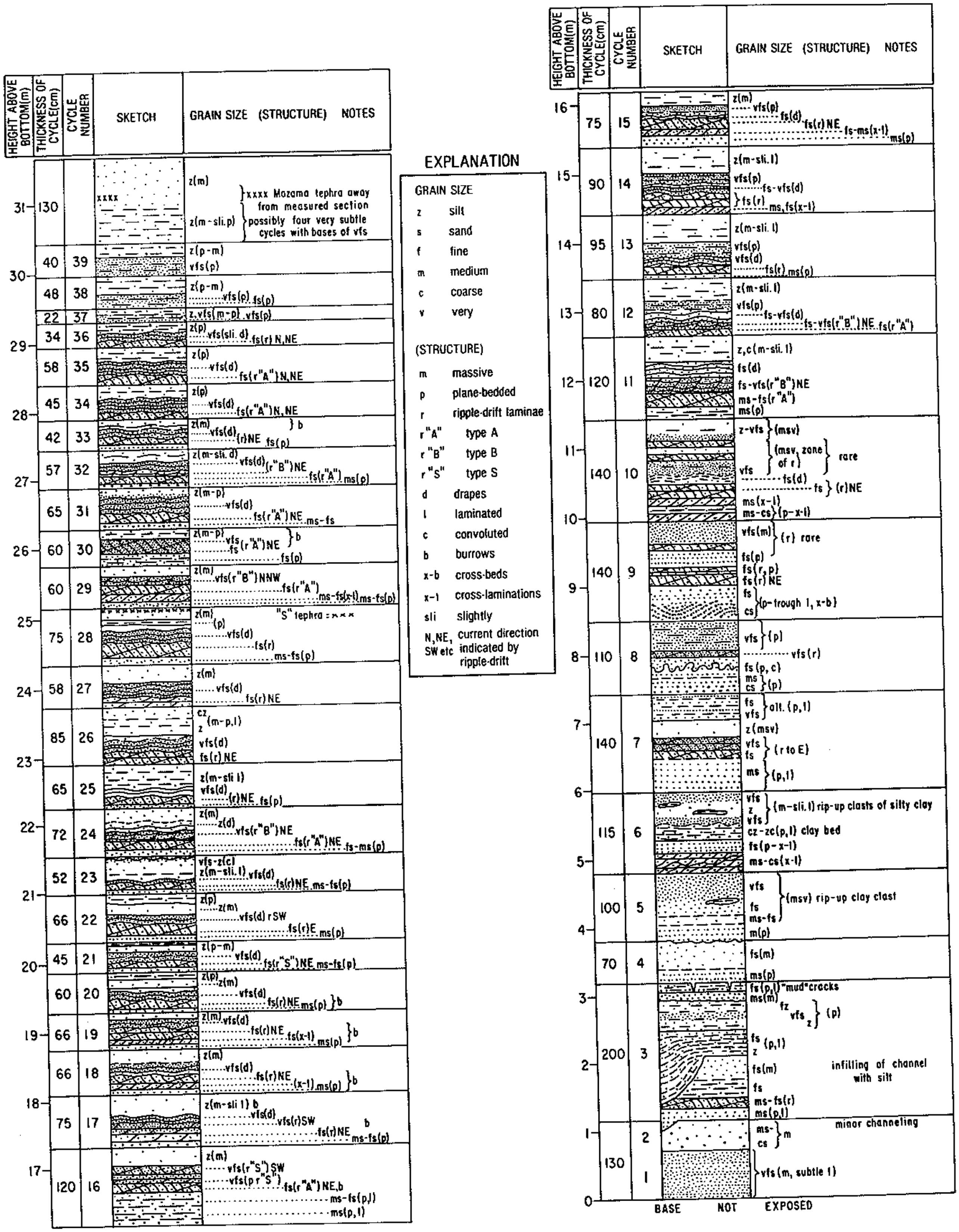

Figure 3. Measured section of 39 rhythmites counted in Burlingame canyon. From Waitt (1980, Fig. 5). See Figure 1 for section locations.

The 100-ft (30-m) section of rhythmic graded beds is capped by about 3 ft (1 m) of loess. The loess is 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 yr B.P. (Bacon, 1983).

Mabton. (Waitt, 1980, 1985). Section located in the lower Yakima valley, south-central Washington. NW¼NW¼Sec.31, T.9N.,R.23E. and adjacent NE¼NE¼Sec.36,R.22E. (near northwest corner of USGS Prosser 15-minute Quadrangle); about 1 mi (1.6 km) north of Mabton, Washington, along main road between Mabton and Sunnyside. Conspicuous exposure is continuous along bluffs defining south side of Yakima River valley for 300 ft (90 m) on both sides of the road. West of road please obtain permission from landowner (through gate and up driveway to top of bluff).

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) coarse bedload deposit of locally derived basalt forms base of many rhythmites, especially those low in section; (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 rhythmite capped by the prominent ash couplet; (5) Dunes at the base of several rhythmites consist half 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; and (6) shells from the base of second rhythmite below the ash couplet give radiocarbon ages of 14,060 ± 450 yr B.P. (USGS-684) and 13,130 ± 350 yr B.P. (W-2983).

Manila Creek (Sanpoil valley). (Atwater, 1986). The composite section in Manila Creek contains about 2,000 to 2,500 varves. These varves are punctuated by 89 graded coarser beds, each attributed to a Missoula flood (Atwater, 1986). The flood beds become generally thinner and finer while varves become thicker toward the top of the composite section (Fig. 4)—to the point that flood-laid beds become difficult to distinguish. Wood fragments from a compound varve in midsection yield a radiocarbon age of 14,490 ± 290 yr B.P. (USGS-1860). Interpretation is that glacial Lake Columbia dammed by the Okanogan lobe (Fig. 1) existed for 2 to 3 millennia and was invaded by scores of separate floods from glacial Lake Missoula. This composite section with 89 inferred flood beds is the most complete in the region.

Varves between flood beds low in the composite section generally number 30 to 50; they decrease to only 1 or 2 in upper part of section; an estimated 200 to 400 varves overlie the highest recognized flood-laid bed. These varve counts confirm what can be qualitatively inferred from the upsection thinning and fining of flood beds at this and other sections: the late Wisconsin glacial lake Missoula floods became smaller and more frequent as the controlling ice dam (Purcell Trench lobe) thinned during deglaciation. From this and other evidence in the Sanpoil valley, Atwater infers relative fluctuations of several lobes of the Cordilleran ice sheet (Figs. 1, 4).

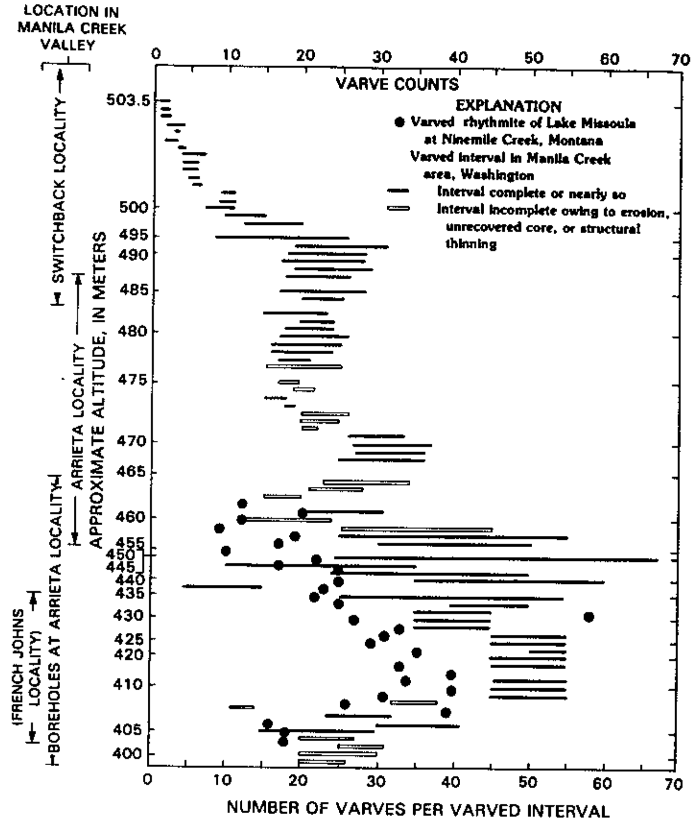

Figure 4. Data on varves interbedded between dozens of flood-laid beds at composite section at Manila Creek, tributary of Sanpoil valley, northern Washington (from Atwater, 1986, Fig. 17).

Latah (Hangman) Creek. (Waitt, 1984, 1985). Section located in Latah (Hangman) Creek valley in northeastern Washington about 5 mi (8 km) south of Spokane, Washington, in SW¼SE¼Sec.31,T.25N.,R.43E. (USGS Spokane SW 7½-minute Quadrangle). From intersection of I-90 and U.S. 195 just west of Spokane, proceed south on U.S. 195 for 2.5 mi (4 km). Site is the tall, conspicuous, south-facing exposure 300 to 1,200 ft (90 to 365 m) east of highway. Park on shoulder and well off pavement of *north*bound lanes of highway. Traffic is fast and sometimes heavy: BE CAREFUL. From highway, walk through grassland and ford the creek.

Lower Latah Creek valley is part of the principal floodway from glacial Lake Missoula to the Channeled Scabland; it is far from the ice-sheet margins that dammed glacial Lake Columbia, an arm of which flooded this area (Fig. 1). Compared with the

Priest valley section, the flood beds here are therefore coarse and thick ('proximal' on Fig. 2) and varves are thin and fine.

The lower two-thirds of section below a conspicuous gravel-lined disconformity is a succession of 16 gravel-sand beds 3 to 10 ft (1 to 3 m) thick punctuated by inconspicuous silty-clay varved beds only 0.4 to 8 in (1 to 20 cm) thick. The relatively coherent varved beds form benches; yet they are so thin and locally discontinuous that the visitor may have to search to find them. The flood beds give evidence of high-energy emplacement: they are coarse and carry rare clasts as large as 3 ft (1 m); foreset beds dip at low angle (<10°) and upvalley; some beds are channeled into underlying beds; some beds were invasive into and beneath varved beds; some varved beds are locally lifted and dismembered, and fragments of dismembered varved beds occur as rip-up clasts in flood beds. As many as 51 varves have been counted in an individual bed; but because the varved beds are eroded, such figures must be taken to represent a minimum number of years between floods.

Above the gravel-lined disconformity is a succession of about 12 lenticular beds, also with low-angle upvalley–dipping foreset beds, but without separating varve beds. These beds are inferred to be flood beds shed up the valley by giant floods after this arm of the glacial lake had been filled with sediment or after the lake had subsided to below the level of this section.

Priest valley, Idaho. (Waitt, 1984, 1985). Section located in Priest River valley in northwestern Idaho 'panhandle' in SW¼SE¼Sec.1,T.56N.,R.5E. (USGS Priest River, Idaho 7½-minute Quadrangle). From town of Priest River on U.S. 2, turn north on Idaho 57 toward Priest Lake. Proceed 3.5 mi (5.6 km) to intersection of Peninsula Road. Turn sharp right onto Peninsula Road and continue 0.2 mi (0.3 km) nearly to top of long hill. Exposure is conspicuous on east (right) side of road.

This site is situated behind a moraine and former ice tongue that blocked the valley mouth and dammed a lake in Priest valley. Only the largest Missoula floods were able to overtop the moraine to reach this site. This site, being close to an ice margin, has relatively thick varves; the floods having been chann roundaboutly, the flood beds are relatively thin and fine ('di on Fig. 2).

The exposure shows about 50 ft (15 m) of silt-to-clay va lake beds punctuated by beds of sand with upvalley–dire ripple-drift laminae (Fig. 2). Each of the sand beds, which a to 5 grain-size (ϕ) intervals coarser than the varved beds, sents a vigorous current invading the valley. Most of the beds show an upward succession of plane beds to ripple dri drapes to plane beds as at Burlingame canyon. The varves tween flood beds number 20 to 50: the period between fl was 2 to 5 decades.

Ninemile Creek, Montana. (Chambers, 1971, appe III; Chambers, 1984; Waitt, 1980, 1985; Waitt and Tho 1983). Located in northwestern Montana in lower Nine Creek near its confluence with the Clark Fork River. Cons ous tall roadcut on both sides of I-90 just east of bridge Clark Fork River 6 mi (9.6 km) west of Frenchtown, Mon which is about 15 mi (24 km) west of Missoula (south cent USGS Alberton, Montana 15-minute Quadrangle). Park fa pavement and BE CAREFUL of fast traffic including trucks.

This long exposure shows a succession of nearly 40 gr beds. Each bed grades up from cross-laminated sand o through silty compound thick varves, to simple clayey varves. This regular motif evidently represents a gradually ening lake whose shoreline progressively migrated north and isolated the main source of sediment (ice-sheet margin) fro center of the lake. The abrupt upward transition from thin c varves to cross-laminated sand represents an abrupt change a deep to a shallow lake. This section therefore records abo gradual deepenings and swift lowerings of glacial Lake Mis There being no notable unconformities or soils within the se this history must all be late Wisconsin. The upsection thi and fining of rhythmites is probably a result of northward r of the Cordilleran ice sheet, which thus gradually remove main sediment source during deglaciation.

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