TENS OF SUCCESSIVE, COLOSSAL MISSOULA FLOODS

AT NORTH AND EAST MARGINS OF CHANNELED SCABLAND

By

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ABSTRACT

In deposits of Pleistocene glacial lakes in northern Idaho and Washington, beds comprising 20 to 55 varves (average = 35-40) separate each successive graded gravel or sand bed that was swiftly emplaced by a catastrophic flood from glacial Lake Missoula. The floodlaid beds are similar to rhythmic successions of 40 or more graded beds in backflooded tributaries of the lower Columbia River. This new field evidence corroborates a controversial hypothesis that the great Pleistocene floods from glacial Lake Missoula were 40 or more colossal, separate jökulhlaups, and refutes the conventional notion that any two successive graded beds were deposited by one flood.

The only outlet of the 2000-km^3 glacial Lake Missoula was through its great ice dam. Calculations show that each time the lake rose to about 600 m deep, it made the glacier buoyant and engendered a catastrophic discharge along the glacier bed (a jökulhlaup). A reconstructed water budget suggests that after a complete draining, the lake refilled in 3 to 6 decades; thus the hydrostatic prerequisites for a jökulhlaup were reëstablished dozens of times during the late-Wisconsin episode of lake damming.

Various intercalated tephra layers, radiocarbon dates, varve successions, and the Bonneville flood deposits in the region suggest that late-Wisconsin glacial Lake Missoula existed for about 2 millennia within the period 15,000 to 12,700(?) yr ago. Varve beds indicate that the mean period between Missoula floods was about 4 decades, but became shorter during the last several floods. Between 20 and 30 of the Missoula jökulhlaups occurred after the single great flood from Lake Bonneville, which according to ^{14}C dating in the Bonneville basin by W. E. Scott and associates and by D. R. Currey occurred some time between 15,000 and 14,000 yr ago.

INTRODUCTION

The notion of even one great 'Spokane flood' through the Channeled Scabland (Bretz, 1923, 1928, 1929, 1959) provoked vehement controversy. Despite Bretz's unambiguous field evidence, it took decades for geologists generally to accept his hypothesis of catastrophic flooding from Pleistocene glacial Lake Missoula. I recently introduced a new development: the late-Wisconsin Missoula floods were several tens of separate jökulhlaups from a glacial lake that self-dumped periodically--a lake that drained each time the rising lake made the ice dam hydrostatically unstable (Waitt, 1980b). This hypothesis has kindled new debate: Did the great late-Wisconsin Missoula floods number only two or a few, controlled by climatic fluctuations of the ice dam (the conventional view)? Or were there instead 40 or more colossal jökulhlaups from a lake that self-dumped periodically because of hydrostatic instability of the ice dam, regardless of climate (my view)?

The 1983 Rocky Mountains Friends of the Pleistocene Field Conference examines evidence that strongly supports the 40-floods hypothesis and gives constraints on the timing and periodicity of floods. On Day 1 (26 August) Brian F. Atwater shows a remarkably diverse suite of exposures in a single backflooded valley (the Sanpoil), including both 'proximal' and 'distal' backflood beds intercalated with varve beds. On Day 2 (27 August), we traverse the north and east perimeter of J H. Bretz's famed Channeled

Scabland. We examine a section of 'proximal' flood beds intercalated with varve beds near Spokane, and examine some 'distal' rhythmites (successive graded beds) near Lewiston that are similar to those on which the 40-floods hypothesis was initially argued. We see the stratigraphic relation of the Missoula jökulhlaups to the great flood from Lake Bonneville, and otherwise see some evidence by which the age and periodicity of Missoula floods are constrained.

Most of the discussion of this guidebook is abstracted from two published papers (Waitt, 1980b; Waitt and Thorson, 1983) and from three papers currently in production (Waitt, 1984, 1984?; Waitt and others, 1984?). Participants may also purchase, at a $2 bargain, a copy of an earlier FOTP guidebook of the westernmost part of the Missoula floodways (Waitt, 1980a).

JÖKULHLAUPS DEBATE

Behind valley constrictions that sharply reduced the erosiveness of prodigious floods from the Columbia River valley, the lower Yakima and other tributary valleys (Fig. 1) (Waitt, 1980b, Figs. 1, 2) were settling basins for the suspended load carried by successive backfloods. These valleys preserve nearly complete rhythmic sequences of graded sand and silt beds by which discrete pulses of flood sedimentation can be readily counted (Waitt, 1980b, Figs. 4-7). Having found evidence of subaerial environments atop many such successive rhythmites, I have argued that each major graded bed is the deposit of a separate flood. Therefore during the late-Wisconsin Glaciation alone there had been about 40 huge, catastrophic discharges of glacial Lake Missoula, each separated by years or decades of 'normal' terrestrial environments (Waitt, 1980b).

Other investigators have inferred that the slackwater sediment was deposited by only a few floods (Richmond and others, 1965; Bretz, 1969; Baker and Nummedal, 1978; Mullineaux and others, 1978). A much-reiterated (but apparently ungrounded) explanation of the commonly rhythmic bedding of slackwater deposits is that some sort of hydraulic surges occurred repeatedly <u>during</u> a flood (Baker, 1973; Webster and others, 1976; Patton and others, 1979; Bjornstad, 1980, 1982; Bunker, 1982).

NEW EVIDENCE FOR TENS OF FLOODS

Several independent lines of evidence--intercalated ash, shell dunes, loess, dispersed skeletons, etc.--have been presented in the field (Waitt, 1980a, 1982) and in a published report (Waitt, 1980b) to show that in southern Washington and in the Lake Missoula basin terrestrial or lacustrine environments persisted for years or decades between successive floods. Although this hypothesis has not been generally accepted, new unambiguously supporting evidence continues to be discovered, such as from <u>Stop 2.1</u> of this guidebook and from B. F. Atwater's independent work in the Sanpoil valley (guidebook for Day 1 of this FOTP conference).

Rip-up Clasts

Angular clasts of rhythmite-top silt or of inter-rhythmite lacustrine sediment are enclosed within the coarse bases of floodlaid rhythmite at several localities, including beds at Latah Creek (Stop 2.1) and in the Sanpoil valley (Atwater's Stop 1.3). These beds that are in places invasive into the varved beds or otherwise show other evidence of having been violently emplaced. The rip-up clasts imply that the rhythmite tops and inter-rhythmite sediment had become coherent before the next flood. Had several rhythmites been deposited by one brief flood, the silty tops could not have become dewatered and coherent enough to be eroded and redeposited as angular blocks during that flood. Thus the clasts are evidence of lengthy interruptions between episodes of flood sedimentation. Because the clasts occur in successive floodlaid beds, there must have been many lengthy interruptions during accumulation of the superposed beds.

Varved Lacustrine Beds Between Floodlaid Beds (Stop 2.1)

Several ice-dammed Pleistocene lakes in northern Idaho and northeastern Washington (Figs. 1, 2, 3) (Waitt and Thorson, 1983) became periodically engorged by sediment from the Lake Missoula floods. Floodlaid beds of gravel or sand alternate with beds of lacustrine mud, each mud bed comprising 20 to 55 silt-to-clay varves. Gravel and sand beds with upvalley-directed paleocurrent indicators at Latah Creek valley (Fig. 3) (Stop 2.1) resemble those of 'proximal' rhythmites in southern Washington (Fig. 4); a succession of graded sand and silt beds with upvalley paleocurrent indicators in the Priest River valley (Waitt, 1984) closely resemble those of 'distal' rhythmites in southern Washington (Fig. 4) (Waitt, 1980b, 1984?).

In lower Latah Creek valley, a Spokane River tributary south of Spokane and downcurrent of the main Rathdrum-valley conduit of Lake Missoula floodwater into Washington (Figs. 2, 3), 16 thick graded beds of gravel and sand with upvalley-dipping foreset beds are each topped by a thin bed of plane-laminated clay. The clay beds each consist as many as 51 laterally persistent clayey varves of regular thickness. The dominating sand-and-gravel beds, 1 to 4 m thick, are some 8 to 12 grain-size (0) units coarser than the clay beds that they regularly interrupt. Latah Creek valley is carved in basalt, but the sand-and-gravel beds with upvalley-dipping foreset beds consist partly of exotic clasts of nonbasaltic crystalline rock like those flooring the main Rathdrum valley floodway.

The gravel-and-sand beds apparently are bedload material carried by floods down Rathdrum valley that were voluminous enough to sweep violently and deeply out of the Spokane valley and up Latah Creek valley. Some varve beds overlie a poorly sorted bed rich in rip-up clasts that was injected as a sill extending from the overlying floodlaid bed. The large boulders, the injected beds, and disruption of clay beds show that the gravel beds were violently floodlaid, not outwash deltas--especially not in this area tens of kilometers beyond the well-defined late Wisconsin ice limits (Figs. 2, 3) (Waitt and Thorson, 1983; Waitt and others, 1984?). The unweathered, uncemented state of the gravel and the absence of weathering and soil horizons within these beds indicate a late Wisconsin age.

The Latah Creek section shows that the usual sedimentation in this varve-producing late Wisconsin glacial lake was quiet and distant from sediment sources, but that it was suddenly interrupted at least 16 times by the violent influx of coarse flood sediment. After each catastrophic interlude, quiet glaciolacustrine sedimentation resumed, accumulating thin and clayey varves for decades.

The alternation of beds comprising tens of clayey varves with backflood sand or gravel beds closely similar to backflood rhythmites in southern Washington (Waitt, 1980b) is unambiguous evidence that decades indeed intervened between successive colossal floods. The only water body voluminous and high enough to vigorously flood through the several glacial lakes in northern Idaho and Washington was glacial Lake Missoula. These stratigraphic sections therefore reveal the behavior of Lake Missoula.

Regional Relations

Figure 5 illustrates inferred relations among the graded rhythmites in southern Washington, the graded rhythmites in northern Washington and Idaho intercalated with clayey varves, and the unique varved rhythmites of glacial Lake Missoula in Montana. Nonflood times recorded by the varved Lake Missoula beds are also recorded by the varves of the separate glacial lakes in northern Washington and Idaho; but these times are represented only by hiatuses or minor eolian beds in southern Washington. Conversely, the brief floods recorded by graded beds in northern and southern Washington are represented only by obscure hiatuses between the Lake Missoula rhythmites.

HYDROLOGY OF GLACIAL LAKE MISSOULA AND OF ICE DAM

Water Budget of Glacial Lake Missoula

An interflood period of 2 to 6 decades is suggested by the maximum number of varves interbedded between successive backflood beds at several localities in northern Washington and Idaho (Waitt, 1984, 1984?; Atwater, 1984?). Similar interflood periods are recorded by varves within bottom-sediment rhythmites of the Missoula basin, where the average number of varves per lake cycle is 27, the range 9 to 58 (Chambers, 1971).

Water was contributed to glacial Lake Missoula mainly by meltwater from the vast Cordilleran icesheet on the north (Fig. 1) (Waitt and Thorson, 1983). Any estimate of the water budget for the Clark Fork drainage during the glacial maximum therefore must add the discharge of the Kootenai River on the north to that of the Clark Fork. The present combined discharge of 15.76 km^3/yr would have filled the maximum 2130 km^3 glacial Lake Missoula in 135 yr.

For the Great Salt Lake basin 700 km south of glacial Lake Missoula, McCoy (1981) calculated the rate of inflow required to continuously enlarge and maintain Pleistocene Lake Bonneville between about 26,000 and 14,000 yr ago. Net inflow to the lake (inflow minus evaporation) was accordingly 3.5 to 5.5 times present net inflow. A discharge of only 2.5 times the present Clark Fork and Kootenai discharges would fill glacial Lake Missoula from empty to <u>maximum</u> volume in only 54 years. A lake of less-than-maximum volume would have filled faster, say in 3 to 5 decades. The average 4-decade cyclicity counted from varves within or between successive rhythmites thus accords with the duration deduced from the lake's water budget (Waitt, 1984?).

Hydrology of Ice Dam

The cause of periodic, catastrophic discharges from glacial Lake Missoula was the same hydrostatic imbalance that causes periodic floods from modern ice-dammed lakes. Glacial Lake Missoula had no outlet except through its great dam of ice. The greatest depth of glacial Lake Missoula against the ice dam was about nine-tenths the maximum thickness of the ice dam--the depth at which the lake ought to have hydrostatically destabilized the ice dam (Thorarinsson, 1939). Field relations thus broadly accord with the proposition that the ice dam failed hydrostatically.

Glacial dams of lakes that lack alternate spillways are inherently unstable; many modern such lakes dump catastrophically each time the impounded water rises deeply against its ice dam (Post and Mayo, 1971). There is neither field evidence nor deductive reason that the huge glacial Lake Missoula should have behaved radically different than small, modern, self-dumping ice-dammed lakes. The number of times Lake Missoula may have self dumped while the ice lay athwart the Clark Fork valley is limited mainly by the discharge of influent streams and by the volume of lakewater that must be replenished after a draining to restore the hydrostatic imbalance.

Water from the rising glacial Lake Missoula exploits the glacier <u>bed</u> (Shreve, 1972; Nye, 1976), because water is denser than ice. As the lake rises it incipiently raises the eastward edge of the dam, progressively narrowing the 'seal' formed by the grounded segment of the glacier. Once the lake rises roughly nine-tenths deep as the ice dam is thick, the glacier bed becomes buoyant, and water begins to flow from the lake and beneath the glacier. Once drainage begins, subglacial tunnels enlarge rapidly. The potential energy lost by the lake water is converted mainly to heat; heat is transfered from the flowing water to the walls of the tunnel. The subglacial tunnels thus enlarge swiftly and exponentially, engendering a jökulhlaup (Nye, 1976; Waitt, 1984?).

AGE AND CORRELATIONS

Relation to radiocarbon dates, ash layers, and Cordilleran icesheet

Glacial Lake Missoula could have existed only within the broad limits between preglacial ^{14}C dates as young as 17,200 yr B.P. and postglacial dates as old as 11,000 yr B.P. in British Columbia (Clague, 1980). If the Purcell Trench lobe took a millennium to advance from British Columbia to the Bitterroot Range and a millennium to retreat, Lake Missoula existed only for an interval between about 16,000 and 12,000 yr B.P. The total number of known varves within the 40 or so cycles of Lake Missoula bottom sediment or between the 40 or more beds laid by floods that invaded glacial Lake Columbia is 2000 or less. The later floods into southern Washington are constrained by an intercalated 13,000 yr B.P. Mount St. Helens tephra (Mullineaux and others, 1978), which underlies 11 flood rhythmites (Waitt, 1980). A radiocarbon date of 14,060 $\pm$ 450 yr B.P. (USGS-684) was obtained on shells 3 rhythmites below that topped by the ash at Mabton, southern Washington (Waitt, 1984?). The 12,000-13,000 yr B.P. Glacier Peak tephra-layer G postdates partial recession of the icesheet in Washington and Montana (Porter, 1978; Waitt and Thorson, 1983). All considered, these and several other limits on the icesheet and floods suggest that glacial Lake Missoula lasted only for about 2000 years within the period 15,000 to 12,800 ^{14}C yr B.P.

Relation to Bonneville flood

Near Lewiston, Idaho the Lake Missoula floods are stratigraphically related to the great Pleistocene flood from Lake Bonneville, Utah. It had been thought that the Bonneville flood occurred about 30,000 yr B.P. and that therefore it substantially predated all of the last-glacial Lake Missoula floods (Malde, 1968; Baker, 1973; Baker and Nummedal, 1978). But Scott and others (1982, Fig. 3) have established a new chronology for Lake Bonneville. These new stratigraphic and chronologic data show that the lake rose gradually between about 26,000 and 16,000 yr B.P., when is stabilized because of overflow northward into the Snake drainage across an alluvial deposit at Red Rock Pass. Some time between 15,000 and 14,000 yr B.P. a headward-propogating cut narrowed the overflow divide, eventually ending in a catastrophic discharge that dropped the lake surface 115 m from the 'Bonneville' to 'Provo' shoreline. Gilbert (1890) inferred that this lowering engendered a "debacle", and Malde (1968) showed that down the Port Neuf valley and Snake River Plain it indeed created scabland, boulder fields, great gravel bars, and other attributes of catastrophic flood. The Bonneville flood descended the lower Snake River canyon, near Lewiston sandwiching its deposits between those of the Missoula floods.

Bonneville-flood gravel

Slackwater-flood deposits exposed in the Snake River valley below Lewiston were laid by the Missoula floods backflowing <u>up</u> the Snake from the easternmost scabland channel (Bretz, 1929, 1969; Bretz and others, 1956). Bretz (1929, p. 423-424) also inferred that a great <u>gravel</u> bar blocking Tammany Creek, a Snake River tributary above Lewiston, was deposited by the Missoula backflood(s); but after Malde's (1968) report appeared, he became suspicious that this gravel may be of the Bonneville flood (Bretz, 1969, p. 531-532). Webster and others (1976) and Baker and Nummedal (1978) also suggested but did not prove that it was Bonneville-flood deposit.

At a downriver extension of Bretz's 'Tammany bar' (<u>Stop 2.3</u>), the deposit of pebble to boulder gravel of angular clasts consists about half of Columbia River Basalt clasts and half of diverse nonbaslatic rocks of upper Snake River provenance. The internal structure of the generally openwork gravel is successive tiers of long-sweeping foreset beds, each several meters thick, dipping universally <u>down</u> the Snake valley. Such deposits occur down the Snake valley to the Clearwater confluence, where a 12-m exposure of this gravel shows long, tall foresets dipping <u>down</u> the Snake and <u>up</u> the Clearwater. The depositing agent therefore was a flood down the Snake voluminous enough to backflood out of the capacious Snake valley and <u>up</u> an equally broad tributary valley, depositing bedload cobble gravel tens of meters above the valley floors. The depositing agent thus could have been no other than the Bonneville flood--which may have been more than half the volume of a maximal Missoula flood (Bretz, 1969).

Missoula-flood beds

Abruptly overlying the coarse mixed-lithology Bonneville-flood gravel are rhythmic beds each consisting of a basal coarse sand to granule gravel overlain by a graded sand-to-silt bed. The basal coarse facies consists entirely of angular fragments of locally derived basalt and has small forsets that dip up the Snake valley. These deposits are clearly of the Missoula backflood(s) as inferred by Bretz (1929); they must be contemporaneous with successions of very similar beds in other valleys tributary to the Columbia or marginal to the Channeled Scabland (Waitt, 1980b, 1984, 1984?). An apparently completely exposed succession in a gravel pit at 'Tammany bar' (Stop 2.3) consists of 12 or 13 relatively thick graded beds overlain by 8 thin ones, showing a general upsection thinning and fining of beds, similar to backflood-rhythmites in other parts of the region (Waitt, 1980b, Figs. 4, 5-7, 13).

Timing and Periodicity of Jökulhlaups

Of the 40 or more graded beds laid by flood in some valleys (Waitt, 1980b, Fig. 4), only 20 or 21 beds overlie the Bonneville-flood gravel at Lewiston. The 20 'missing' graded beds suggest that 10 to 20 Missoula backfloods predated the Bonneville flood. In the Lewiston area the Bonneville-flood gravel must have buried deposits of the early part of the Missoula-flood sequence. The 13,000 to 14,000 yr B.P. ^{14}C ages provided by the intercalated Mount St. Helens tephra and by shells from the upper-middle parts of flood-rhythmite sections in southern Washington (Waitt, 1980b, 1984?), accord with the age of 15,000-14,000 yr B.P. for the Bonneville flood (Scott and others, 1982), which evidently occurred relatively early during the succession of Missoula floods.

Several of the relatively small, last hlaups from Lake Missoula may have flowed only down the Columbia valley (and Grand Coulee?), avoiding the high-level eastern scabland channels that had earlier conveyed the largest floods directly to the Snake valley. Because of the very long distance of backflooding from Pasco basin to the Lewiston area (200 km), the last, small hlaups that deposited beds only at low altitudes off Pasco basin cannot be represented at the high-level Lewiston section. Of the late, small floods, 11 postdated the 13,000 yr B.P. Mount St. Helens 'set S' tephra at low-altitude rhythmite sections, yet only 4 of these are represented at slightly higher sections (Waitt, 1980b). If all 11 post-tephra floods are missing at Lewiston, the 20-21 beds there indicate that 20-21 floods occurred between 15,000-14,000 and about 13,000 yr B.P., thus indicating that the mean interflood period somewhere between 45 and 100 years.

As thus judged from stratigraphic sections that relate ^{14}C dates from Mount St. Helens, from Lake Bonneville, and from the Missoula-flood beds, the average period of the Missoula floods was somewhere between 45 and 100 years. This range is entirely compatible (1) with the period of 30-60 years counted from interflood varves at many northern locations and (2) with the period of 35-65 years suggested by a reconstructed water budget for glacial Lake Missoula (Waitt, 1984?).

ROADLOG FOR DAY 2 (Route shown on Figure 6)

MILEAGE	OBSERVATIONS
0.0	Restroom at National Park Service campground near Keller Ferry, south side of Columbia River. This crudely terracelike form at altitude 1310 ft is altitude of 'Great Terrace' at Chelan.
0.2	Turn right onto Wash. Hwy 21 south.
0.8	Start up through Nespelem terrace.
1.2	At bend in road, gravel and overlying sand have long foresets dipping southwestward, downvalley--probably floodlaid deposit. Crude scabland on opposite side of valley was eroded by floods taking straight course; scabland develops best on the more quarryable Columbia River Basalt (CRB).
1.3	Attain top of Nespelem terrace at about altitude 1560 ft, approximately the level of the Grand Coulee spillway at Coulee City.
2.4	Along back edge of Nespelem terrace. Flows of the Columbia River Basalt (CRB) are in situ on the left just above road level, yet the cliffs ahead show the contact between the crysatalline and CRB much higher. The CRB encroached over a mature erosion surface cut in crystalline rocks.
3.0	Leave Columbia valley and head up tributary dammed at level of Nespelem terrace.
4.0	Spur ahead shows about 4 faint strandlines, the highest about altitude 2000 ft. These represent higher levels of glacial Lake Columbia I. Borrow pit on right exposes lacustrine sand that accumulated in this lake.
4.3	Angular material in cuts on left is colluvium from basalt upslope.
4.8	At switchback begin climb up through CRB to top of Columbia "Plateau" (actually a plain).
5.6	Pillows at base of basalt flow on left.
6.1	Quarry on left shows lacustrine deposit (member of Latah Formation) overlain by basalt flow (member of CRB Group). Base of flow is 1-2 m of pillowed palagonite, indicating depth of the Miocene lake dammed by the preceding flow.

MILEAGE	OBSERVATIONS
6.8	Several pillow-palagonite zones in successive flows are each several meters thick. Therefore each successive flow dammed the local drainage.
7.4	Attain top of "plateau" at altitude 2680 ft. Rolling loess-covered topography is typical of tracts beyond the drift limit and above the level of catastrophic floods from glacial Lake Missoula. The white clasts are plowed-up calcrete from a long-developing soil. During emplacement of the basalt, the northern rim was relatively low; southward basining since then has made the northern rim a high part of the basalt surface. From here we descend southward an incised structural slope on the basalt, opposite to the original northward depositional slope. Exposures in the next 2.5 miles show basalt, its basal palagonite, and fluvial-lacustrine interbeds.
9.0	Canyon merges with loess-covered basalt.
13.7	Junction with Wash Hwy 174. Turn left. We have descended to altitude 2200 ft. This is the north edge of a flood-eroded scabland tract showing rock basins and scarped loess, markedly contrasting with the rolling loessial terrain to the north. Floods flowed westward through here, one of 10 simultaneously occupied scabland distributaries out of the Tedford area.
14.2	Junction with U.S Hwy 2. Turn left toward Spokane. Proceed toward Wilbur, opposite to direction of flood flow.
15.0	Wilbur.
16.6	Scabland including potholes on upper surface has relief of 10 m.
18.1	Climb onto loess-covered upland, above level of floods. Therefore maximum depth of flow through the scabland channel to the north was about 120 ft.
21.1	Return downslope to scabland again.
23.6	Creston. Scabland tract here is 20 mi wide, emanating from Columbia River valley about 6 mi to the north. There is a whole series of distributaries out of this tract; yet this entire tract was just one of several routes by which the great floods escaped the south rim of the Columbia valley. Flint (1937, Pl.5), who did not believe in Bretz's catastrophic flood, interpreted such gravelly areas that we cross between here and Spokane as being behind the last-glacial drift limit. The drift limit is in fact far to the north.
24.0	Surface here is at altitude 2480 ft; flood limit is about 2500 ft: hills to south protruded 200-350 ft through flood surface.

MILEAGE	OBSERVATIONS
25.0	Roadcuts expose poorly sorted basaltic gravel, and area is 'in wheat'. Scabland tracts thus are not entirely rocky wasteland, but include broad flat to undulating gravel surfaces. Only in places, particularly in distinct valleys, do flood-gravel deposits have the distinct form of bars first noted by Bretz. In the very broad scabland tracts, such as here, gravel is in the form of a discontinuous sheet of varying thickness.
25.5	Intersection of road to Kettle Falls. Stay on U.S. 2. Steep scarps to NE are carved by floods into loess overlying the basalt.
26.3	We have descended through the basalt carapace into underlying gneissic rock, illustrating the significant relief of the basal contact of the CRB. The floods have carved a scabland of basins and buttes with relief of 10-20 m, much like basalt scabland. This is deepest segment of scabland tract between Creston and Davenport.
26.7	Climb back up onto basalt caprock
27.0	Still below flood level. Cluster of granite clasts at fence on left is 1-2 m boulder that has been blasted apart. It is granodiorite, evidently ice rafted from Lake Pend Oreille area, Idaho by the great floods.
27.7	Another dip into inlier of crystalline rock beneath the basalt caprock.
28.6	Low-relief scabland, mainly erosional. Scattered basalt-gravel patches. For next several miles scabland has local relief of 2-10 m, including rock basins, buttes, and shallow anastomosing troughs trending generally S or SW.
37.7	We have gradually climbed almost up to flood limit, which is at base of scarp cut in 'island' of loess to the south. For next several miles we are on a generally basalt-gravel plain.
38.7	Stones culled from field are mainly of basalt, but there are also several exotic non-basalt clasts as well.
40.9	Climb up to flood limit at about 2500 ft, indicated by scarped loess hill. For next 3 mi we are in typical loess topography scarcely affected by the floods. Some flat channel forms, though, may have conveyed thin sheets of water essentially at flood limit.
44.3	Davenport. We have descended below flood limit again, indicated by gravel deposits shown in cuts on east side of town.

MILEAGE	OBSERVATIONS
44.8	Junction Wash. Hwy 25 north to Kettle Falls. Stay on U.S. 2.
45.0	Ascend across flood limit. Next 9 mi is in wheat-farmed loess topography wholly different than flood-swept scabland tracts.
53.9	Descend across flood limit and into scabland tract.
54.3	Floor of narrow scabland tract. Road south to Sprague. Poor farming conditions, entirely different than loessial upland area we have just crossed since Davenport.
57.0	Reardan. We are just below flood limit: west-trending scabland tract is on left, but uneroded loessial and basalt hills on right.
57.2	Intersection of Wash. Hwy 231 north to Springdale. Stay on U.S. 2.
58.5	After crossing weak scabland nearly at flood limit, we pass into loess-capped basalt upland for several miles.
63.3	Descend below flood limit, expressed by basalt-gravel deposits and flatter depositional surfaces than to the west. This is the western edge of the great Cheney-Palouse scabland tract, focus of the debate between Bretz (1923, 1928) and Flint (1938).
64.1	Cross railroad bridge. Bretz (1928, 1959) placed his ice limit just ahead, yet there is no moraine or any other basis for it.
65.6	Deep Creek. Sand on west side is probably floodlaid.
66.3	Attain low-relief surface underlain by basaltic gravel attributable to flood. Therefore Weis and Richmond (1965) moved the inferred glacial border northward from that of earlier workers (Flint, 1937; Bretz, 1928, 1959; Bretz and others, 1956)--whose limits we are now well behind.
68.5	Entrance to Fairchild AFB. The depositional plain continues. The plain is underlain by poorly sorted basaltic cobble gravel carrying rare boulders to 1.5 m or more in intermediate diameter. Several roadcuts and gravel pits in next 3 mi expose the gravel. Hummocks of the surface are depositional.
71.8	Basalt bedrock peeks through. Thus the surface is essentially unscabbed basalt with a skim of floodlaid gravel. None of these deposits is till, all are waterlaid.
74.5	We have passed into erosional scabland at only slightly lower altitude than the gravel plain. Still no basis for a glacial lobe here.

MILEAGE	OBSERVATIONS
75.0	Exit for Spokane airport.
76.2	Exit for Interstate Hwy 90 (I-90) west. Stay on US Hwy 2.
76.9	Merge with I-90 east. We are descending into valley of Spokane River, cut deeply into Columbia River Basalt.
78.0	Take Exit 279 to US Hwy 195 south.
78.3	On US 195 south. We are ascending Latah Creek valley, tributary to the Spokane valley. Valley is cut into the Miocene Columbia River Basalt and interbedded sandstone and mudstone of the Miocene Latah Formation. The valley is partly infilled with catastrophic-flood sediment.
80.5	Granule-gravel beds in cut on left dip upvalley, and were deposited by invading flood(s). Cobble-gravel bed at unconformity is deposit of Latah Creek in immediately postflood time.
81.1	At break in median strip at side road from right, U-turn onto northbound lanes of US 195. Pull to right shoulder and cross to median one vehicle at a time. BE CAREFUL: TRAFFIC IN BOTH DIRECTIONS IS USUALLY 55 MPH.
81.3	Park on right shoulder completely off pavement. Walk to creek and cross to north side. White layer near top of bluff on left is Mazama ash (6900 yr B.P.).

STOP 2-1 (Text pages 5-6)

Exposed in the tall streamcut here are 16 gravel-sand beds with upvalley-dipping foreset structure, each bed topped by a thin bed of varves. The gravel clasts are of diverse rock types besides the CRB in which Latah Creek is cut. I interpret each main gravel as the deposit of a separate flood, and each topping varved bed as the deposit of a lake that persisted for decades before the next flood. These beds are discussed further in text (p. 5-6).

This rhythmic sequence is cut by a disconformity lined by basaltic boulders, above which is interbedded gravel and sand also with upvalley-dipping foresets but evidently lacking the interrupting beds of varved clay. The clasts in these beds are mostly CRB. I infer this sequence to be the deposit of several later Missoula floods that swept into Latah Creek valley after the lake there (glacial Lake Spokane or Columbia) had lowered or drained.

This exposure has been independently examined by Kiver and Stradling (1982) and by Rigby (1982), with whose correlations and inferred mode of deposition I disagree:

(1) They infer that the beds below the unconformity relate to an inexplicable mid-Wisconsin episode of flooding; I instead infer these beds to be between 15,000 and 13,000 yr old.
(2) They infer that only the beds above the unconformity correlate with the rhythmic slackwater beds in southern Washington; I instead so correlate the beds beneath the unconformity as well as the beds above.
(3) They infer the graded beds below the unconformity to have been deposited by classic turbidity currents; I instead infer them to be the accumulation of colossal jökulhlaups that totally overwhelmed the topography by a high head of water flowing from high to low altitude. Quite unlike turbidity currents, the entire column of water was in violent motion downcurrent, impelled by a sloping water surface (see my discussion of this subject in southern Washington (Waitt, 1980b, p. 672-673).

MILEAGE	OBSERVATIONS
0.0	Pull back onto pavement, US Hwy 195 northbound.
0.7	At break in divider, U-turn onto southbound lanes. Here about 20 cars can line up in left-turn lane.
2.9	On left, basaltic gravel with upvalley-dipping foreset beds: a flood deposit.
3.7	Begin climb out of Latah Creek valley.
6.1	Attain canyon rim. This surface at altitude 2300-2400 ft is continuous with floodswept surface near Fairchild AFB. Thus floodwater ascending Latah Creek valley escaped southward at high level into the Channeled Scabland. Scabland is sparsely developed here, but it becomes more distinct downcurrent to the SSW.
6.7	Next 2 mi shows a series of cuts into CRB and interbedded Latah Formation.
8.7	Summit. We are still within limit of Bretz's 'Spangle lobe' of the icesheet--yet there is still no evidence for it! This surface at about altitude 2600 ft apparently was flooded, but is unglaciated.
9.7	We have gradually descended onto gravelly surface.

MILEAGE	OBSERVATIONS
10.4	Distinctly floodswept lower surface approaches from right. Topography remains nonerosional.
11.2	Closed depression, distinctive of scabland tract, which here is generally nonerosional.
13.1	Overpass over railroad. Scarps against loessial hills on left suggest limit of flooding, with unaltered loessial topography beyond.
13.8	Spangle. Begin climb above flood limit onto loessial upland. This is east margin of Cheney-Palouse tract. Width of this scabland tract is about 25 mi. During a maximum flood, the water was a continuous sheet perhaps 100 ft deep on the average. This tract is at same altitude as the 19-mi-wide scabland tract that we crossed between Creston and Davenport. One of Bretz's many early arguments for a catastrophic 'Spokane' flood was that both of these broad tracts were simultaneously discharging water overflowing from the Spokane-Columbia valley.
14.2	This flat-floored valley at Spangle was mapped by Bretz (1959) as floored by floodlaid sand and silt near upper limit of floodwater. Note the unaltered surrounding loessial hills.
15.5	Climb above flood limit onto hills of Palouse loess. We are in this topography for 10 miles.
25.2	Descend toward a narrow, easternmost scabland tract.
25.8	Meet floor of scabland.
26.2	Missoula floodwater followed scabland tract to right. We will ascend a backflooded tributary to Rosalia. This scabland path also emanates from Latah Creek valley; it joins the main Cheney-Palouse scabland tract about 16 sinuous mi to the SW.
28.0	Intersection of road to Rosalia. We stay on US Hwy 195 south and ascend above flood limit and back into loessial uplands. We see no further effects of the floods until we descend into the Snake River valley at Lewiston.
38.0	Here and for next 6 miles, local relief on the loess surface is about 200 ft, typical topography of the 'Palouse Hills'. The relief is partly due to the incised surface of the basalt over which it is laid. The 650-ft eminence to the east is Steptoe Butte, an inlier surrounded by basalt, illustrating the mature topography over which the basalt flows encroached in Miocene time. The loess is derived from two related sources: (1) mostly from Cordilleran-icesheet outwash in the Columbia River valley far to the west, and (2) from floodlaid deposits not far to the west.

MILEAGE	OBSERVATIONS
38.0 (cont.)	The moisture-retaining silt is important to the wheat farming. The region was formerly lush with grasses, on which the natives nourished and bred horses renowned throughout the 19th-century West. A Palouse horse = Appaloosa.
45.6	Steptoe.
52.7	Descend to Palouse River valley, through a section of Columbia River Basalt.
54.0	Junction of Wash. Hwy 26; stay on U.S. 195 south.
54.7	Junction Wash. Hwy 272 in Colfax; stay on 195
55.4	Begin climb up out of Palouse canyon through section of basalt.
57.7	Back into typical Palouse country.
67.9	Junction of Wash Hwy 270 to Pullman and Wash. State Univ; stay on U.S. 195.
70.4	Junction Wash. Hwy 27 to Pullman. Turn right, continue on U.S. 195 toward Lewiston.
83.2	Colton.
90.2	Intersection of U.S. Hwy 95 to Moscow.
90.5	Welcome to Idaho.
91.2	Merge with U.S. Hwy 95 south.
91.8	Turn right toward Scenic Overlook.
92.1	Turn right into Scenic Overlook.

STOP 2.2 (Text pages 8-9)

This is the 'Lewiston embayment' of the Columbia River Basalt plain (Camp and Hooper, 1981), where the Clearwater River from the east meets the Snake River from the south. Lewiston ID is east of the Snake, Clarkston WA is west. Lewis and Clark descended the Clearwater westbound in autumn 1805, and ascended it on return journey in spring 1806.

We are on the 'up' side of a great monoclinal flexure across which the surface of the Columbia River Basalt is thrown down about 2000 ft to the south. Note the plateaulike surface south of Lewiston, which corresponds stratigraphically to the uppermost basalt on north side of flexure (above level of Vista site). South-tilted basalt on flank of monocline can be seen both E & W of Vista dipping 10-20° southward. The Lewiston area actually is a W-plunging syncline: the basalt beds also slope northward from the Blue Mountains 30 km to the south, and dips gently westward along the valley of the Clearwater from the mountains to the east.

The Bonneville flood (Malde, 1968), which rapidly drew Lake Bonneville down by 375 ft from the 'Bonneville' to 'Provo' shorelines (Gilbert, 1890; Scott and others, 1982), descended the Snake valley from the south. From Lewiston the flood was channeled westward down the lower Snake valley; but as we shall see, it was voluminous enough also to backflood up the Clearwater.

The Missoula flood(s), on the other hand, backflooded up the lower Snake valley from Scabland embouchures far to the west (Bretz, 1929; Bretz and others, 1956). Bretz noted a great gravel bar obsrtucting the mouth of Tammany Creek, which enters the Snake 5 mi south of Lewiston. He initially inferred the gravel to be a deposit of a Scabland flood (1929), but he later (1969) suggested that it may be a deposit of the Bonneville flood. At Stop 2.3 at this bar we in fact will see the relative effects of the Bonneville and Missoula floods.

On the slope below us can be seen successive highways up the 'Lewiston grade', infamous to truckers. A steep road near tin shack to the west was a 19th-century grade. The numerous switchbacks below Vista, including unpaved abandoned segment just below, are of road built in 1918. This road was partly regraded in 1935, when Vista was put in. The long-sweeping curves and deep fills are of the modern highway, completed in 1977. We will forego adventure and return to this highway.

MILEAGE	OBSERVATIONS
0.0	Turn back uphill and return to modern highway.
0.4	U.S Hwy 95. Turn right toward Lewiston. We are at altitude about 2700 ft; at Lewiston we will be at a higher stratigraphic position but at altitude 900 ft. Next 5 mi is a series of cuts in Columbia River Basalt, in places folded and faulted, on the S-dipping monoclinal flank.
5.3	Here and next 1/2 mi are cuts in semiconsolidated gravel, the so-called "Clarkston gravels", overlying basalt. Basal unconformity is visible in one cut.
6.0	Take exit to U.S. Hwy 12 west.
6.7	Intersection; bear left, south; stay on U.S. 12 west.

MILEAGE	OBSERVATIONS
7.3	Center of bridge over Clearwater River. The Snake and Clearwater are ponded by Lower Granite dam on lower Snake. The water level is above the level of parts of Lewiston, which is defended against innundation by a dike system.
7.6	Continue on U.S. 12 west, around right curve.
7.85	At signal light, turn right, following U.S. 12 west.
9.5	At intersection do NOT follow U.S. 12; instead, continue straight, beneath bridge, toward Hells Gate State Park. Stay in right lane.
9.8	At intersection, turn right toward Hells Gate State Park. NOTE GRAVEL BEDS ON LEFT WHOSE TALL FORESETS DIP OUT OF THE UPPER SNAKE VALLEY AND UP THE CLEARWATER VALLEY.
11.3	Onramp to bridge. Continue straight beneath bridge.
13.1	Pass Hellsgate State Park on right and active gravel pit on left. Foreset beds in gravel dipping down the Snake valley are capped by rhythmic beds of sand and silt.
13.6	Turn left into gravel pit. Park in upper end. CAUTION: most of area is soft fill, easy to get stuck in.

STOP 2.3 (Text pages 8-9)

In 1979 during an overnight visit with J Harlen Bretz that I shall ever cherish, the old master, inquisitive to the end, puzzled over the field relations at his 'Tammany bar' near Lewiston. He lamented that he could never return to the field, but would I go there? He had aptly described field relations of waterlaid deposits in the Lewiston area (Bretz, 1929, p. 419-427, 505-509), which he imaginatively but correctly attributed to catastrophic flood rather than to ordinary river dynamics. In particular he attributed these deposits to the upvalley backrush of the 'Spokane flood', whose effects he was systematically cataloging throughout the region. But after Malde's (1968) report appeared and long after his last field visit in the late 1920s, Bretz (1969) reconsidered, suggesting that the gravel deposit of Tammany bar may be of the Bonneville flood.

Mixed-lithology, round-stone, openwork pebble to cobble gravel in the lower half of the exposure displays several tiers of universally downvalley-dipping foreset beds, apparently the same deposit as dips out of the Snake at Lewiston (Mileage 9.8). Bretz (1929) could not have seen such foresets this well exposed, or he would not have attributed this material to a Spokane-flood backrush up the Snake. The clast size, structure, and lithology of the cobble-gravel facies here and the great foresets in the same material at Lewiston more or less prove that this deposit is a product of the great flood from that Lake Bonneville swept down the Snake valley.

The Bonneville-flood gravel is overlain by 20-21 graded sand-to-silt beds, some having basaltic granule-gravel bases channeled into the underlying graded bed(s). Foresets in the basal gravel are upvalley, showing that the initial inrush was upvalley. If each bed represents a separate flood, at least 20 or 21 Missoula floods followed the Bonneville flood.

I did not find definitive evidence here for lengthy interludes between successive graded beds. But these beds are quite similar to rhythmic sequences elsewhere that show definite evidence that each bed is the deposit of a separate flood (e.g., Waitt, 1980b, Figs. 3-6; FOTP Stop 2-1; Atwater's FOTP stops on Day 1). Each graded bed here must also represent a separate Missoula backflood followed by decades of nonflood conditions.

An interesting phenomenon in these beds--characteristic also of backflood rhythmites in the Walla Walla and Tucannon valleys to the west--is that each of many Missoula-flood rhythmite has a set of downvalley-dipping foreset laminae overlying the basal upvalley-dipping foreset laminae. The implied sequence is always the same, never vice versa: upvalley-flowing current followed by downvalley-flowing current. I infer this very common sequence to record a single rise and fall of the water surface during each flood. Thus the initial upvalley-dipping foresets record the incoming and deepening backflood; the downvalley-dipping foresets record the subsequent downvalley draining as the flood subsides.

MILEAGE	OBSERVATIONS
0.0	Pull back onto road and head north.
2.0	Pass beneath bridge.
3.8	Turn left onto U.S. Hwy 12.
4.0	Continue straight onto U.S. 12 east.
5.7	Signal light. Turn left, following U.S. 12 east.
6.0	Signal light. Continue straight and bear left across bridge.
6.6	Signal light. Continue straight on U.S. 12. Follow U.S. Hwys 12 and 95 toward McCall Idaho.

END OF DAY 2. Bon voyage!

REFERENCES

Atwater, B. F., 1984?, Lake Missoula jökulhlaups in the Sanpoil arm of glacial Lake Columbia, northeastern Washington: (intended for GSA Geology [in review]).

Baker, V. R., 1973, Paleohydrology and sedimentology of Lake Missoula flooding in eastern Washington: Geological Society of America Special Paper 144, 79 p.

Baker, V. R. and Nummedal, D., 1978, The Channeled Scabland: National Aeronautics and Space Administration, Washington, D.C., 186 p.

Bjornstad, B. N., 1980, Sedimentology and depositional environment of the Touchet Beds, Walla Walla River basin, Washington: Document RHO-BWI-SA-44 Rockwell Hanford Operations, Richland, WA (also M. S. thesis, Eastern Washington University, Cheney).

Bjornstad, B. N., 1982, Catastrophic flood surging represented in the Touchet Beds of the Walla Walla valley, Washington: American Quaternary Association, 7th biennial conference, Program and Abstracts, p. 72.

Bretz, J H., 1923, The channeled scablands of the Columbia Plateau: Journal of Geology, v. 31, p. 617-649.

Bretz, J H., 1928, The Channeled Scabland of eastern Washington: Geographical Review, v. 18, p. 446-77.

Bretz, J H., 1929, Valley deposits immediately east of the channeled scabland of Washington: Journal of Geology, v. 37, p. 393-427, 505-541.

Bretz, J H., 1959, Washington's Channeled Scabland: Washington Division of Mines and Geology Bulletin 45.

Bretz, J H., 1969, The Lake Missoula floods and the Channeled Scabland: Journal of Geology, v. 77, p. 505-543.

Bretz, J H., Smith, H. T. U., and Neff, G. E., 1956, Channeled Scabland of Washington--new data and interpretations: Geological Society of America Bulletin, v. 67, p. 957-1049.

Bunker, R. C., 1982, Evidence of multiple late-Wisconsin floods from glacial Lake Missoula in Badger coulee, Washington: Quaternary Research, v. 18, p. 17-31.

Camp, V. E., and Hooper, P. R., 1981, Geologic studies of the Columbia Plateau: Part I. Late Cenozoic of the southeast part of the Columbia River basalt province: Geological Society of America Bulletin, Part I., v. 92, p. 659-668.

Chambers, R. L., 1971, Sedimentation in glacial Lake Missoula: M.S. thesis, University of Montana, Missoula.

Clague, J. J, 1980, Late Quaternary geology and geochronology of British Columbia: Part I. Radiocarbon dates: Geological Survey of Canada Paper 80-13.

Flint, R. F., 1937, Pleistocene drift border in eastern Washington: Geological Society of America Bulletin, v. 48, p. 203-232.

Flint, R. F., 1938, Origin of the Cheney-Palouse scabland tract, Washington: Geological Society of America Bulletin, v. 49, p. 461-524.

Gilbert, G. K., 1890, Lake Bonneville: U.S. Geological Survey Monograph 1, 438 p.

Kiver, E. P. and Stradling, D. F., 1982, Quaternary geology of the Spokane area: Tobacco Root Geological Society, Guidebook for 1980 field conference, p. 26-44.

Malde, H. E., 1968, The catastrophic late Pleistocene Bonneville flood in the Snake River Plain, Idaho: U.S. Geological Survey Professional Paper 596, 52 p.
McCoy, W. D., 1981, Quaternary aminostratigraphy of the Bonneville and Lahontan basins, western U.S., with paleoclimatic implications: Ph.D. thesis, University of Colorado.
Mullineaux, D. R., Wilcox, R. E., Ebaugh, W. F., Fryxell, R., and Rubin, M., 1978, Age of the last major scabland flood of the Columbia Plateau in eastern Washington: Quaternary Research, v. 10, p. 171-80.
Nye, J. F., 1976, Water flow in glaciers--jökulhlaups, tunnels and veins: Journal of Glaciology, v. 17, p. 181-207.
Patton, P. C., Baker, V. R., and Kochel, R. C., 1979, Slack-water deposits--a geomorphic technique for the interpretation of fluvial paleohydrology, in Adjustments of the fluvial system: Dubuque, Iowa, Kendall/Hunt, p. 225-253.
Porter, S. C., 1978, Glacier Peak tephra in the North Cascade Range, Washington: stratigraphy distribution, and relationship to late-glacial events: Quaternary Research, v. 10, p. 30-41.
Post, A. and Mayo, L. R., 1971, Glacier-dammed lakes and outburst floods in Alaska: U.S. Geological Survey, Hydrologic Investigations Atlas HA-455.
Richmond, G. M., Fryxell, R., Neff, G. E., and Weis, P. L., 1965, The Cordilleran ice sheet on the northern Rocky Mountains, in The Quaternary of the United States: Princeton University Press, p. 231-242.
Rigby, J. G., 1982, The sedimentology, mineralogy, and depositional environment of a sequence of Quaternary catastrophic flood-derived lacustrine turbidites near Spokane, Washington: M. S. thesis, University of Idaho, Moscow.
Scott, W. E., Shroba, R. R., and McCoy, W. D., 1982, Little Valley and Jordan Valley, Utah (modified from U.S. Geological Survey Open-File Report 82-845): Guidebook for the 1982 Friends of the Pleistocene, Rocky Mountain Cell, Field Trip to central Utah.
Shreve, R. L., 1972, Movement of water in glaciers: Journal of Glaciology, v. 11, p. 205-214.
Thorarinsson, S. 1939, The ice-dammed lakes of Iceland with particular reference to their value as indicators of glacier oscillations: Geografiska Annaler, v. 21, p. 216-242.
Waitt, R. B., Jr., 1980a, Cordilleran icesheet and Lake Missoula catastrophic floods, Columbia River valley, Chelan to Walla Walla: Guidebook for West Coast Friends of the Pleistocene Field Conference.
Waitt, R. B. Jr., 1980b, About forty last-glacial Lake Missoula jökulhlaups through southern Washington: Journal of Geology, v. 88, p. 653-679.
Waitt, R. B., Jr., 1982, Quaternary and late-Tertiary history of Columbia River valley and adjacent Cascade Range and Columbia Plateau, central Washington: Partial guidebook for Field Trip D, American Quaternary Association (AMQUA), Quaternary Research Center, University of Washington, Seattle, 23 p.
Waitt, R. B., Jr., 1984, Periodic jökulhlaups from Pleistocene glacial Lake Missoula--new evidence from varved sediment in northern Idaho and Washington: Quaternary Research, in press.
Waitt, R. B., Jr., 1984?, The case for periodic, colossal jökulhlaups from Pleistocene glacial Lake Missoula: (intended for Geological Society of America Bulletin [in journal review]).

Waitt, R. B., Jr. and Thorson, R. M., 1983, The Cordilleran Ice Sheet in Washington, Idaho, and Montana, Chapter 3 in Volume 1, Late Pleistocene Environments of the United States (S. C. Porter, ed.); in Late Quaternary Environments of the United States and USSR (H. E. Wright, Jr., ed.): University of Minnesota Press, Minneapolis, pp. 53-70.

Waitt, R. B., Jr., Kiver, E. P., and Stradling, D. F., 1984?, Limits of the Fraser (Late Wisconsin) Cordilleran icesheet and of multiple Lake Missoula catastrophic floods in northern Idaho and northeastern Washington: (intended for American Journal of Science [in preparation]).

Webster, G. D., Baker, V. R., and Gustafson, C. E., 1976, Channeled Scablands of southeastern Washington--a roadlog via Spokane, Coulee City, Vantage, Washtucna, Lewiston, Pullman: Department of Geology, Washington State University, Pullman, 25 p.

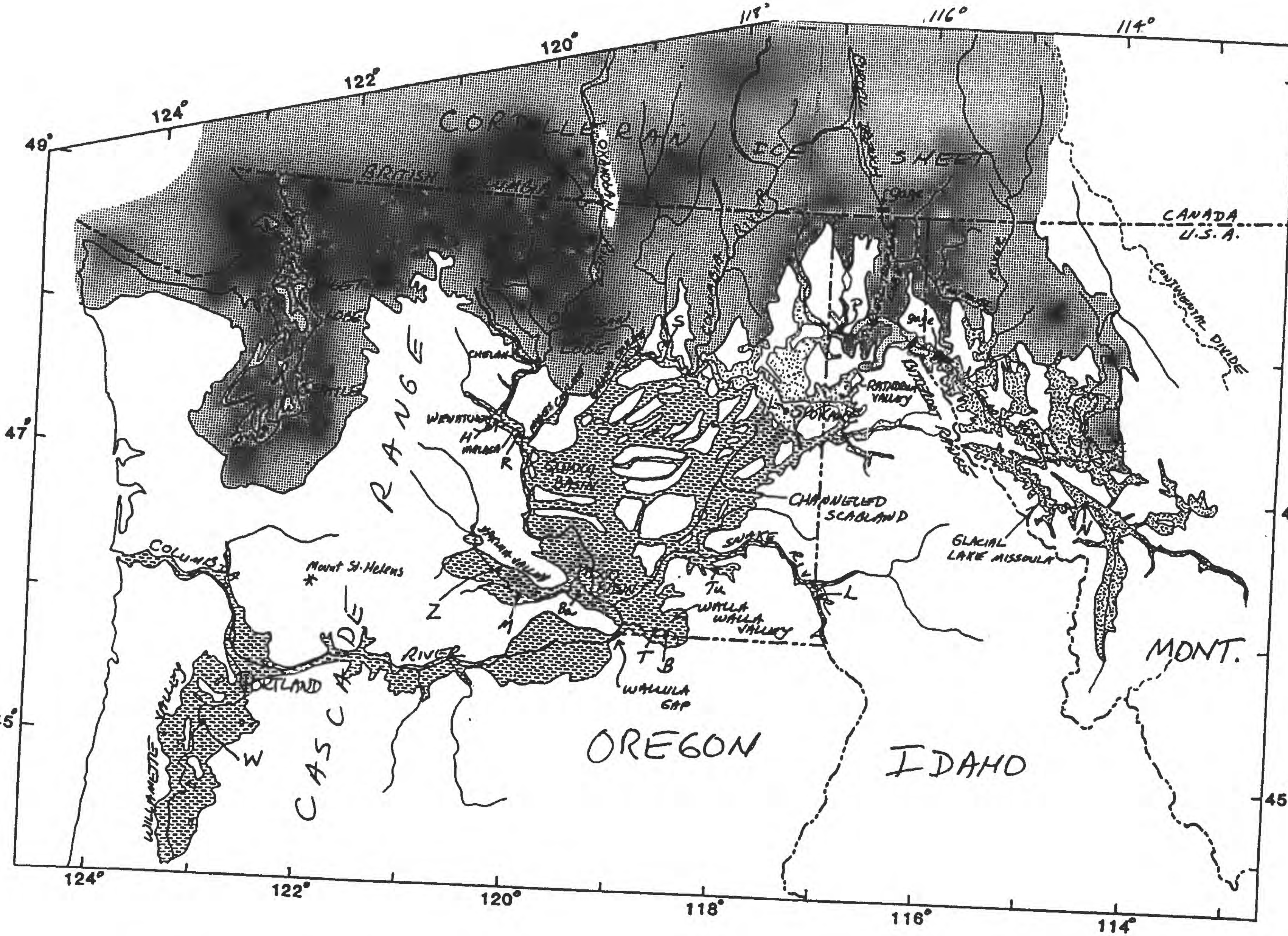


Figure 1. Map of Cordilleran icesheet, Channeled Scabland, Columbia River valley, and tributaries. B = Burlingame canyon, L = Latah Creek, Le = Lewiston, M = Mabton, P = Priest valley, S = Sanpoil valley, Tu = Tucannon valley, Z = Zillah.

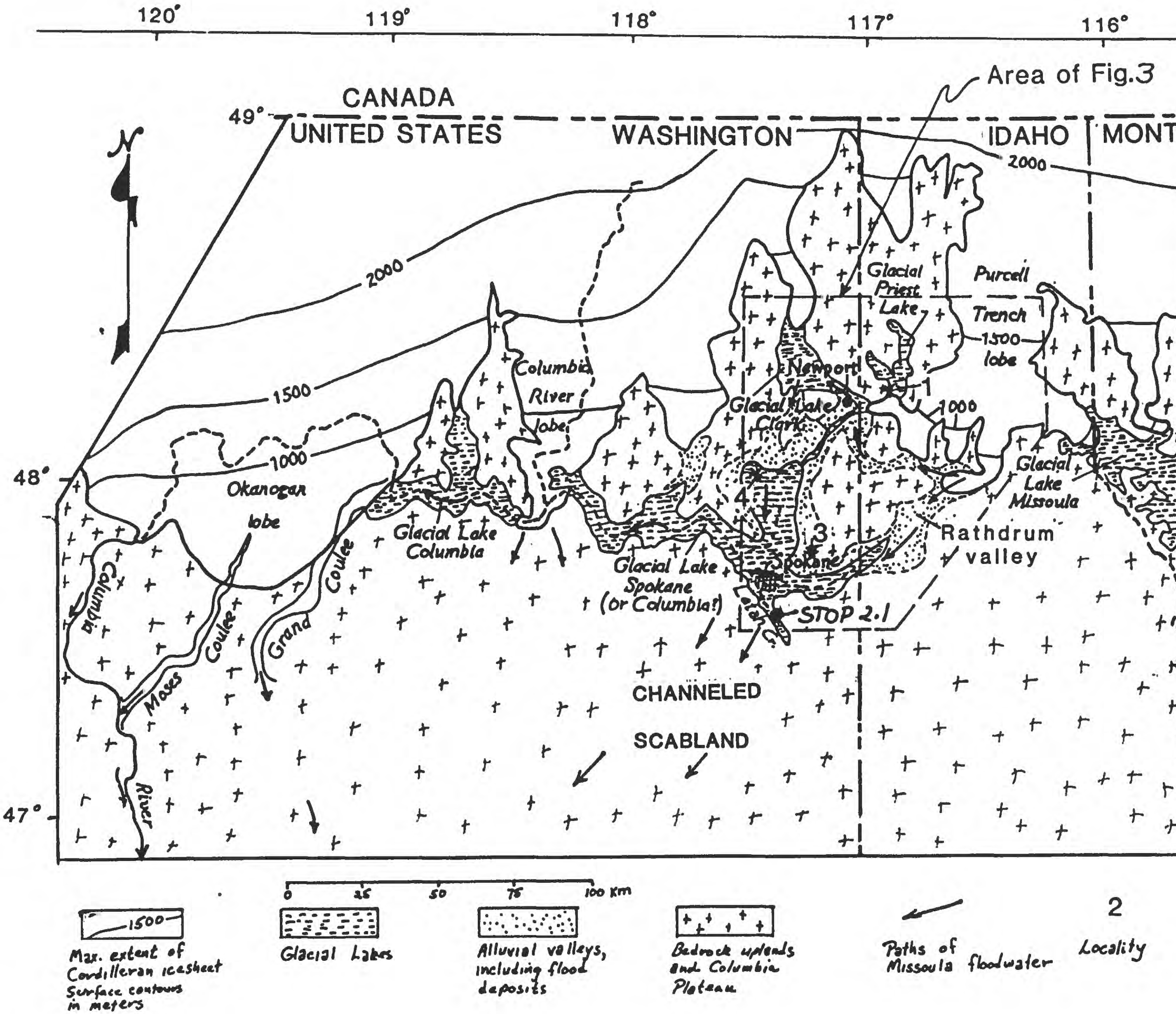


Figure 2

Figure 2. Map of Cordilleran icesheet and glacial lakes in northern Washington and Idaho

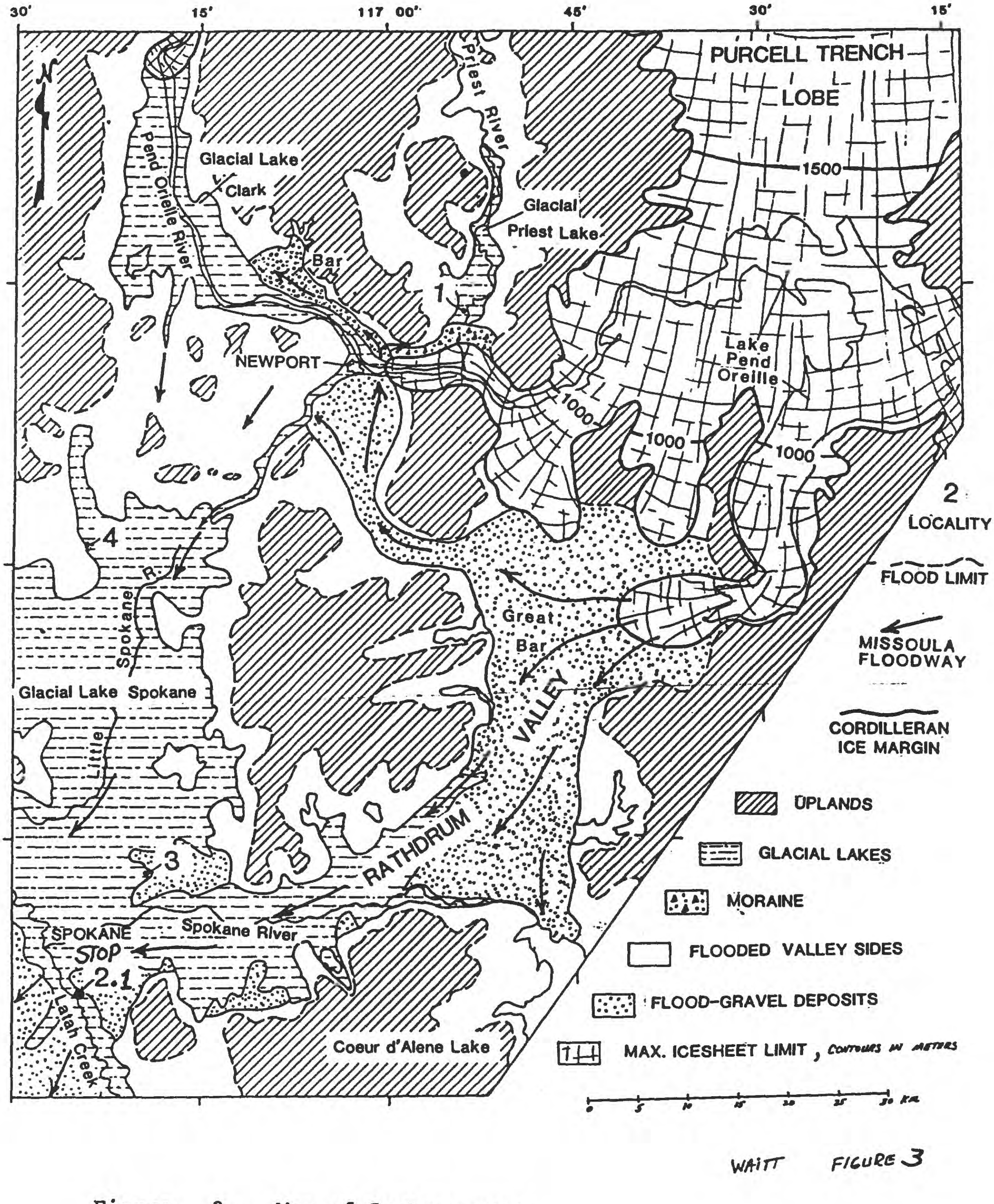
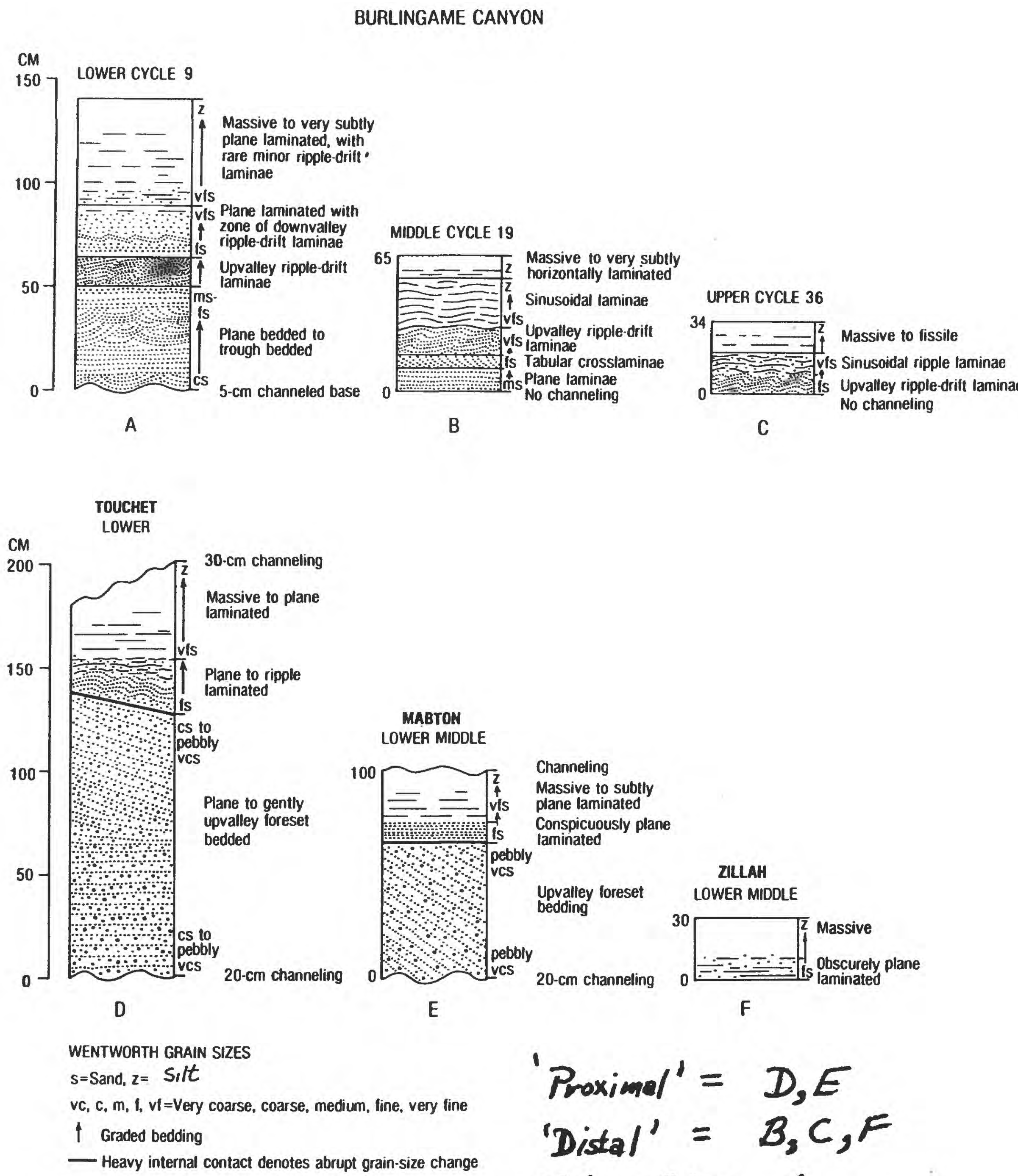


Figure 3. Map of Spokane area.



'Proximal' = D, E
'Distal' = B, C, F
Intermediate = A

Figure 4

Figure 4. Proximal and distal rhythmites in southern Washington (From Waitt, 1980, Fig. 3).

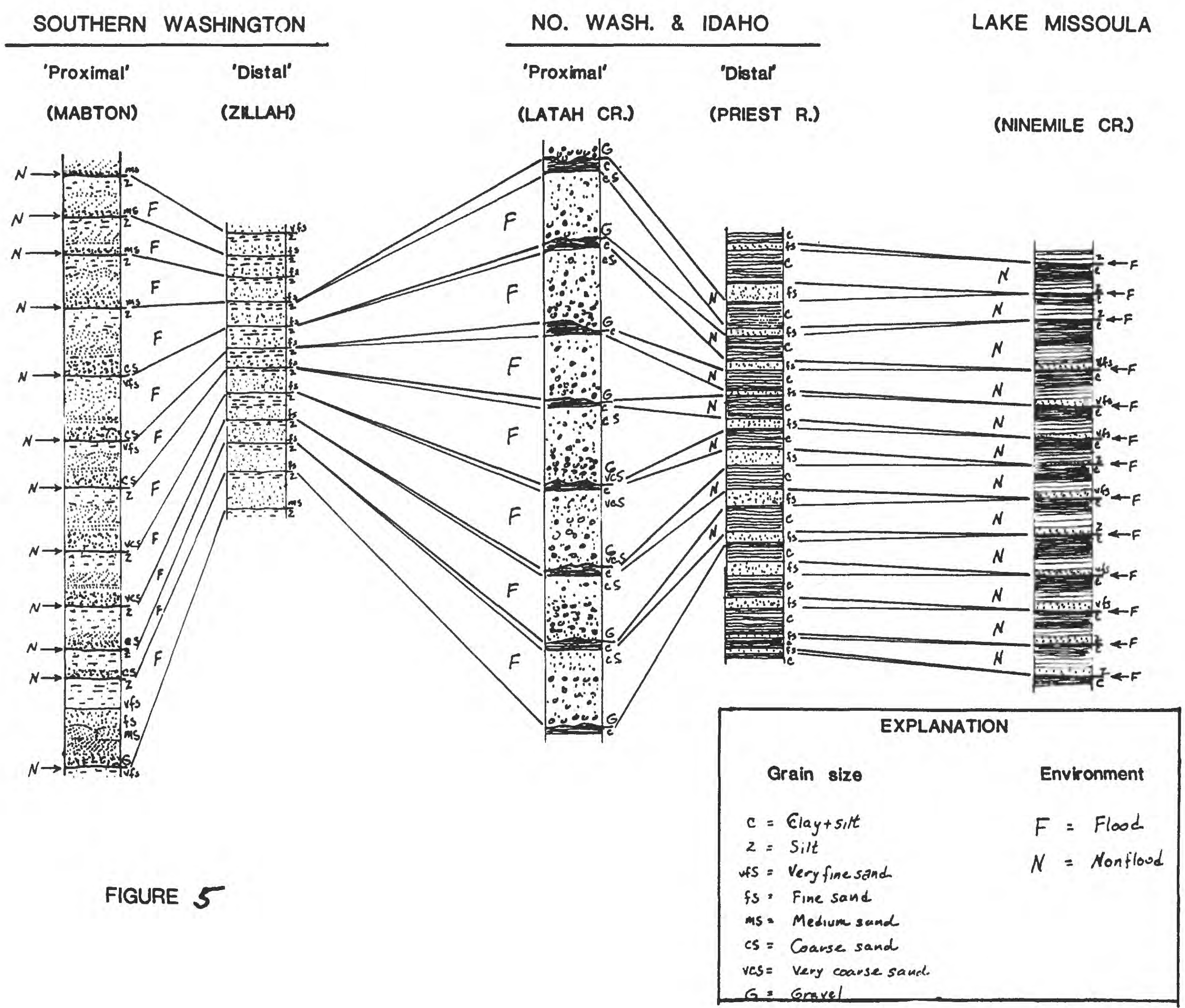


FIGURE 5

Figure 5. Inferred relations between rhythmites in southern Washington, northern Idaho, and western Montana.

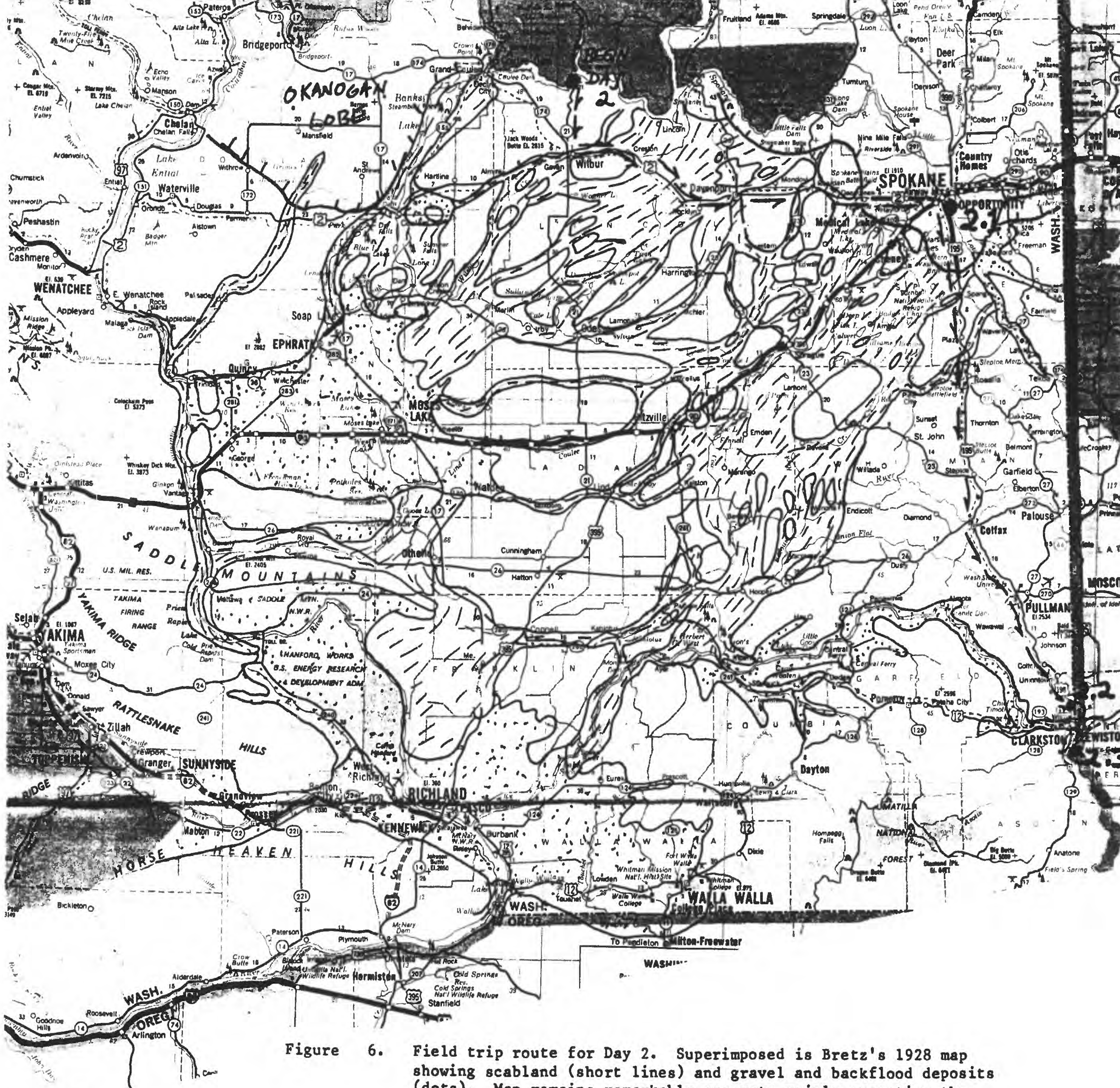


Figure 6. Field trip route for Day 2. Superimposed is Bretz's 1928 map showing scabland (short lines) and gravel and backflood deposits (dots). Map remains remarkably accurate mainly excepting the inferred icesheet margin in the northeast, which is 50 km too far south.