CHAPTER 2
GLACIAL LAKE MISSOULA:
SEDIMENTARY EVIDENCE FOR MULTIPLE DRAINAGES

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INTRODUCTION

Periodically during the Pleistocene, a lobe of glacial ice advanced down the Purcell Trench in northern Idaho and dammed the Clark Fork River drainage near the present site of Pend Oreille Lake. The ice dam impounded water to the east and created glacial Lake Missoula. The lake once occupied six major intermontane basins in western Montana.

For nearly 80 years numerous investigators have endeavored to decipher the glacial history of the northwestern United States. Part of this research was an attempt to understand the complex relationship between the glacial events, Lake Missoula and the scablands of eastern Washington. The publications which resulted from these investigations have produced some of the most acrimonious scientific debates ever recorded in the geological literature.

LOCATION

This part of the field trip guide briefly describes the possible origin of the glaciolacustrine sediments, giant current ripples and other geomorphic features associated with the rapid drainage of the former glacial Lake Missoula. The Lake Missoula portion of the field trip begins at Missoula, Montana, and ends at Camas Prairie about 100 km northwest of Missoula. Main access is via Interstate 90 and US 93 and from Montana Highways 200 and 382. These are all-season paved roads. Unpaved roads will be used for short distances to access one or two sites (Fig. 1).

REGIONAL SETTING

The field trip area lies within the Rocky Mountain physiographic province. Deformation during the Laramide orogeny produced a series of north to northwest trending mountain ranges and intermontane valleys.
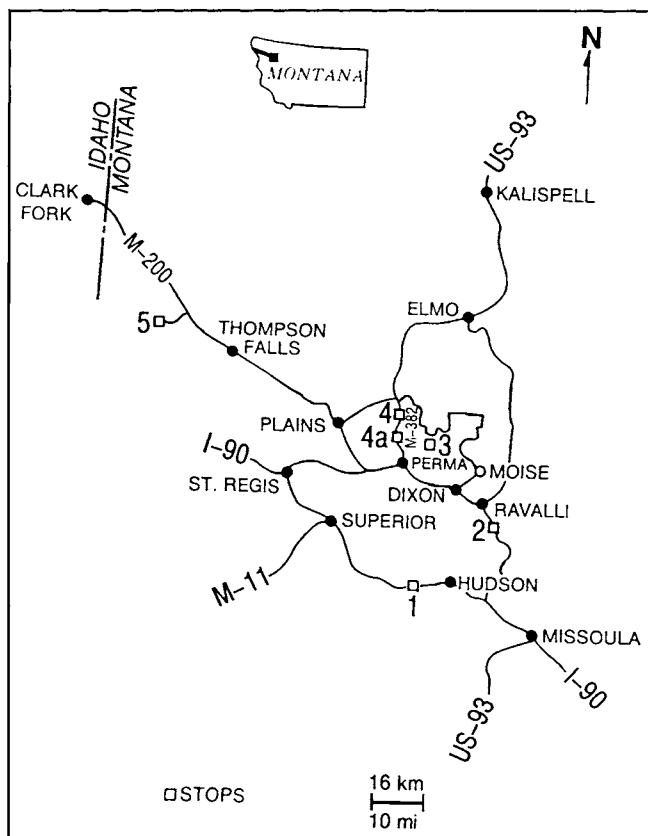

FIGURE 1 Map of field trip route.

Geologic units extend in age from Precambrian to Recent, with only the Mesozoic systems missing. Tertiary volcanics are locally widespread, with Tertiary basin sediments found within the Missoula and Bitterroot valleys (Sahinen, 1957). Pleistocene glacial and glaciolacustrine sediments are widespread.

Drainage is to the northwest by the Clark Fork River which flows into the Columbia River and ultimately into the Pacific Ocean at Portland, Oregon. The Clark Fork is fed by a number of tributaries, principal of which are the Bitterroot and Rock Creek drainages and the Blackfoot and Flathead rivers.

A BRIEF HISTORICAL REVIEW

More than 100 years ago Chamberlin (1885) noted "a series of parallel watermarks . . . sweeping around the valleys . . . like gigantic musical staves" in the Flathead Lake Region of northwestern Montana. He believed that a lake had formerly occupied this region, impounded by glacial ice located in the Pend Oreille region of northern Idaho. Chamberlin suggested its outflow was by way of Spokane, Washington.

Pardee (1910) made the first significant study of glacial Lake Missoula. He described the lake and suggested that an ice dam was once located near the present site of Pend Oreille Lake. Pardee felt that there was ample evidence for at least two Lakes Missoula, the first lake drained rapidly, followed by a slower second drainage. He did not, however, address the question of how the lake drained.

In 1923, Bretz presented his catastrophic flood hypothesis for the origin of the "channeled scablands," a term he used to describe the severely scrubbed bare rock surfaces of what appeared to be drainageways in the lowlands of eastern Washington. With a series of articles, Bretz (1925, 1928a, b, c, 1929, 1930a, 1932) staunchly defended his flood hypothesis much to the disgust of his more uniformitarian audience. The biggest flaw in his argument was a plausible source of water for such a devastating flood, although he believed Lake Missoula was the most likely candidate. Flint (1935, 1936, 1938) rebuffed Bretz and suggested instead that the scablands were merely the product of normal proglacial discharges. The terms "flood, catastrophic, bars and channels" were repulsive to Flint.

The work of Pardee (1942) finally provided Bretz with his desperately needed source of water for the "Spokane flood." Pardee presented strong evidence that the ice dam which had contained Lake Missoula ruptured and released enormous quantities of water in a very short period of time. He calculated an initial discharge rate of nearly 40 km^3 (9.5 mi^3) per hour. Pardee cited the erosional and depositional features found along the Clark Fork River and within the Camas Prairie basin as evidence for this huge rush of water.

In his comprehensive review of the evidence for repeated catastrophic drainages of Lake Missoula, Bretz (1969) remarked that very little was known about the lake bottom sediments, except that they were varved. He believed an investigation of these deposits would provide valuable clues to the question of how many times the lake drained and refilled. Bretz felt that an unconformity surface would separate each lake sequence.

The first detailed description of the Lake Missoula bottom sediments was presented by Chambers (1971), with a follow up article in 1984, which has been included as a handout to the field trip participants.

Waitt (1980) related the stratigraphic sequences described by Chambers (1971) to the rhythmically bedded Touchet Beds in Washington. He believed that the striking similarity in number (40) and overall morphology between these deposits was evidence for at least 40 jökulhlaups, or catastrophic drainages of Lake Missoula by ice dam failure.

This review is by no means meant to be comprehensive or complete. Interested readers are referred to other articles listed in the references cited herein and to those suggested throughout the field trip.

DESCRIPTION OF TRIP ROUTE AND STOPS

In an effort to avoid duplication, the site descriptions within this field guide will be as brief as possible. For more detailed information you are referred to the 1984 article of Chambers.
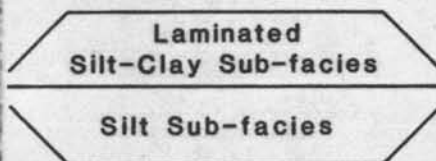
En Route to Stop 1:

In Missoula, the shorelines on the side of Mt. Sentinel are clearly visible. The highest, at around 1265 m elevation, is just above the University's letter "M". As we drive west out of the city, you see Tertiary basin-filling gravels and silts exposed on the right (north). Precambrian Belt Supergroup rocks, primarily quartzites and argillites, make up the forested hillsides around the Missoula basin. The area of the airport west of Missoula is a dissected series of glacial lake sediments, almost flat, overlying Tertiary and Quaternary gravels. As we drop down onto the floodplain of the Clark Fork River, we come to Frenchtown. Here Lewis and Clark, in their 1805 expedition to establish an American presence in the great western wilderness, found a small village with regular street patterns and blue-eyed light-skinned "indians" that just happened to have French surnames! Those names persist today on the tribal roles.

Stop 1: Ninemile Creek, "Type" Section

This site represents the most completely described section of Lake Missoula rhythmites and has been designated the "type" section. The Ninemile Creek site is located approximately 35 km (21 mi) west of Missoula (Fig. 1) and consists of large road and stream cut terraces along I-90 near the Ninemile Creek exit. Many other exposures of lake bottom sediments are accessible between Missoula and Stop 1, but none are as complete as the one seen at Ninemile Creek.

Figures 2 and 3 illustrate the gross sedimentary motif of the Lake Missoula bottom sediments. The 25 m thick section is composed of 40 well-developed small-scale cycles, up to several meters thick. Each cycle, or rhythmite, consists of the basal silt subfacies (light-toned layers), which grades upward into a well-formed sequence of glaciolacustrine varves of the Laminated Silt-Clay subfacies (dark-toned layers). In general, rhythmites (1-25) in the

FIGURE 2 View of the rhythmically bedded Lake Missoula sediment at the "type" locality. The Lake Missoula rhythmite consists of two major subfacies: the silt subfacies (light-toned) and the laminated silt-clay subfacies (dark-toned).
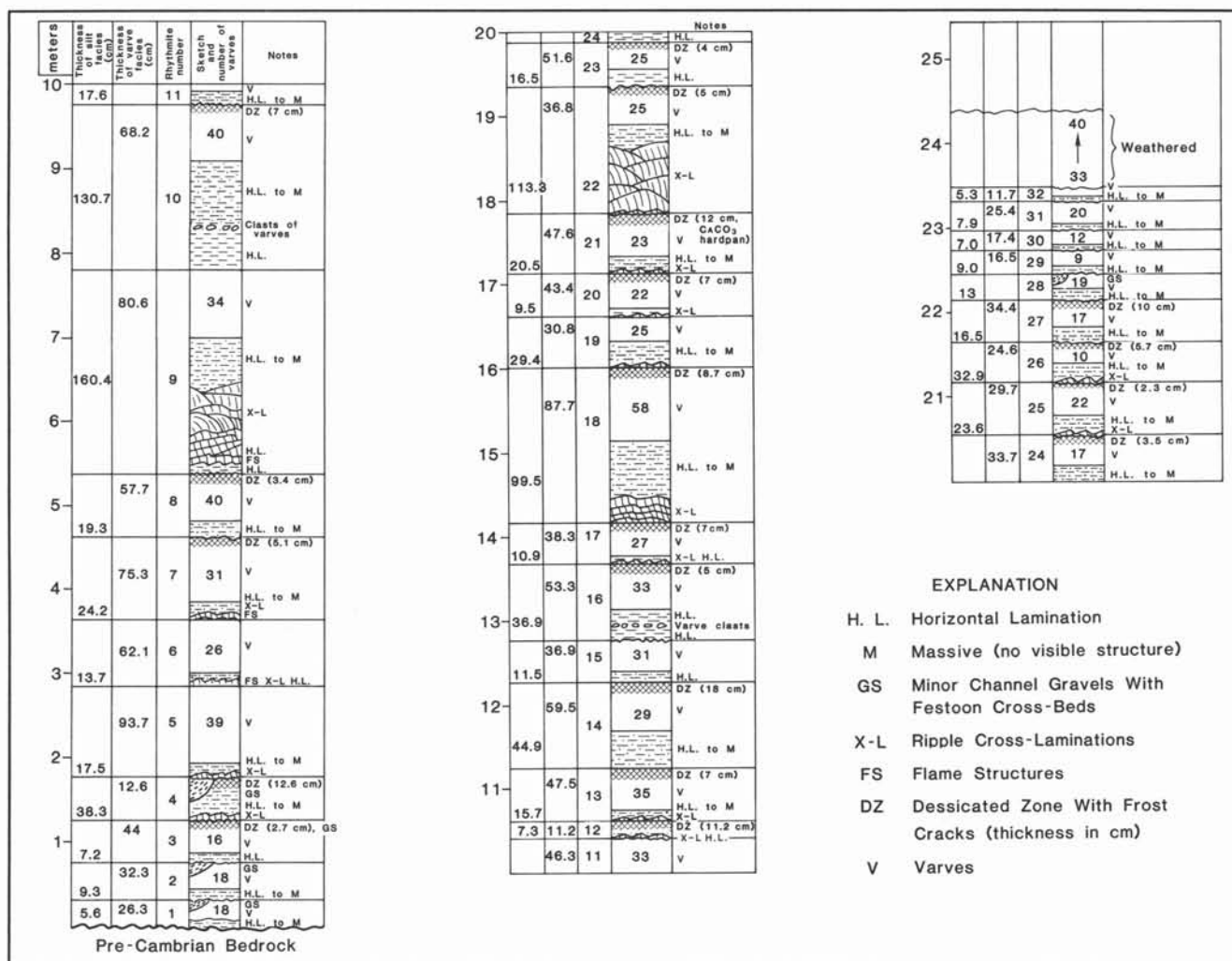

FIGURE 3 Measured section of the 40 rhythmites comprising the Missoula-Ninemile basin type locality.
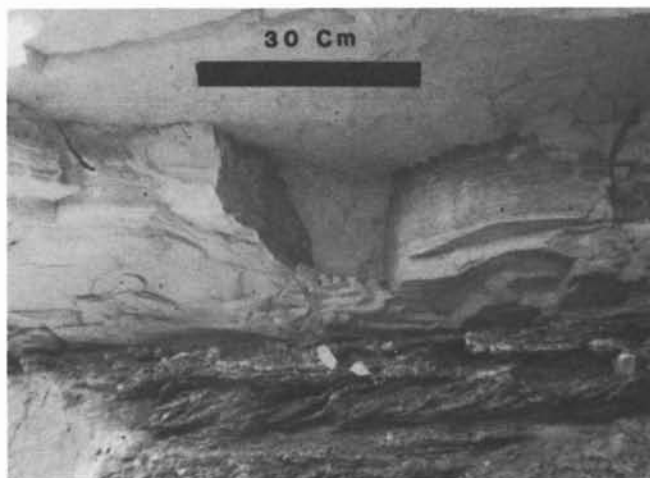
FIGURE 4 Channel fill deposit of the Gravel subfacies overlain by flat-bedded silt of the next cycle at the Jocko Valley site.

lower portion of the section are thicker (50-100 cm) than those higher in the section (26-40), which range between 15-33 cm in thickness.

The gravel subfacies Figure 4 is a relatively minor de-positional unit; however, this subfacies has particular importance in that it represents deposition upon the drained lake floor.

The lake sediments are not coextensive with the maximum area of the former lake floor. Because the Ninemile Creek section is approximately 375 m above the base of the ice dam, interpretations about the depositional history of the lake based upon this outcrop are both spatially and temporally biased.

It is important to note that the terms "rhythmite" and "varve" are not synonymous. Varves connote time, usually representing annual deposits, whereas rhythmite describes the cyclic sets of Lake Missoula bottom sediments (Anderson and Dean, 1988).

Primary sedimentary structures of the Silt subfacies have been described (Figure 4; Chambers, 1984) and assigned to hydrodynamic states (Allen, 1970; Shaw, 1975). At this location the Silt subfacies is dominated by parallel, flat-bedded sediment within the sandy-silt to silty-sand size grade. Small scale cross-laminations, flame structures and soft-sediment deformation features are also found within this subfacies. (Figure 5).

The Laminated Silt-Clay subfacies is characterized by well-developed varves composed of silt-clay couplets
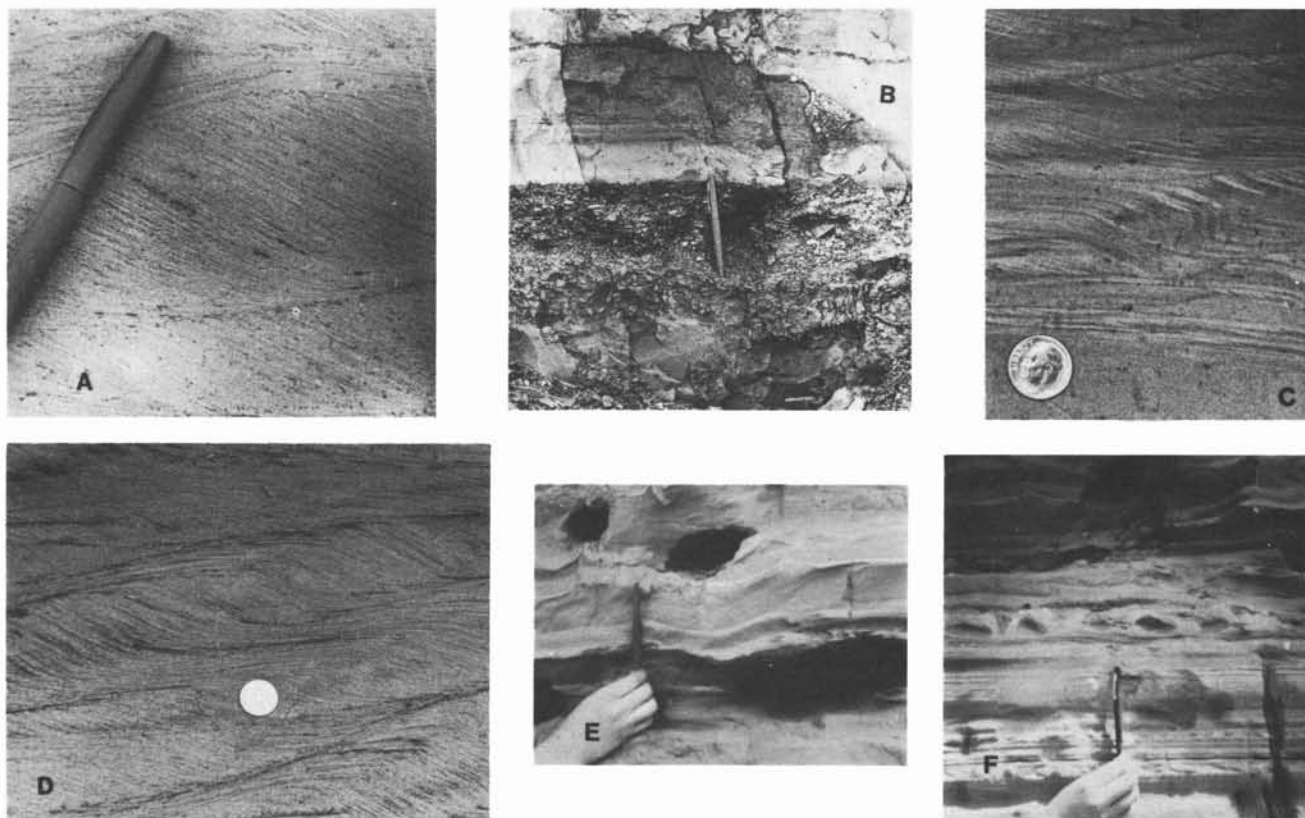

FIGURE 5 Hydrodynamic states: (A) cross-bedded sand; (B) flat-bedded silt (above and below pen) and channel fill of the Gravel subfacies; (C) massive and flat-bedded silt overlain by ripple cross-laminated silt; (D) Type B ripple cross-laminations; (E) sinusoidal ripple laminations; (F) from bottom to top, flat-bedded silt, load casts, flame structures, and sinusoidal ripple laminations. The pen is 14 cm in length and a dime is used for scale in C and D.

FIGURE 6 Structural varve groups classified according to the criteria of Ashley (1975). (A) Group I varves; (B) Group II and Group III varves. The simple and composite varve types described by Antevs (1951) can also be observed in this photograph. Pen = 14 cm.

(Sieja, 1959; Chambers, 1971, 1984) and are classified into the structural groups recognized by Ashley (1975). Figure 6 illustrates the varve types. Because of a deep weathering zone, only 32 of the 40 rhythmites were accurately measured. There are 729 varves at the Ninemile section, averaging 24 per cycle. The varves per cycle (range between 9 and 58) generally decrease in number from the bottom to top of the section. Notice that the varves within any one cycle also decrease in thickness from bottom to top, which suggests a progressively deepening lake and expanding lake floor.

The unconformities as predicted by Bretz (1969) are present within the lake bottom sediments; however, they possibly are not like he expected them to look. Rather than surfaces occupied by forests and bogs, the unconformities are characterized by thin (2-20 cm thick) "weathered" zones, which separate at least 22 rhythmites within the "type" section. Figure 7 shows two of these "weathered" zones. Small-scale, sediment filled frost wedges are commonly preserved along this surface (Figure 7b).

The "weathered" zones probably represent periods of subaerially exposed lake floor which was subjected to fluvial scouring and erosion by small streams (Gravel subfacies) and freeze-thaw, periglacial conditions (frost cracks and wedges).

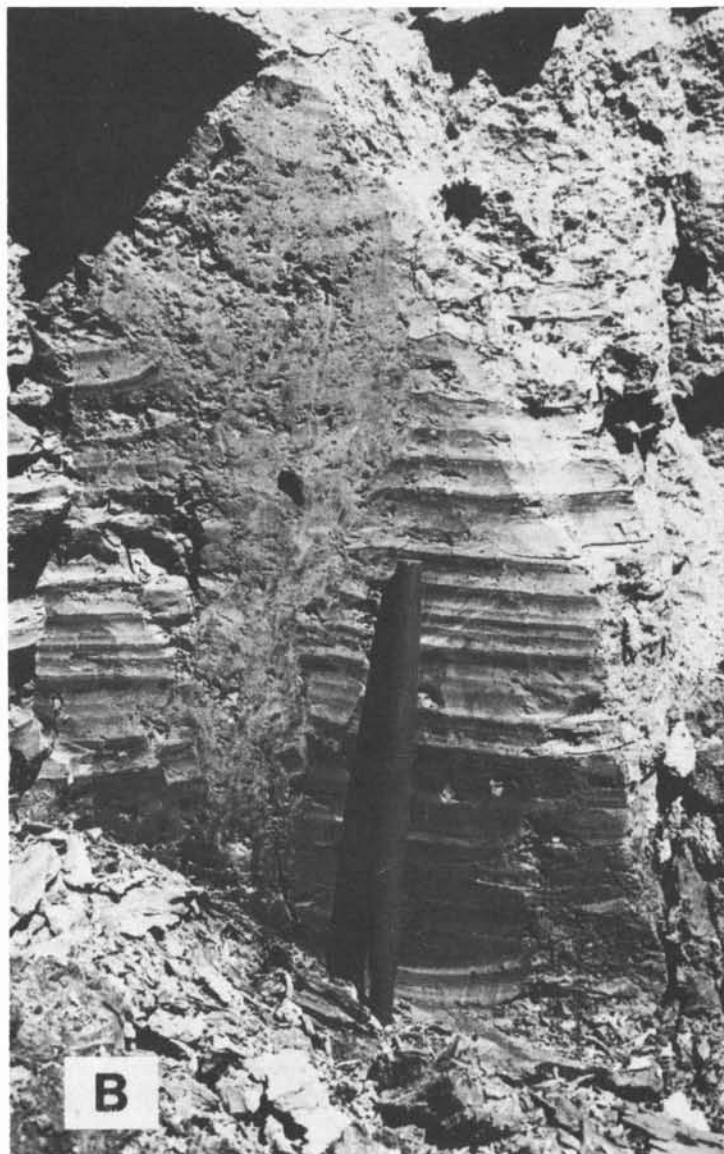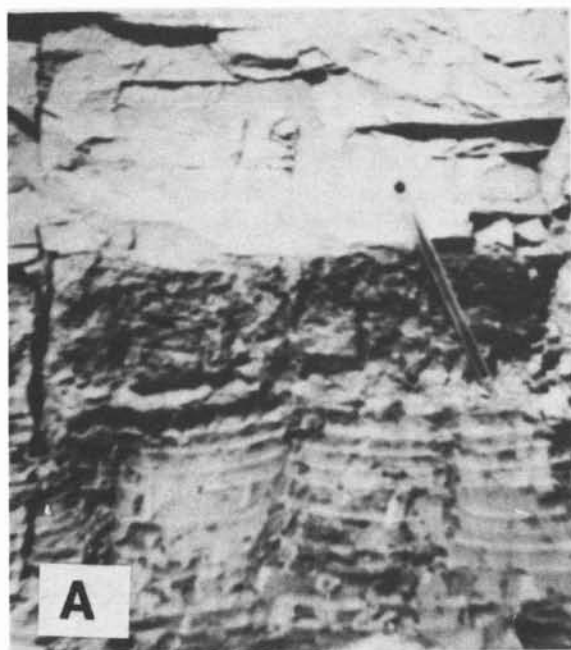The proposed depositional model for the Lake Mis-

FIGURE 7 Unconformities with the Lake Missoula rhythmites: (A) a thick "weathered" zone is present at the top of rhythmite 18. The surface was scoured during the deposition of the next cycle (pen = 15 cm); (B) small scale frost wedge and "weathered" zone within the Laminated Silt-Clay subfacies (pen = 14 cm).

soula rhythmites is schematically illustrated in Figure 8 and discussed in detail by Chambers (1984, p. 194-198).

En Route to Stop 2

We return via Interstate 90 eastward to its junction with Highway 93 northbound. Passing over a low saddle (Evaro Hill) through which Lake Missoula drained primarily northward based upon gravel deposits, we enter the Flathead Indian Reservation (of the Confederated Kootenai-Salish Tribes). The Rattlesnake Mountains are to the east, and the Mission Mountains to the northeast. We descend into the Jocko Valley, passing Arlee and

crossing the Jocko River. Lake sediments are seen on the bench to our right after Arlee (northeast).

Stop 2: Jocko Valley Site

The Jocko Valley site is located along US 93, on the north side of the highway, approximately 3.5 km south of the US-93 and Montana 200 highway junction at Ravelli (Fig. 1). Seventeen rhythmites, containing 308 varves, are recognized in this 10-m-thick section of lake bottom sediments. The lowermost rhythmite rests unconformably upon a 5-m-thick subaqueous (?) mudflow (?). Notice the stream channel cut into the lower right (south)
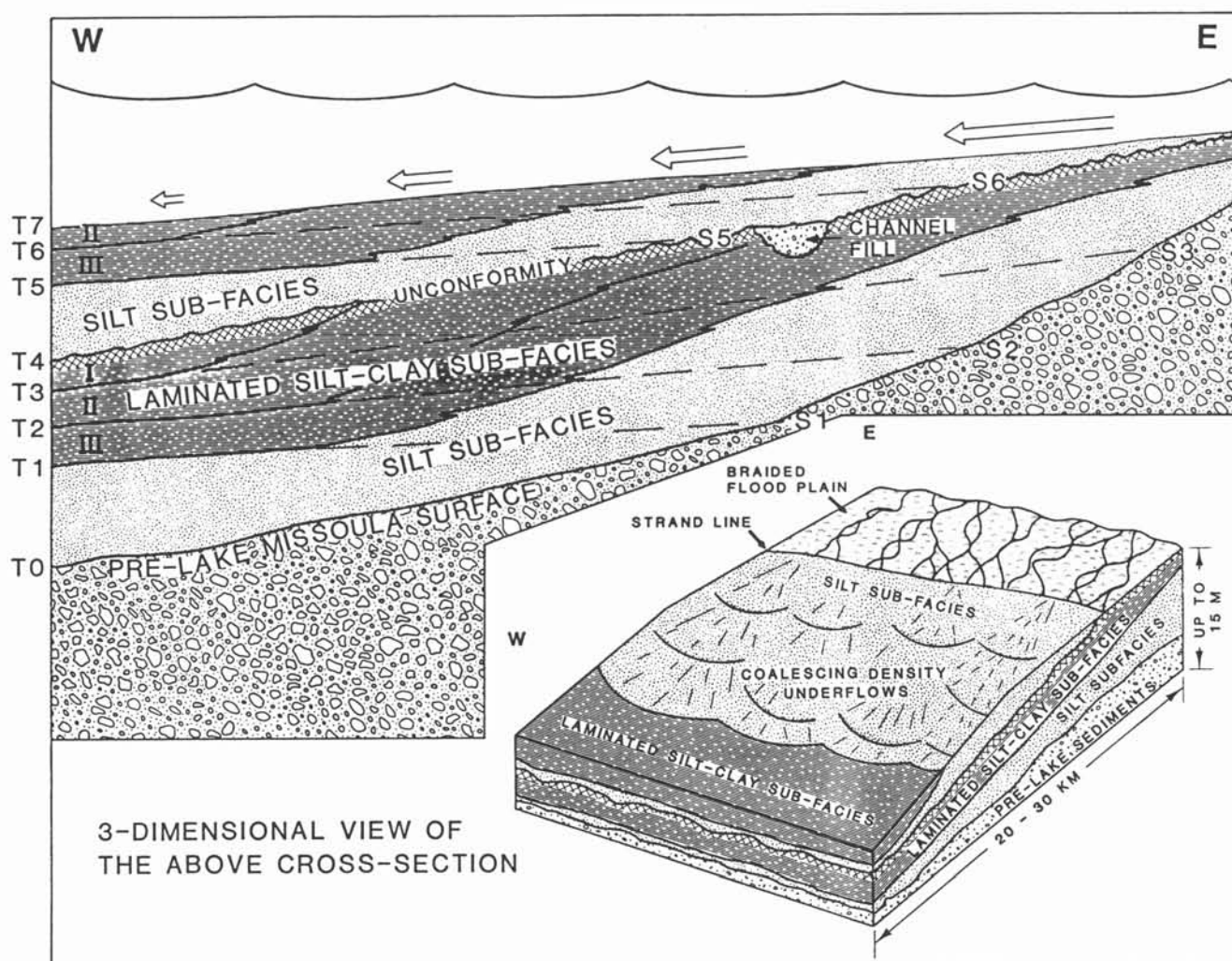
FIGURE 8 Schematic illustrating the proposed depositional model for the Lake Missoula rhythmites. The insert shows a 3-dimensional view of the cross-section. Note that the vertical scale is in meters and the horizontal scale represents tens of kilometers. Isochrons are indicated on the left (T) and hypothetical strandlines (S) on the right. The transgressive nature of the rhythmites are illustrated in this figure. T4 represents a time of lake drainage and subaerial exposure of the lake floor. Channeling is also indicated. The arrows represent density underflows entering the lake basin, and their length relates to the relative flow rate intensity.

corner of the mudflow.

There is also a greater abundance of cross-laminated deposits and soft sediment deformation structures at this site than are observed at the Ninemile Creek location. There is a good example of the Gravel subfacies approximately half-way up the right-hand (southern) portion of this outcrop.

A moderately well-developed basal B and C soil horizon fragment is visible within a 1.5-2 m thick oxidized layer of the mudflow. Also, notice the caliche layer which forms a nearly continuous zone near the upper part of the mudflow.

Fragments of a similar hardpan have been seen at Stop 4a in Camas Prairie. At that site, caliche-cemented cross-bedded flood gravel fragments have been incor-

porated into later giant current ripples. These soils may most reasonably be assigned to inter-stadial or inter-glacial times as dry or drier than today. If the observed cemented fragments in the glacial Lake Missoula deposits represent distinct K-horizons as described by Gile and others (1965, 1966), then multiple periods of ice-dam flooding are suggested. The present inter-stadial has seen only the beginning of caliche cementation at Camas Prairie and little or none here at the Jocko site.

En Route to Stop 3:

Across the Jocko River from Stop 2 is a large bluff of Lake Missoula beds that drape well-exposed hummocky compact red-brown glacial till of unknown age. The

unconformity between the till and overlying sediments is clean, fresh and angular with no evidence of pedogenesis or colluvium. The source of this till is unknown. It could be derived locally from the Mission Mountains via the Jocko River Valley or could be part of the deposits of the Flathead Lobe of ice. It has been interpreted as pre-Illinoian (Alden, 1953; Curry, 1977; Richmond, 1986) based upon its weathering and position beyond the inferred limit of Illinoian Flathead Lobe ice.

Passing northward through the Ravalli Narrows (not evidently glaciated) we leave US 93 at Ravalli and follow the Jocko River west on Montana highway 200 down-stream to its junction with the Flathead River (Dixon, Montana). Pockets of lake silts are seen in protected sites on both sides of the Jocko River. Upland areas of Belt rocks are stripped of soils and colluvium as is typical of the canyons that carried the repeated outburst floods we will see from here downstream to Portland, Oregon. At Dixon, we temporarily leave our downstream course to look at lake deposits in the vicinity of contemporaneous ice margins in the Flathead Valley via secondary roads (Montana 211 and 212). Near Moise we will stop briefly.

National Bison Range,
Moise, Flathead Indian Reservation

Here a brief rest stop may afford us an opportunity to see a few American Bison (*Bison bison bison*) against the backdrop of the Mission Range. This is a government wildlife refuge established near the center of the Confederated Kootenai-Salish tribal Indian lands. Few bison, if any, were native to this site. The great herds that migrated annually from the Canadian prairies into what is now Texas were primarily restricted to sites east of the Rocky Mountains. A few isolated populations lived or were driven to mountain valleys south and east of the Mission Range, where they were hunted by the Plains Indians but not by the Flathead tribes. The great herds were extirpated by white hunters at the time of construction of the railroads about 1883.

We will travel a complex course up the Flathead River through agricultural lands that were largely sold to white families at the urging of the government Indian agents about 1900. We travel over thick glacial tills and outwash capped with fertile lake silts. Four till units of three ages are recognized beneath us. Based upon correlation with the Kootenai River deposits in British Columbia, Canada, Richmond (1986) suggests ages of between 25 Ka and 19 Ka for the lowest "Dublin Gulch Till" and "Post Creek tills." Over these farther north and all exposed in the Flathead river gorge, are the Ninepipe Till (between 19 Ka and 17 Ka) and the Pablo Reservoir Till (between 17 Ka and possibly 15.5 Ka (Richmond). All these tills are mantled with varved lake silts, as for example you can see as we near the terminus of the Ninepipes moraine when we first drop down to the level of the Flathead River. To the east, the Mission Range has been greatly modified by glacial ice. Major ice masses completely overtopped the range to the north but the southern end of the range maintains an alpine characteristic with horns and aretes indicating that ice was confined to the valleys.

Stop 3: Big Bend, Flathead River

This stop is located in a remote area of the Flathead Reservation. We will look at a full section of 40 or more rhythmite sequences capping a thick compact glacial sequence of what is probably the Dublin Gulch Till. The site is somewhat hazardous because of the extensive piping cavities caused by groundwater erosion of vertical joints and fissures in the deeply incised section. Use caution at the cliff face. There is no way back up the cliffs without rope. The cliffs are home to osprey and eagles who do not welcome visitors.

Note the shorelines on the bedrock hills to the south and the huge gravel point bar on the Flathead River at this site. The rhythmite sequence we saw at Stop 1 is probably contemporaneous with what we see here, but now we are within a few km of the glacier termini. Although these lacustrine sediments rest on till, there is no evidence of Flathead Lobe ice south of the margin of the hills immediately south of us here. This was probably a site where many ice advances were defeated by topography and where proglacial lakes formed repeatedly before and during the latest phase of Lake Missoula damming (25 Ka to 19 Ka).

Stop 4: The Giant Current Ripples of Camas Prairie (as seen from the Markle and Wills Creek Pass Location)

This stop is located between the Little Bitterroot Valley to the north and Camas Prairie to the south (Fig. 1). Wills Creek (elevation 990 m) and Markle Pass (elevation 1,036 m) were the major spillways between the two valleys. Bedrock in all the passes is Precambrian Belt quartzite and argillites and form extremely resistant rock (Alt, 1987).

Upon failure of the ice dam, the initial water level within the Plains Valley and Camas Prairie dropped rapidly and created a steep hydraulic gradient between these basins and the Little Bitterroot and Flathead valleys to the north and east (Chambers, 1984). The numerous "mountain-top" or pass-top bedrock basins seen at this stop attest to the violent, erosive, cavitative-plucking action as water poured through these passes, almost certainly in upper regime flow (Alt, 1987). Once the water level dropped below Wills Creek Pass, water still contained in the Little Bitterroot Valley drained through the Flathead River valley (Chambers, 1984; Alt, 1987).

High eddy deposits are located immediately down-slope of the passes, which inturn grade into two distinct

trains of giant flood ripples composed of angular pebble-cobbled-size debris (Chambers 1971, 1984; Alt, 1987). The largest giant ripples have an amplitude as great as 11 m and a wave length greater than 90 m (Pardee, 1942). A recent study (Lister, 1981) suggests that at least some of the ripples near the head of Camas Prairie are antidunes. Hydraulic computations and sedimentologic work show that the upper-regime flow ultimately dropped to transition flow regime but maintained the in-phase surface and bed-form ripples, and then stopped rather abruptly to preserve the symmetric bed-forms as the water-levels receded below the pass summits (Curry, unpublished).

Because of the high discharge rates associated with the formation of the giant ripples, it is probable that later floods destroyed evidence of previous floods. It is also probable that the giant current ripples could only form when catastrophic flood water spilled from the Little Bitterroot Valley into Camas Prairie. There are at least seven shorelines on the hillsides above Markle and Wills Creek Passes, therefore, the opportunity existed for at least seven periods of ripple formation. However, how many times was one strandline reoccupied?

**Stop 4a - Optional: Pardee Gravel Pit,
Located East of Montana 382, Central Camas Prairie**

This stop is conditional based upon exposure in an active gravel pit at the time of our trip. At this location we have an opportunity to examine the giant current ripples in cross-section. These deposits make up the Flood Gravel subfacies (Chambers, 1984). The giant current ripples exposed in this pit exhibit crude, large scale cross-bedding. Notice that the ripple troughs are filled with several thin rhythmites, but they are too deeply weathered to detail the internal structure. Fossil grasses (?) have been found (Chambers, 1971) between the lake bottom sediments and the flood gravels. The presence of rhythmites in the ripple troughs suggest that the last few Lake Missoula drainages were rather quiescent.

Fragments of a torn apart caliche-like soil, similar in morphology to the one described in the mudflow at Jocko Valley, were found within the Flood Gravel subfacies. Deposits thus far have been interpreted to record events during the late Wisconsin glaciation. Until more out-crops are studied in detail and radiometric dates become available, ages of the events recorded in the lake bottom sediments remain unknown.

En Route to Stop 5:

Our route now crosses Camas Prairie over a train of giant ripples of progressively decreasing amplitude. We pass south following the course of Camas Prairie drainage, through a bedrock-controlled narrows and over a falls below which are mid-channel and backwater gravel bars through which the highway cuts. As we drop down to the Flathead River, we see these low-elevation gravels capped again with lake silts, suggesting again that the last lake fillings drained quietly. As we turn northwest on the south side of the Flathead River, look back north to see the backwater gravel pocket surrounded by "scabbed" (stripped and smoothed) flood-modified topography. About 10 km down river, we leave the Reservation and soon join the Clark Fork River. We continue downstream sometimes on rolling silt-capped terraces and other times on flood-modified bedrock through the hamlets of Paradise and Wild Horse Plains. Passing through Plains, the Clark Fork flows on or near bedrock. Side canyons joining the main Clark Fork canyon are often characterized by perched gravel backwater or eddy deposits. These can be seen on both sides of the river. At Thompson Falls we ascend a large gravel bench. These benches become more common as we go northwest toward the ice-dam area in Idaho. A few kilometers west of Thompson Falls, we enter a narrower canyon with prominent cliffs and talus deposits. Here highway crews encountered interstitial ice while constructing our route along the south side of the river. Despite hot summer temperatures, occurrences of ice are not uncommon in this region. In winter cold air drains into the open talus cooling the rock to temperatures that freezes spring meltwaters and blocks entry of warmer summer air into the mass.

On the north side of the highway, low-amplitude mega-ripples that are capped with lake silts characterize the open grassland areas. In the Mosquito Creek area, stratified terrace remnants can occasionally be seen along the river on our right (north). We are now entering the region of direct influence by the Pend Oreille ice lobe.