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FLUCTUATIONS OF GLACIAL LAKE MISSOULA.

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CORRELATION OF PLEISTOCENE GLACIATION IN THE BITTERROOT RANGE, MONTANA, WITH FLUCTUATIONS OF GLACIAL LAKE MISSOULA

by

WILLIAM MARK WEBER

A thesis submitted in partial fulfillment
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

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Approved by Stephen C. Porter
(Chairman of Supervisory Committee)

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Date: April 14, 1971

We have carefully read the dissertation entitled Glacial Geology of the Bitterroot Range and Bitterroot Valley, Montana submitted by William Mark Weber in partial fulfillment of the requirements of the degree of Doctor of Philosophy and recommend its acceptance. In support of this recommendation we present the following joint statement of evaluation to be filed with the dissertation.

Terminal fluctuations of a massive glacier lobe that dammed the Clark Fork River in western Montana during the Pleistocene ice ages resulted in repeated release of impounded waters from glacial Lake Missoula, and their subsequent passage as catastrophic floods across northeastern Washington where they carved the famed Channeled Scablands. Although studies in Washington have suggested as many as seven major Missoula floods, none is adequately dated, nor more than broadly correlated with glacial events inferred from the geologic record. Weber's dissertation is the first detailed stratigraphic study made to compare the relative-age relationships of alpine glacier variations within the Lake Missoula drainage basin with changes in the level of the lake. The Bitterroot Range and adjacent valley were studied because end moraines marking former terminal positions of long alpine valley glaciers are interstratified with shoreline sediments of Lake Missoula at several different levels. Weber's study has shown that during the last glacial age the lake occupied a number of levels, possibly reflecting repeated foundering and reestablishment of the ice dam.

Subdivision and correlation of the glacial stratigraphic record relied heavily on semi-quantitative relative-age criteria and comparative study of soil-stratigraphic units. Most earlier glacial geologic studies in Montana were descriptive in character and qualitative in their approach to correlation, so this report of research provides one of the few rigorous local stratigraphic successions of Quaternary strata yet established in the Northern Rocky Mountains.

DISSERTATION READING COMMITTEE: Stephen C. Porter

Minze Stuiver

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INTRODUCTION

Pleistocene glaciation has directly and indirectly affected broad areas of western Montana, northern Idaho, and adjacent portions of eastern Washington. Throughout the southern part of this region, most individual mountain ranges show evidence of multiple episodes of expansion and recession of alpine glaciers. North of about 47° 30' latitude, however, the terrain is mantled by drift deposited by the Cordilleran Ice Sheet which originated as coalescent piedmont glaciers in the Rocky Mountains and Cascade Range of Canada. Locally along the southern lobate margin of the Cordilleran Ice Sheet, alpine glaciers were incorporated in the larger ice mass.

Ten major lobes formed the southern margin of the Cordilleran Ice Sheet (Richmond and others, 1965). One of these, the Lake Pend Oreille lobe, flowed south along the Purcell Trench into the Lake Pend Oreille region and perhaps as far south and west as Spokane, Washington. In the vicinity of Lake Pend Oreille this ice lobe was more than 3500 ft thick, and formed a dam across the Clark Fork River just east of the Montana-Idaho border (Richmond and others, 1965).

Damming of the Clark Fork caused the ponding of glacial Lake Missoula (Pardee, 1910), which at its maximum extent covered an area of 3300 mi^2 and had a volume of more than 500 mi^2 (Pardee, 1942; Alden, 1953). The lake represented the accumulated drainage of the Clark Fork, Flathead, Blackfoot, and Bitterroot rivers. Several authors subsequently have inferred the repeated advance of the Cordilleran Ice Sheet into the Lake Pend Oreille region.

The bursting of this ice dam at the mouth of the Clark Fork and the resulting catastrophic Missoula floods are regarded as being responsible for the scouring of the Channeled Scablands of eastern Washington (Bretz and others, 1956). This colorful and controversial topic in North American geology has been the object of active investigation and discussion for more than four decades. Despite the considerable attention devoted to the genesis of the scabland tract little is known of the chronology of the flooding.

The Bitterroot Range and adjacent Bitterroot Valley lie west of the Continental Divide in southwestern Montana (Fig. 1). The Bitterroot Range, as delineated by Lindgren (1904), extends from Lolo Creek, 10 mi south of Missoula, Montana, southward 84 mi to the headwaters of the West Fork of the Bitterroot River near the Idaho border. The mountain range is well defined, topographically and geologically, and in many places attains elevations of more than 9,000 ft. The maximum elevation of the range is reached in its southern portion at Trapper Peak (10,157 ft).

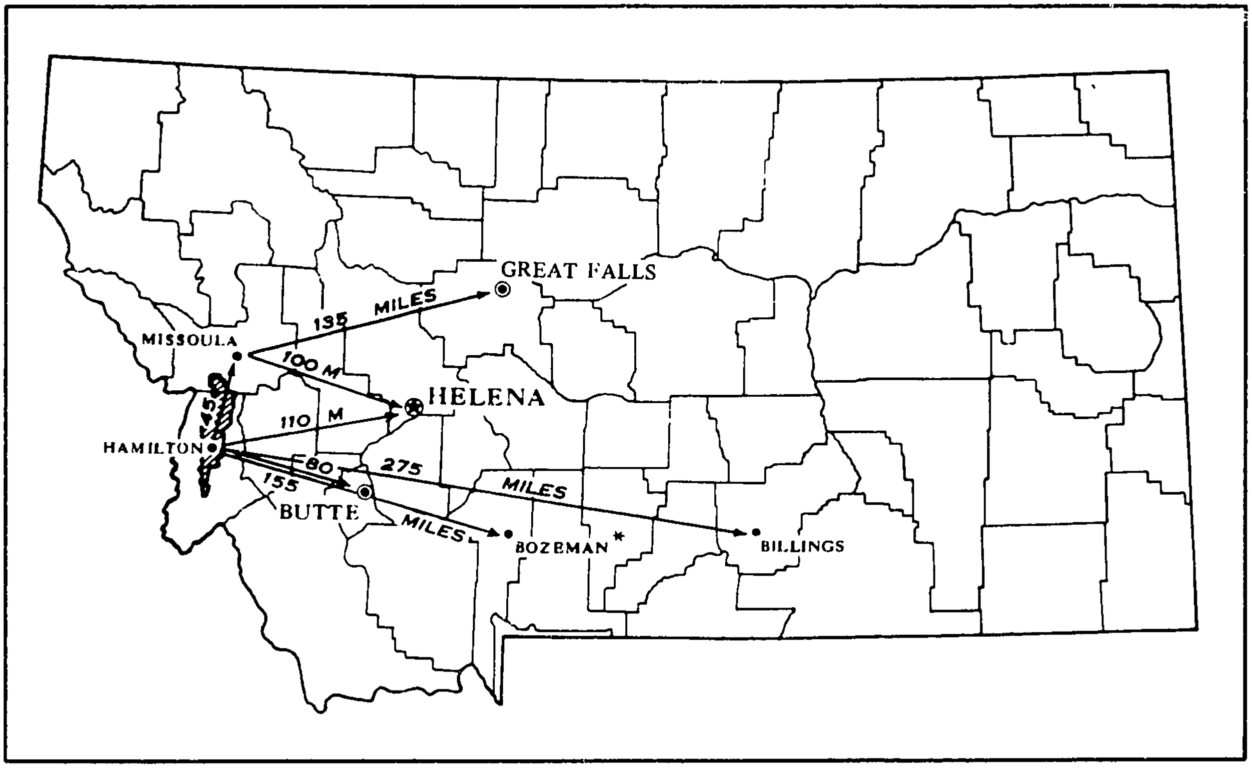


Figure 1 - Location of the Bitterroot Valley in Montana.

The valley of the Bitterroot River lies between the Bitterroot Range on the west and the Sapphire Mountains on the east. At the confluence of the East and West Forks of the Bitterroot River near Conner, Montana, the elevation is approximately 3,150 ft; thus Bitterroot River has a gradient of about 15 ft/mi.

Local relief between major landscape elements generally does not exceed 3,000 to 4,000 ft. Within the valley proper, local relief may be as much as 200 to 300 ft at the edges of prominent benches, but in most places it is less.

The Bitterroot Range is located in a unique position in relation to the former complex interaction of alpine glaciers in the Northern Rocky Mountains and the Cordilleran Ice Sheet, and the development and fluctuation of glacial Lake Missoula. Of the mountain ranges contiguous with the Lake Missoula Basin, only the Bitterroot Range possesses a complete alpine glacial sequence uncomplicated by fluctuations of the Flathead, Thompson River, and Bull River lobes of the Cordilleran Ice Sheet. Glaciers in the remaining ranges were either tributary to the Cordilleran Ice Sheet or did not extend down to the maximum lake level recorded by Lake Missoula.

Within the Bitterroot Valley a complex of nested moraine loops and related outwash deposits occur along the east-draining tributaries of the Bitterroot Range in the foothills belt above the trunk drainage. These deposits lie within the Lake Missoula

Basin at elevations at, or below, former lake levels. Intimately associated with glacial and glacio-fluvial sediments are beach and deltaic deposits as well as scattered, sparse remnants of glacio-lacustrine detritus.

The east side of the Bitterroot Valley is bordered by the lower and less-imposing Sapphire Mountains. Along the length of the west flank of this range and the foothills belt adjoining it, a multitude of closely spaced strandlines marking former stands of Lake Missoula are etched in delicate relief.

PREVIOUS INVESTIGATIONS

The glacial geology of the Bitterroot Range was first discussed by Lindgren (1904), who observed that "all the familiar phenomena of extensive glaciated areas are represented in the Bitterroot Range on a grand, instructive scale." The earliest comprehensive study of glacial Lake Missoula was made by Pardee (1910), who described in considerable detail the gross features of the lake, its approximate extent, the location of the ice dam, and many of its geomorphic effects. Subsequently, Pardee (1942) devoted further attention to unusual geomorphic features within the Lake Missoula Basin and their hydraulic interpretation.

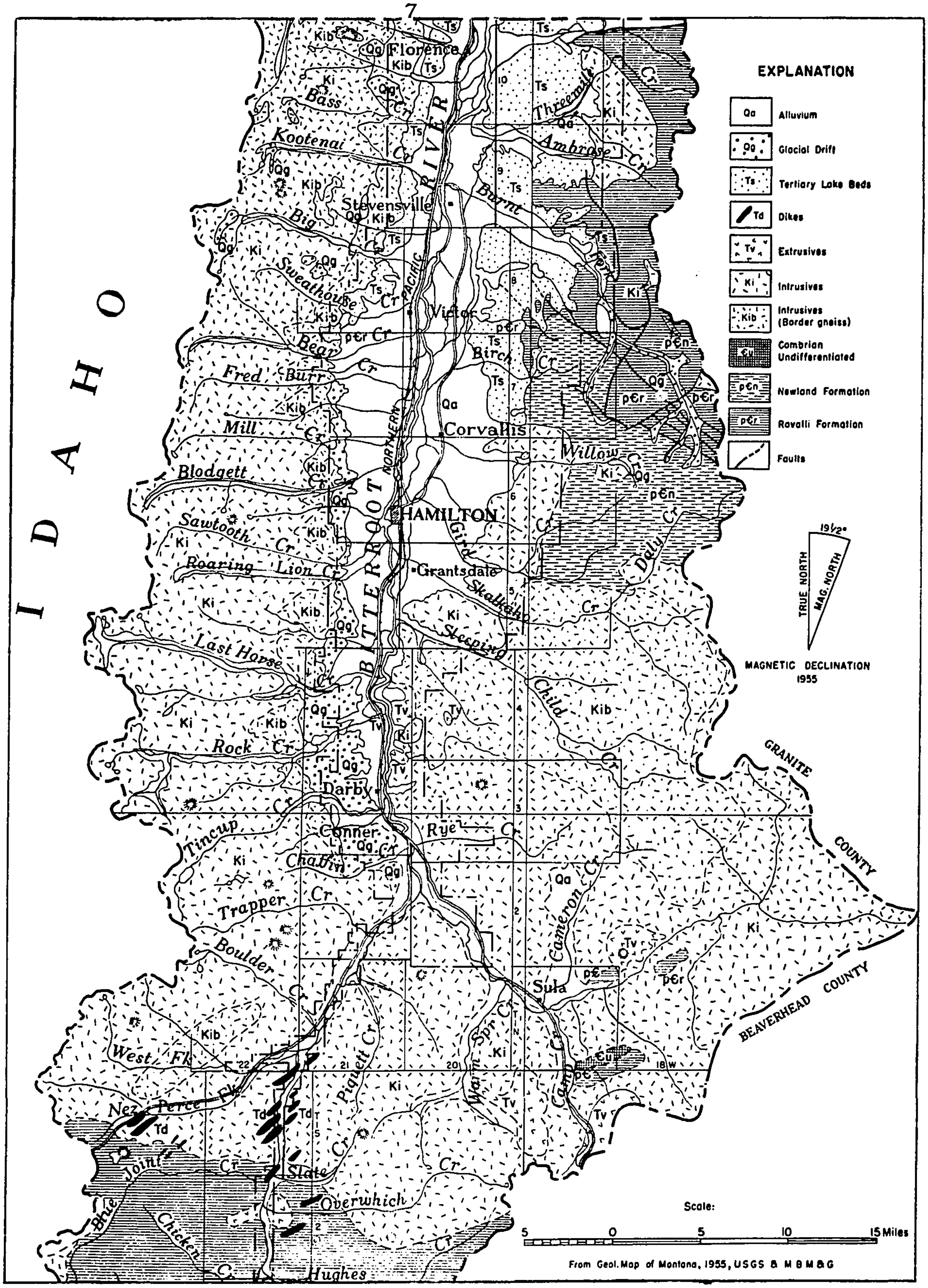
In 1953, Alden published the first, and to date the only, detailed survey of the physiography and glaciation of the Bitterroot Range. He recognized a sequence of piedmont surfaces and stream terraces inferred to range in age from Pliocene (?) to late Pleistocene. Alden also described the morainal sequence at several of the canyon mouths along the length of the Bitterroot Range. Using the freshness of the moraine morphology and the relation of glacial drift and moraines to the terrace sequence, he inferred three major episodes of glaciation and assigned them to the Early Pleistocene (?), Illinoian or Wisconsin (Iowan), and the Wisconsin.

The chronology and correlations made by Alden (1953) were the result of a reconnaissance of approximately 50,200 mi^2 of western Montana during almost 30 years. To a considerable extent Alden's Pleistocene chronology was established earlier in eastern Montana (Alden, 1932). Subsequent workers in the Bitterroot region have based their studies largely upon the chronology established by Alden, and little detail has been added to the Pleistocene history of the region.

BEDROCK GEOLOGY

The bedrock geology of the Bitterroot Valley is fully described by Langton (1935), Ross (1950), and Pardee (1950). A generalized geologic map of the valley is presented as Figure 2.

The granitic rocks of the Idaho Batholith consist of light-grey, coarse-grained to porphyritic, frequently gneissic quartz monzonite. Although typically composed of quartz, orthoclase, oligoclase, and biotite, the composition of these



From Geol. Map of Montana, 1955, USGS & M B M & G

Figure 2 - Generalized geologic map of the Bitterroot Valley.

rocks varies considerably, especially near the gneissic border zone. In the rocks which exhibit a gneissic structure, biotite tends to be concentrated in thin, discontinuous laminae, and the long axes of the quartz and feldspar grains are roughly parallel to these laminae (Ross, 1950).

The Bitterroot Range front is underlain by gneissic and schistose granitic rocks dipping 18-26° east (Lindgren, 1904; Ross, 1950). Because of the structural orientation of this gneissic zone, peripheral to the granites and quartz monzonites of the Idaho Batholith, and a very well developed and closely spaced joint pattern, the range front was highly susceptible to glacial plucking and scour. As a result, drift deposited by the Bitterroot glaciers that traversed all or part of the 1- to 4-mile broad gneissic zone has a high percentage of gneissic lithologies.

GLACIAL GEOLOGY

Introduction

Summit elevations of the Bitterroot Range show a general rise of 400-600 ft towards the southern portion of the range. Similarly, an increase of 200-300 ft in the elevation of tributary canyon mouths is observed southward along the north-draining trunk stream. Thus, as one proceeds from north to south along the front of the range, the evidence of glaciation becomes more widespread (Fig. 3). Carlton, One Horse, Bass,

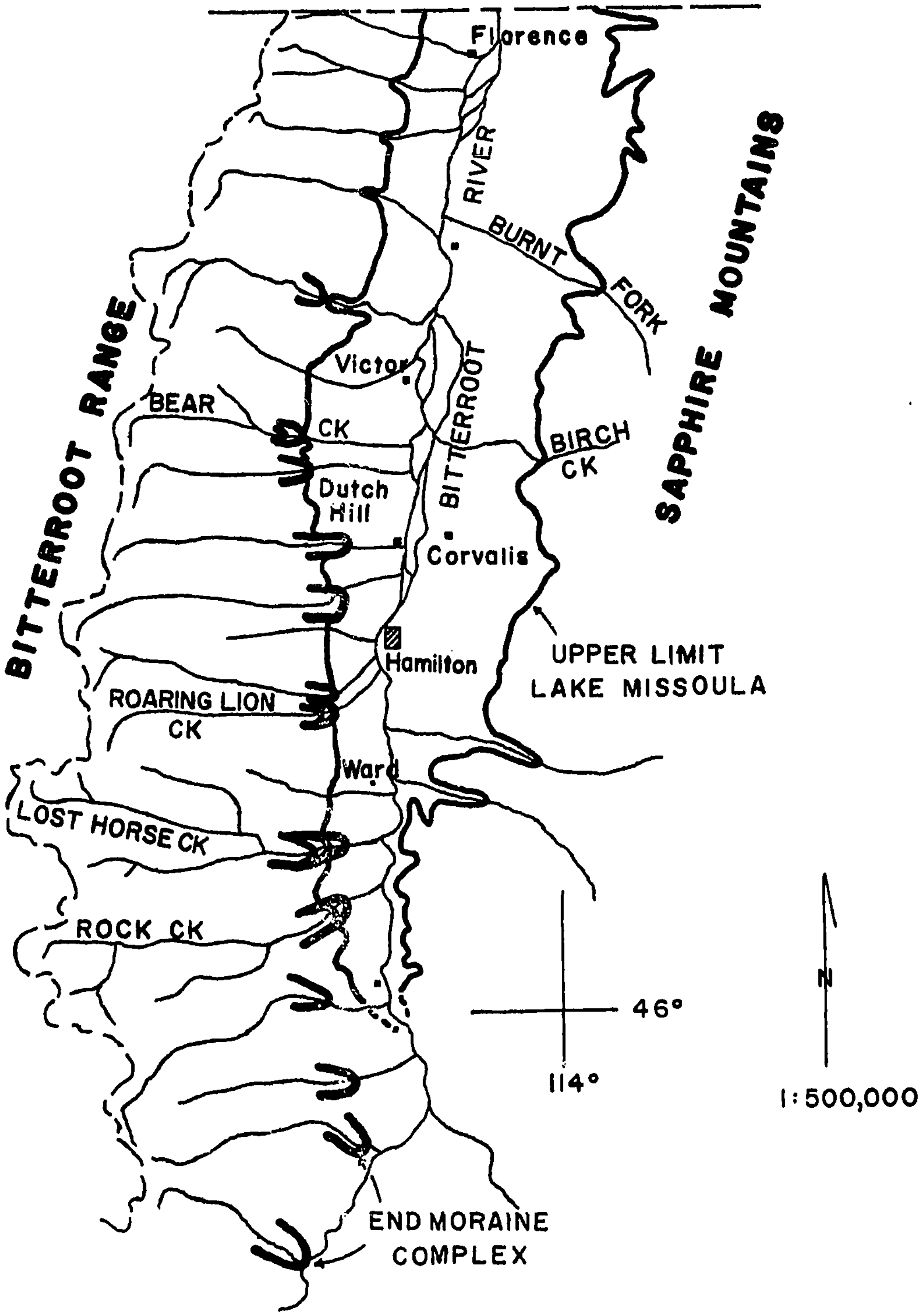


Figure 3 - Major glaciated valleys of the Bitterroot Range and the upper limit of glacial Lake Missoula.

Kootenai, and Big creeks emerge from the abrupt Bitterroot front along the northern part of the range in narrow, steep gorges, the lower parts of which apparently never were glaciated. Farther south, the canyon mouths from Bear Creek to Rock Creek are broadly U-shaped and plugged with a sequence of nested moraines. The looping end moraines and high, sweeping lateral moraines lie close to the mountain front at Bear Creek and about two miles beyond the mountain front at Rock Creek.

Four valleys along the front of the Bitterroot Range were selected for study of details of the alpine glacial sequence (Fig. 3). From north to south, they are the drainages of Bear, Roaring Lion, Lost Horse, and Rock creeks. Bear Creek, approximately 10 mi north of Hamilton, Montana drains into the portion of the Bitterroot Valley referred to locally as the "lower valley". In this region, from Hamilton north to Lolo, the Bitterroot Valley reaches a maximum width of approximately 15 mi and is characterized by the braided pattern of the Bitterroot River and the wide geographic extent of the Pleistocene geomorphic surfaces.

In the "upper valley", from Hamilton south to the Bitterroot drainage divide, the valley narrows markedly and commonly is from 1 to 5 mi wide. In this segment, characterized by a meandering river channel and prominent piedmont interfluves, Roaring Lion, Lost Horse, and Rock creeks join the main stream.

In each of the four valleys moraines extend below the uppermost strand of glacial Lake Missoula. Access to the lower reaches of the valleys is by United States Forest Service roads; in Lost Horse Creek the Bitterroot Range Divide and the Idaho state border can be reached along the only USFS road penetrating the Bitterroot Range.

The glacial record in the Bear, Roaring Lion, Lost Horse, and Rock creek drainage basins has been used to define the stratigraphic sequence of alpine glaciation in the Bitterroot Range and to serve as a local stratigraphic framework for the fluctuations of glacial Lake Missoula.

Criteria of Age and Means of Correlation

The Quaternary stratigraphic units recognized in the Bitterroot region are presented in Table 1. The relative age of these stratigraphic units has been determined largely through their geomorphic expression and weathering characteristics. The following discussion summarizes the criteria on which these relative-age assignments were based.

Morphology

The relative freshness of the morphologic expression of the surficial Pleistocene units yields a general subdivision of these units. The relative height, sharpness of crest, size of the largest erratic, presence or absence of

Time-stratigraphic units		Rock-stratigraphic units		Soil-stratigraphic units	Morphologic units
Quaternary Period	Holocene Epoch			Moose Creek paleosol	
	Pleistocene Epoch	Lost Horse Drift	Upper Member		Riverside terrace
			Middle Member		
			Lower Member		
				Ward paleosol	
		Charlos Drift	Upper Member		Hamilton terrace Poverty surface
			Lower Member		
				Indian Prairie paleosol	
		Judd Drift			Dutch Hill terrace

Table 1 - Pleistocene stratigraphy of the Bitterroot Valley.

kettles, and the degree of incision or breaching by the stream delineate a basic two-fold subdivision of the nested moraines near the canyon mouths. The same features can be used to characterize the isolated morainal loops located at higher elevations in the Bitterroot Range.

As most of the morainal drift lies at, or slightly beyond the mountain front, the human influences of clearing, grazing, and cultivation often obscure natural morphology, thereby influencing the apparent relative age difference. For example, the widespread construction of stone fences (some reaching 6 ft in height, 14 ft in width, and 0.25 mi long) and rock piles in areas underlain by moraines or related drift have precluded the use of surface boulder frequency as a relative-age parameter.

Granite Weathering Ratios

Granite weathering ratios (GWR) were determined for the morainal sequence of the Bitterroot Range using the method of Blackwelder (1931). All GWR determinations were done by sampling 50 quartz-monzonite cobbles, three inches or more in diameter, lying on moraine crests or very gently sloping surfaces. The cobbles were assigned to three separate classes: fresh, partly rotted, and rotted. Fresh cobbles were defined as those unaffected by a hard blow of the rockhammer. Partly rotted cobbles show surface disintegration or minor cracking upon striking, and rotted cobbles show complete disintegration or crumbling where hit. Table 2 lists the average GWR values

DRAINAGE DRIFT	ROCK CREEK	LOST HORSE CREEK	ROARING LION CREEK	BEAR CREEK
LOST HORSE DRIFT	46-54-0 44-56-0 42-58-0 42-58-0 40-60-0 38-62-0 38-62-0 32-68-0 30-70-0 30-70-0 30-70-0 28-72-0	74-26-0 72-28-0 68-32-0 62-38-0 62-38-0 60-40-0 60-40-0 60-40-0 58-42-0 52-48-0 46-54-0 40-60-0 40-60-0 32-68-0	30-70-0 30-70-0 28-72-0 22-78-0 20-80-0 20-80-0 16-84-0 16-84-0 14-86-0 14-86-0 12-88-0 12-88-0 12-88-0	28-72-0 22-78-0 22-78-0 18-82-0 16-84-0 16-84-0 16-84-0 16-84-0 14-86-0 14-86-0
CHARLOS DRIFT	16-84-0 12-84-0 10-90-0 8-92-0	22-76-2 18-80-2 18-80-2 18-78-4 18-78-4 16-80-4 12-88-0 12-88-0 10-86-4	10-90- 0 10-90- 0 10-90- 0 6-88- 6 4-96- 0 4-86-10 2-98- 0 2-96- 2 2-94- 4	4-96-0 4-94-2 4-94-2 4-94-2 2-94-4 4-94-2 4-94-2
JUDD DRIFT	2-92- 6 2-92- 6 0-94- 6 0-92- 8 0-90-10 0-90-10	2-82-16 0-96- 4 0-96- 4 0-86-14 0-82-18 0-82-18	0-78-22 0-62-38 0-62-38	

Table 2 - Average Granite Weathering Ratios of drift units in select drainages of the Bitterroot Range, Montana. Each ratio represents the average of three or more determinations at a single site.

obtained on the Bitterroot Range moraines. Within any single drainage basin GWR values delineate a 2- or 3-fold subdivision of the morainal sequence and tend to show progressive variation within a single relative-age group. However, regional lithologic variation of the quartz monzonite is sufficient to alter the absolute values expressed in the GWR and, thus, precludes detailed intrabasin correlation. Probably weathered drift of earlier glaciations is reworked and incorporated in the drift of the initial advances of later glaciations, thereby producing a greater apparent spread in the GWR values of a single drift unit.

Terrace Development and Correlation

Terraces and outwash fans in the Bitterroot Valley provide yet another basis of inter- and intrabasin correlation and relative-age determination of the Pleistocene units. Prominent outwash terraces and outwash-fan complexes developed during the glacial intervals. The lowest outwash terrace, here termed the Riverside terrace, lies approximately 10-15 ft above the floodplain, and extends through the outermost moraine complex, heading at or near the inner group of moraines. A second terrace, here termed the Hamilton terrace, heads at the front of the outermost moraine complex approximately 5-20 ft above the Riverside terrace, and is found within the valley walls of the tributary drainages and along the Bitterroot

River. Both the Riverside and Hamilton terraces converge downvalley. Correlation of these and other terrace remnants is based largely upon the position of the terrace relative to the modern floodplain and on the character of the soils developed upon terrace surfaces.

North of Roaring Lion Creek, broad outwash-fan complexes, rather than terraces, head at the outermost moraine loops. These outwash fans have no lateral constraints, and coalesce to form a nearly continuous piedmont outwash plain here named the Poverty surface. Incised into the Poverty surface are the present channels and lower terrace remnants. Along the trunk stream both the Riverside and Hamilton terraces cut the Poverty surface. Elsewhere, the alluvium of the Hamilton terrace appears to intertongue with or overlie the Poverty surface. These relationships demonstrate that portions of the Poverty surface were constructed prior to the completion of the Hamilton outwash terrace.

Standing above this terrace and fan sequence are highly dissected remnants of the "great second terrace" of Alden (1953, p. 68). This terrace or bench remnant, here called the Dutch Hill terrace, forms the interfluves between many of the tributary drainages of the Bitterroot and Sapphire ranges. The altitude of the Dutch Hill terrace decreases northward, with most interfluve remnants ending in a low line of bluffs (100-250 ft above the present floodplain) where they have been cut back by the shifting Bitterroot River. All of the interfluve remnants grade away from the mountain front toward the axial stream and commonly are defended in their lower segments by truncated bedrock knobs.

The highest geomorphic surfaces in the Bitterroot Valley appear to comprise a highly dissected, narrow piedmont belt extending 1 to 3 mi beyond the mountain front and heading 1000 ft or more above the course of the Bitterroot River. Within the area of the valley covered by this study this surface or group of surfaces consists of steep, narrow-crested, drift-covered, bedrock-cored, interfluve spurs graded from the mountain front. Both granite gneiss and Tertiary "lake bed" sediments have been observed very near the crests of these spurs. The most spectacular, sweeping lateral moraines in the Bitterroot Range are built on the crest and flanks of these bedrock spurs. Alden (1953) saw considerable similarity between these surface remnants and other remnants of high benches ("No. 1" terrace) along the east front of the Rocky Mountains. The "No. 1" terrace is currently considered correlative with the Flaxville Plain of eastern Montana and is judged to be Miocene or Pliocene in age (Lembke and others, 1965, p. 25).

Soils

The soils of the Bitterroot Valley region are remarkably diversified. A detailed soil survey of the area defined over 50 soil series of which 36 soils were considered zonal (Soil

Survey Staff, 1959). Among the zonal order of soils present in the Bitterroot Valley the Brown, Chestnut, Chernozem, Gray Wooded, and Brown Podzolic great soil groups are represented.

Developed on the various landscape or geomorphic elements previously discussed, a characteristic group of soils occurs in a characteristic pattern. These soil-landscape associations are consistent over wide areas. Although the individual soil members of a single soil association may consist of zonal, intrazonal, and azonal soil series, the better developed or zonal soils are the most characteristic of the association. In a similar manner, the differences between the various soil associations is best developed between the zonal members of the respective associations.

The relative degree of soil-profile development serves as a useful index for comparing the difference between the various soil-landscape associations. Soil profile descriptions, as well as limited data on the textural development of the soils, have been used to document the degree of profile development (Fig. 4).

Critical examination of the mapped soil-landscape associations also reveals that the soil group found on any single geomorphic or landscape element shows regional, and to a certain extent altitudinal, variation due to local variation in the soil forming factors. In this respect, evaluation of Jenny's (1941) soil-forming factors point up

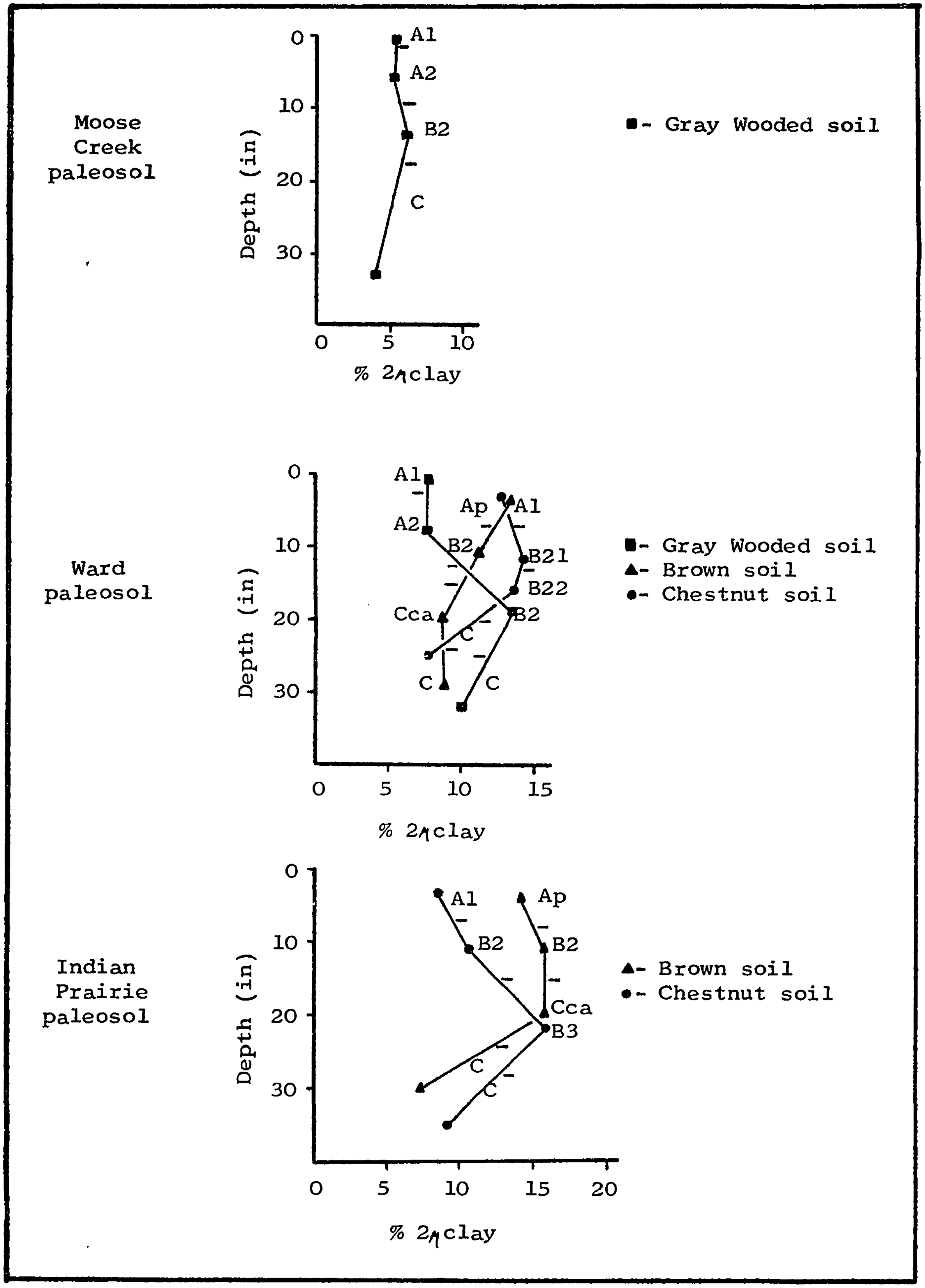


Figure 4 - Textural variation of Bitterroot Valley paleosols. All textural data on Brown and Chestnut soils is taken from Soil Survey Staff (1959, p. 15-17).

several regional differences and similarities in the Bitterroot region. The parent material of the terraces and fans of the west side of the valley is broadly similar, and consists largely of quartz monzonite, while on the east side Tertiary and Precambrian sedimentary rocks and Cretaceous-Tertiary (?) granites, differing noticeably from the Bitterroot Range quartz monzonites, contribute substantial quantities of detritus to the terrace and fan complexes.

Although detailed meterologic data are lacking for all but a few points in or adjacent to the Bitterroot Valley, the present floristic patterns suggest that a strong precipitation gradient, and to a lesser extent, temperature gradient, exists from west to east across the region (Donald R. Graham, personal communication, 1969). Unpublished data and observatinns indicate that annual precipitation along the Bitterroot front may be as high as 30 in, while the east front of the Sapphire Mountains may receive as little as 7 in. The common occurrence of caliche horizons in the modern soils and relict paleosols of the east side benches, as contrasted with the absence of caliche on the west side benches, may point to the persistance of a similar climatic gradient throughout the soil-forming intervals of the late Pleistocene.

Despite such inherent differences, the soils of any one soil-landscape association commonly maintain a near-uniform degree of soil profile development relative to the profile development of the adjacent associations. The only marked deviation from this general rule appears when the soils above the highest Lake Missoula strandline (approx. 4200 ft) are contrasted with the soils located below this level.

Thus, apparently despite interregional variation in the soil-forming factors, the major zonal soils of the soil-landscape associations maintain constant relationship relative to one another. On this basis, three soil-stratigraphic units, here termed relict paleosols (Ruhe, 1965), are recognized and correlated within the Bitterroot area. These paleosols, from oldest to youngest, are called the Indian Prairie, Ward, and Moose Creek paleosols.

Judd Drift

The occurrence of many large, highly weathered boulders of granite and gneiss located high on the interfluve spurs above more clearly defined lateral moraines prompted Alden (1953) to suggest an episode of early Pleistocene glaciation in the Bitterroot Range. The boulders, many 10 to 20 ft in diameter, are especially common where high, interfluve spurs join the mountain front. Close examination of these highly weathered boulders has disclosed that, without exception, they were derived from the nearby gneissic zone of the mountain front. This foliated granitic or quartz-monzonite rock is, in all drifts examined, more prone to splitting along planes of foliation and to granular disintegration than the more massive plutonic rocks of the main Idaho Batholith. Thus, many of Alden's highly weathered "early" Pleistocene erratics are found in association with much less-weathered quartz-monzonite and granite stones. Consequently, an "early" Pleistocene age for these deposits appears unlikely. Most of the erratic boulders can be related to the outermost group of end moraines which consist of Charlos Drift. However, a few bouldery deposits on interfluve remnants adjacent to the drainages of Lost Horse and Rock creeks, as well as adjacent to Judd Creek (just south of Roaring Lion Creek) appear to lie outside the limit of Charlos Drift.

Definition

Judd Drift (Fig. 5) is named for a bouldery diamicton, interpreted as till, on the north side of Judd Creek (S ½ sec. 15, T.5 N., R.21 W.). The till in this type area is composed of a poorly sorted assemblage of angular to subrounded boulders and cobbles of quartz monzonite, granite, and gneiss in a coarse sandy matrix. Granite weathering ratios are typically 0-62-38 to 0-78-22 in the type deposit of this drift (Table 2).

The largest erratic found in the till measures 10 by 12 by 7 ft and protrudes from the northeast side of the deposit at an elevation of 3910 ft. The till apparently is truncated by erosion near its upper limit of exposure at 4600 ft and is overlain by the right-lateral moraine of Charlos Drift in

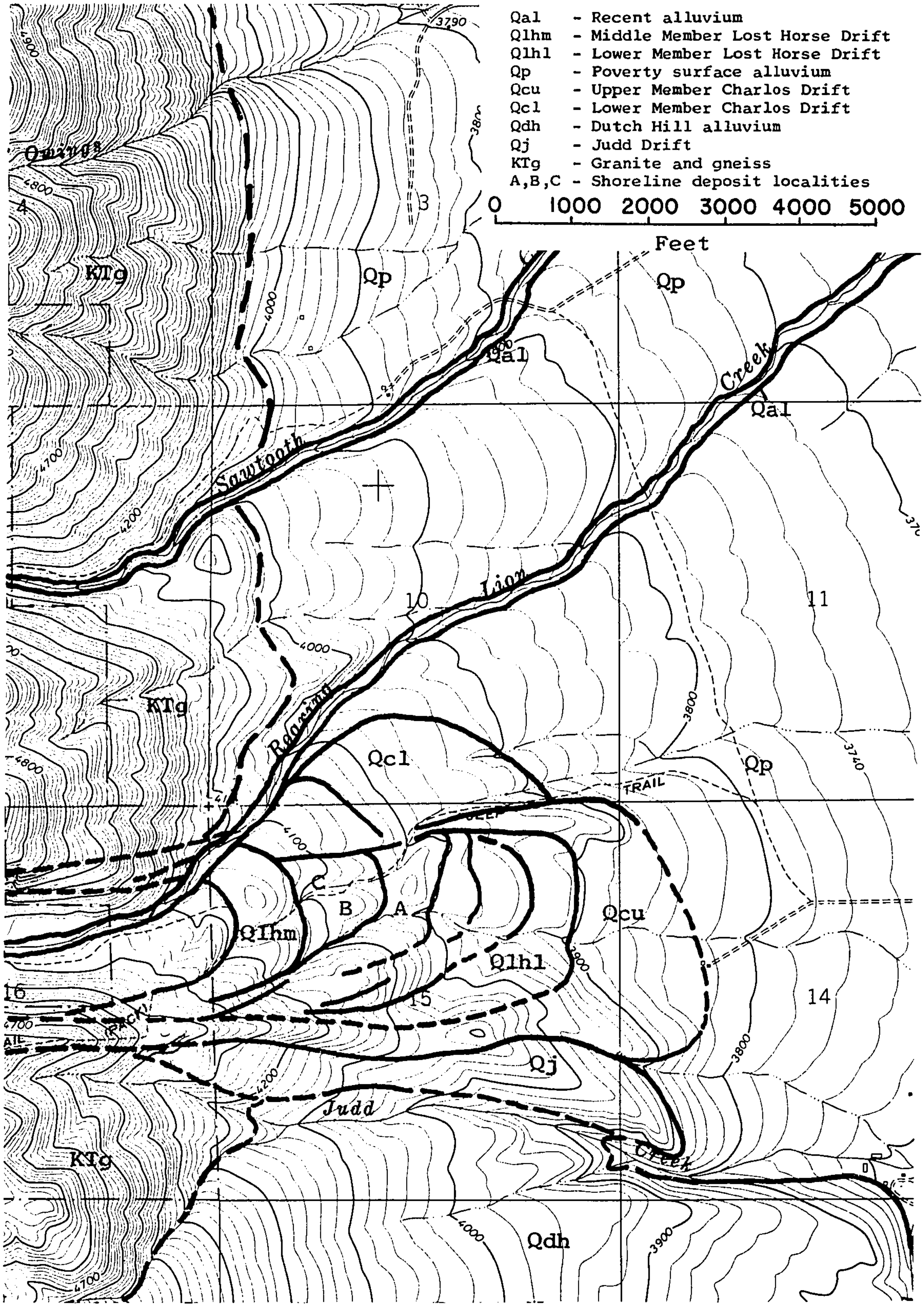


Figure 5 - Drift deposits at Roaring Lion Creek.

the drainage basin of Roaring Lion Creek. The till can be traced downslope to nearly 3880 ft where it locally is overlain by younger alluvium and colluvium.

The till of the type area forms a smooth, low, east-southeast-trending ridge below 4080 ft and appears to form a pre-Charlos right-lateral moraine along Roaring Lion Creek. In its upper portion, the outcrop is restricted to the south side of the ridge capped by the outermost Charlos lateral moraine. This Charlos lateral moraine apparently is constructed upon Judd till, which in turn overlies gneiss of the Bitterroot frontal zone, although this basal contact is not exposed in the Judd Creek drainage basin.

Drift in the Lick Creek Area

The area between the major tributary drainages of Lost Horse and Rock creeks is drained by a small stream named Lick Creek. Unlike the major tributaries that head at the crest of the Bitterroot Range, Lick Creek drains only a small area on the Bitterroot Range front. At the time the Judd Drift was deposited, however, ice from both the Lost Horse and Rock Creek drainage basins spilled over the Lick Creek drainage divides and formed a broad, coalescent, piedmont glacier in the upper reaches of Lick Creek.

Scattered formless drift and large erratics occur throughout this drainage basin, well beyond the morphologically distinct moraines of later glaciations (Fig. 7). The largest erratic found in the Lick Creek area measures 6 by 6 by 2.5 ft and protrudes from a south-facing slope at an elevation of 4140 ft. GWR values for these deposits are included with values for the Lost Horse and Rock Creek drainages in Table 2.

Dutch Hill Terrace

The Dutch Hill terrace is named for Dutch Hill (sec. 35, T.7 N., R.21 W.) northwest of Hamilton, Montana, where it is well developed. The terrace is highly dissected and composed of piedmont alluvium deposited at the foot of both the Bitterroot Range and Sapphire Mountains. The terrace deposits occur as interfluve remnants along the entire length of the Bitterroot Valley, although the terrace is best preserved in the southern part of the valley.

Along the front of the Bitterroot Range, the terrace remnants commonly slope from 60-120 ft/mi towards the Bitterroot River. In the upper valley near Rock Creek the Dutch Hill terrace is truncated by lower terraces along the river and stands as a high bluff at an approximate elevation of 4000 ft, or 180 ft above the river. The terrace grades upward to the mountain front where it merges imperceptibly with steeper slopes at an approximate elevation of 4200 ft.

Near Lost Horse Creek the Dutch Hill terrace stands as a high line of bluffs or foothill belt 150 to 200 ft above the river, rising from between 3900 and 3960 ft near the river to approximately 4200 ft at the mountain front. On the north side of Lost Horse Creek a remnant of the Dutch Hill terrace stands as a narrow interfluve flanked by lower terraces and traversed along its length by the main road into the Lost Horse drainage. Shallow roadcuts expose a highly weathered, subrounded to rounded, boulder-cobble gravel. Many cobbles of both quartz monzonite and the border gneiss are so intensely weathered as to be "ghosts"; i.e., the outline of the weathered cobble is barely perceptible, as weathering has caused the texture and internal cohesiveness of the cobble to become nearly indistinguishable from the arkosic gravel matrix. GWR values at this site average 2-86-12 and reflect the relative frequency of the thoroughly weathered, "ghost" cobbles.

Adjacent to the mouth of Bear Creek stand several low remnants of the Dutch Hill terrace. Near the Bitterroot River the terrace stands at an elevation of approximately 3480 ft, or 100 ft above the river, and rises 80 to 160 ft/mi until it merges with the mountain front at approximately 4100 ft. Photogeologic reconnaissance of this segment of the lower valley suggests that the range-front fault has been active subsequent to the development of the Dutch Hill terrace, and consequently the upper limit of this terrace may only be the trace of the fault. The field evidence for faulting in this area is rather ambiguous; however, the elevations of Pleistocene features in this region may not agree with similar features in less tectonically active parts of the valley. Furthermore, in 1898 faulting took place near the mouth of Big Creek, some five miles north of Bear Creek. Records indicate that 1 to 2 ft of displacement occurred along a fault trace 3000 ft in length, the downthrown block being the eastern or Bitterroot Valley block (Lindgren, 1904, p. 49).

Two high-standing remnants of a massive alluvial-fan complex on the east side of the Bitterroot Valley, flanking the nonglaciated Burnt Fork of the Bitterroot River, are correlated with the Dutch Hill terrace. The alluvial-fan complex has been dissected longitudinally into two nearly symmetrical halves by the Burnt Fork, and lower terraces flank its channel. Near the river, the fan remnants stand at an elevation of 3480 to 3680 ft, or 220 to 380 ft above the river, and grade from 100 to 150 ft/mi to the front of the Sapphire Mountains where they merge at an elevation of approximately 4600 ft. Near the apex of the fan, exposures reveal as much as 100 ft of interbedded, coarse- to fine-grained sand and cobble gravel overlying the highly calcareous sand, silt, and conglomerate of the Bozeman "lake beds" (Miocene-Pliocene ?). Closer to the mountain front alluvium overlying the "lake beds" is generally much thinner. Observations also indicate that parallel to the mountain front the contact between the fan alluvium and the "lake beds" has considerable relief.

In the lower valley at Dutch Hill, the terrace lies a mile west of the Bitterroot River. The upper surface of the terrace grades from about 3700 ft, or 140 ft above the river, to 4100 to 4200 ft at the mountain front. Roadcuts and gravel pits on the flanks of this terrace expose fine-grained gravels and, to a lesser extent, cobble gravels.

Similar fine-grained gravels are exposed elsewhere in the side of the Dutch Hill terrace in both the upper and lower valley. One excellent exposure in the upper valley is located at the mouth of Bunkhouse Creek and is shown diagrammatically in Figure 6A. The lignite chips in the basal bed very likely were derived from the Bozeman "lake beds" which crop out nearby in the upper valley, and thus may indicate a Pleistocene age for the lowest unit exposed.

In the lower valley, approximately two miles northeast of Florence, a thick section of fine-grained gravel and sand with interbedded clay is exposed in a steep cliff where the Bitterroot River swings against the edge of a remnant of the Dutch Hill terrace (Fig. 6B).

The section was first described by Alden (1953, p. 21), who assigned the sediments below the humic-stained clay "soil" to the Bozeman "lake beds". The only fossils that have been found in this exposure are a few fragments of silicified, dicotyledonous wood embedded in the sand about 15 ft below the disconformity. Eight miles south, Pardee (1913, p. 234) reported a few Miocene vertebrate remains in light-colored sands and tuff just north of Stevensville. Correlation was inferred between these areas, but there is some doubt about the inferred Miocene age of the lower sediments in the cut near Florence.

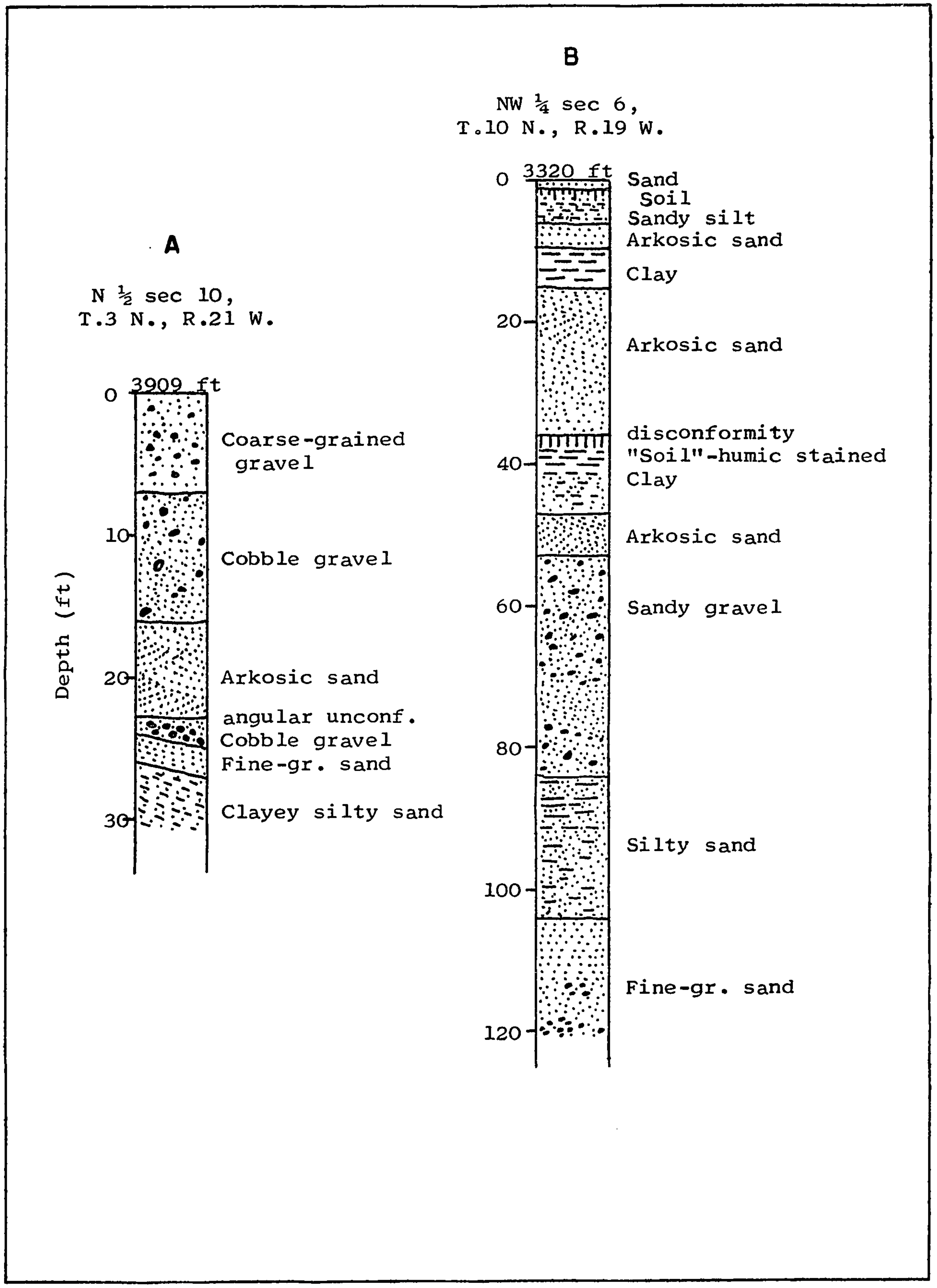


Figure 6 - Stratigraphic sections of fine-grained sediments underlying the Dutch Hill terrace.

Elsewhere in the lower and upper valley of the Bitterroot, where Bozeman "lake beds" were observed during the present study, the sediments are prominently indurated with a firm calcite cement and, if fine-grained, are commonly rich in volcanic ash. Thus, a Quaternary age for the lower nonindurated sediments of both sections seems reasonable, in view of the regional character of the Miocene-Pliocene (?) units.

In both the Bunkhouse and Florence sections it is not clear whether the upper sediments are Dutch Hill terrace alluvium or truncated pre-Dutch Hill alluvium. Outcrops elsewhere suggest that the latter relationship is true. Between Rock Creek and Roaring Lion Creek the Dutch Hill terrace scarps frequently expose truncated granitic gneiss or Tertiary rhyolite overlain by variable thicknesses of coarse cobble gravel. This cobble gravel can be found capping most of the dissected remnants of the Dutch Hill terrace, but exposures of the contact between the uppermost cobble gravel and the fine-grained sediments in the terrace are lacking.

The lithologic contrast between the cobble gravels and the fine-grained sediments suggests markedly different stream regimens, and therefore the uppermost gravel of the Dutch Hill terrace is inferred to be an outwash facies of the Judd Drift. However, exposures have not been found to confirm direct stratigraphic correlation between the gravels and till of the Judd Drift.

Indian Prairie Paleosol

A geomorphically distinct soil, here formally defined as the Indian Prairie paleosol, is widespread on remnants of the Dutch Hill terrace as well as on the sparse remnants of the Judd till. The type locality of the Indian Prairie paleosol is approximately four miles north of Victor, in an area locally known and referred to on USFS maps as Indian Prairie (SE ¼ SW ¼ Sec. 6, T.8 N., R.20 W.). There it is developed on outwash gravel of the Dutch Hill terrace and is exposed on this geomorphic surface as a relict paleosol (Ruhe, 1965). The paleosol comprises several mapped soil series of zonal and intrazonal order (Soil Survey Staff, 1959). The major soil series represented are members of the Brown, Chestnut, and Planosol great soil groups, and include the Bass, Blodgett, Charlos, Burnt Fork, Ravalli, and Willoughby soils.

The individual soils series comprising the Indian Prairie paleosol are distinct from other soil series in the Bitterroot region by their consistent association with the same geomorphic surface (Dutch Hill terrace) and by their greater degree of profile development compared with other mapped soil series. The paleosol has not been traced into a buried occurrence between major stratigraphic units in the region, but has been observed to be buried locally by colluvial deposits.

The paleosol is recognized in two facies. The Chestnut soil facies is developed widely on the granitic and gneissic terrane along the west side of the valley, whereas the Brown soil facies is developed on Tertiary siltstones and conglomerates common to the east margin of the valley.

The following is a typical Chestnut soil-facies profile (Soil Survey Staff, 1959, p. 75):

Type Locality Profile of the Indian Prairie Paleosol,
Flank of Bitterroot Range
SE ¼ SW ¼ sec. 6, T.8 N., R.20 W.

A1	0 to 7 in, very-dark-gray (10YR 3/2), coarse sandy loam; moderate crumb structure; slightly acid.
B2	7 to 13 in, Brown (10YR 5/3), gritty loam or coarse sandy loam; weak, subangular, block structure; somewhat sticky but friable; slightly acid.
B3	13 to 24 in, Brown (10YR 5/3), coarse sandy loam; contains strongly weathered cobbles and boulders; slightly acid.
C	24 to 48 in, grayish-brown (10YR 5/2), strongly weathered quartz monzonite boulders and cobbles in matrix of coarse, arkosic sand and gravel; sediment becomes looser and less weathered with depth.

Soil profiles on the east side of the valley reflect the greater diversity of parent material and greater aridity of the east side. The lithologically variable, highly calcareous Bozeman "lake beds" underlying most geomorphic surfaces on the east side yield greater profile variation as contrasted with the soils of the granitic terrace. The following is a typical

Brown soil facies profile (Soil Survey Staff, 1959, p. 33):

Profile of Indian Prairie Paleosol,
Flank of Sapphire Range
SE ¼ SW ¼ sec. 23, T.7 N., R.20 W.

Ap	0-8 in, very dark-grayish-brown (10YR 3/2), friable loam; fine to medium crumb structure; a few pebbles and cobbles scattered on the surface and through the soil; moderate organic matter content.
B2	8 to 15 in, brown (10YR 5/3), friable loam; weak, medium subangular blocky structure; noticeable gravel and cobble content; clear transition to the Cca horizon.
Cca	15 to 24 in, very-pale-brown (10YR 8/3), friable loam; massive; very highly calcareous; gradual transition to C horizon.
C	24 to 48 in, white to very-pale-brown (10YR 8/2, 8/3), highly calcareous, gravelly, silty sand; cobbles mainly granite but some quartzite present.

The distribution of clay-size sediment for the west- and east-side soil profiles is shown in Figure 4.

Charlos Drift

Charlos Drift in the Bitterroot Valley includes till and outwash gravel. These deposits locally overlap the Judd Drift or occur in channels eroded in the older deposits. The upper limit of till of the Charlos Drift commonly lies below and within the limits of till of the Judd Drift. Locally, till of the Charlos Drift can be subdivided vertically into two distinct units. The deposits characteristically have a Brown or Chestnut soil formed on them, and they are the youngest deposits to bear these soils.

Adjacent to the mountain front or within the mouths of canyons the Charlos Drift is either overlapped by Lost Horse Drift or is cut by channels containing such deposits. Thus, the Charlos Drift represents a glaciation intermediate between the oldest recognized in the region and the last major glaciation of the canyons.

Definition

Charlos Drift (Fig. 7) is named for the till which underlies the low, rounded, outermost set of moraines at the mouth of the canyon of Lost Horse Creek (sec. 9, 19, 15, & 16, T.4 N., R. 21 W.). The name is derived from the small community just to the north of the type area.

Till in the type area consists of moderately weathered, poorly sorted, subrounded to angular boulders and cobbles in a compact matrix of arkosic sand and silt. Boulders and cobbles are relatively common on the undisturbed surfaces of moraines, but many areas have been cleared for agricultural purposes. Most of the large boulders are gneiss of the Bitterroot Range frontal zone, whereas the cobble-size clasts are commonly quartz monzonite from the interior of the range. Most boulders

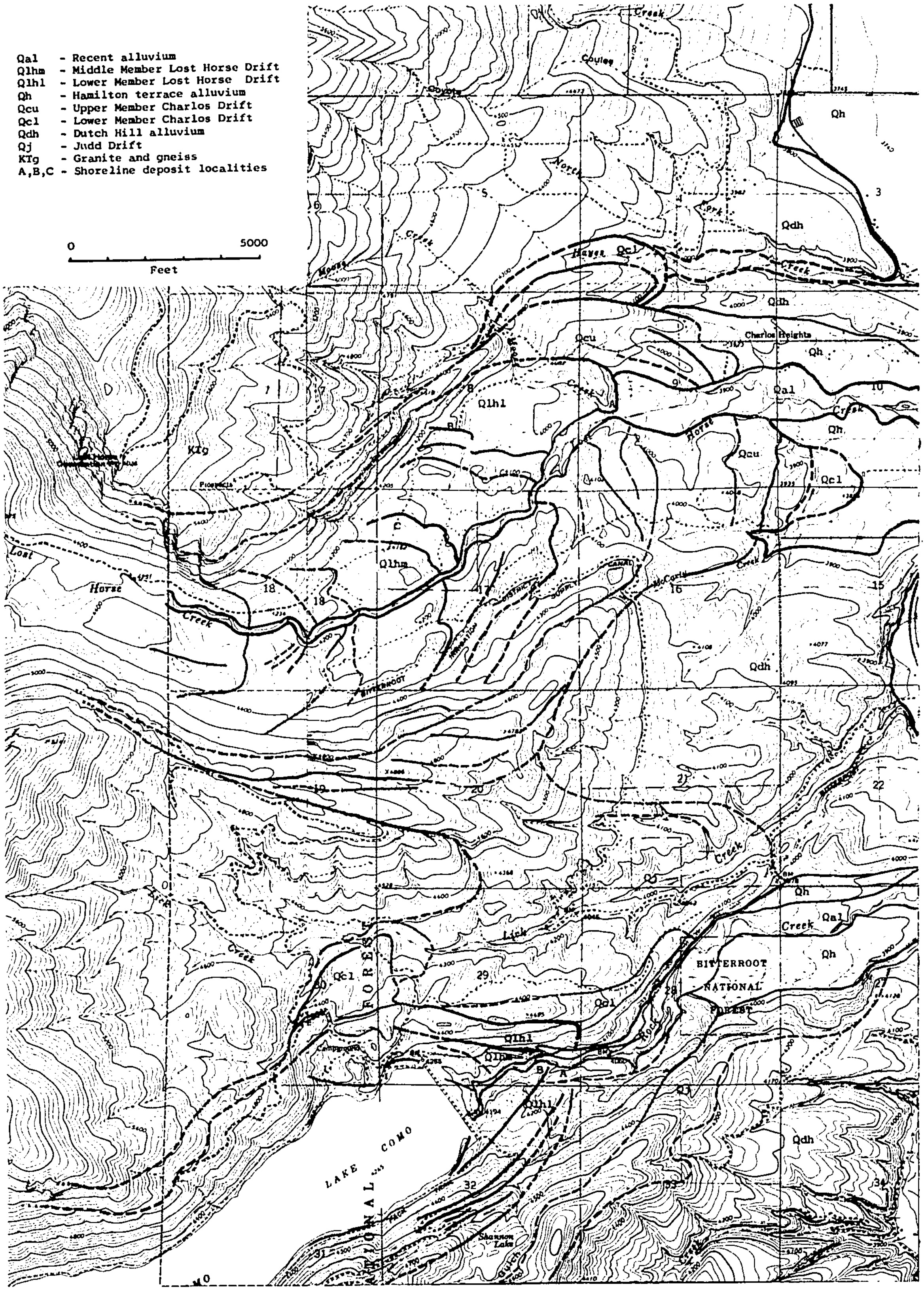


Figure 7 - Drift deposits at Lost Horse and Rock creeks.

are shattered or split, but some are deeply disintegrated.

Granite weathering ratios commonly range from 10-86-4 to 22-76-2 at the type deposit (Table 2), and reflect the abundance of moderately weathered debris in these moraines. Numerous hand-dug pits reveal that weathering of the till has produced a moderately developed zonal soil - the Ward paleosol - and that iron staining and oxidation has proceeded to considerable depth.

The outermost moraine in the type area extends to a lower elevation of 3840 ft, where it merges with an outwash terrace of the same age. Upstream from the outermost moraine three more dissected end moraines of similar character cross the valley, the uppermost overlapped by till of the succeeding Lost Horse Drift at an elevation of approximately 4020 ft.

The morainal belt lies within a broad channel cut into sediments of the Dutch Hill terrace. To the south, the well-developed south lateral moraine of Charlos Drift overlaps remnants of Judd Drift in the Lick Creek drainage basin. Excavations in this area reveal the characteristic Indian Prairie and Ward paleosols developed on the surface of their respective deposits, but no evidence of a buried paleosol separating the deposits could be found. Several of the cobbles incorporated in the Charlos Drift in this area are much more deeply weathered than adjacent cobbles of similar lithology. Apparently these rotted cobbles were scoured from the Judd Drift and mixed with till of the Charlos Drift; thus in the type area probably the weathered zone separating these two tills was largely, if not entirely, removed.

The moraines are relatively smooth in form, with minor colluvial deposits developed sporadically on the flanks of the moraines. Much of the rounding or smoothing of the surface of the moraines, however, does not seem to relate to the development of colluvium. The frontal or distal slopes of the moraines of the Charlos Drift in Lost Horse Creek, as well as many other canyons examined, are typically 15 - 20° steeper than the proximal slopes, many of which are practically flat. Boulders and cobbles also are more common on the distal moraine slopes, yet corresponding colluvial or alluvial deposits do not seem to be developed at the base of these slopes. The form of these moraines may be, in part, the product of wave erosion during an early cycle of glacial Lake Missoula. The boulder-rich moraine front may represent the lag concentrate of such wave erosion. Several excavations disclosed no significant difference in soil development on either distal or proximal slopes; consequently, wave modification of these moraines probably took place largely prior to development of the Ward paleosol.

Although no difference was discernable in the internal stratigraphy or degree of weathering of the four dissected Charlos end moraines in the drainage of Lost Horse Creek, their morphologic expression permits a two-fold subdivision of the Charlos Drift.

Upstream from the end moraine zone, moderately well-developed lateral moraines or boulder lines rise on both sides of the canyon. The left lateral moraine, before entering into the restricted canyon in the mountain front at 5080 ft, serves as a low drainage divide between Lost Horse Creek and the much smaller Hayes Creek (Fig. 7). In this section of Hayes Creek are two partially dissected, low, bouldery end moraine loops. The character of these moraines is identical with those of Charlos age previously discussed, except that they are truncated by the lateral moraine forming the drainage divide. When this lateral moraine is traced to the end-moraine zone it appears to merge with the third moraine in the sequence. Therefore, the two inner moraines apparently represent a readvance that truncated earlier moraines, and comprise Upper and Lower members respectively, of the Charlos Drift.

Moraines along Rock Creek

Charlos Drift is poorly preserved within the drainage basin of Rock Creek. Contrasted with Lost Horse Creek to the north, the lower part of Rock Creek, beyond the mountain front, is much narrower and more steep-sided. Thus, the effects of erosion have been concentrated largely within the valley of Rock Creek and much of the record has been destroyed.

Two well-developed lateral moraines flanking the mouth of the canyon at the mountain front descend from an elevation of 5200 ft to the valley floor where they join to form a single dissected end moraine at an elevation of 4000 ft (Fig. 7).

Granite weathering ratios along this moraine loop range from 16-84-0 to 8-92-0 (Table 2). Most of the erratic boulders are from the gneissic zone of the mountain front and commonly are split or shattered.

Soil capping the deposits in Rock Creek is more weakly developed than the soil formed on the moraines along Lost Horse Creek, but is thought to be equivalent to the Ward paleosol. The steeper slopes and greater landscape dissection in the Rock Creek area probably have resulted in considerable truncation of the soil.

The rounding and smoothing of the end moraine in Rock Creek is also not as pronounced as in Lost Horse Creek, but it is difficult to separate the effects of past and present erosion and mass-wasting in this valley.

The outermost moraine is assigned to the Lower Member of the Charlos Drift; moraines of the Upper Member are believed to have been eroded or overridden and buried beneath Lost Horse Drift.

Moraines along Roaring Lion Creek

Charlos moraines are moderately well developed at the mouth of Roaring Lion Creek (Fig. 5). A two-fold subdivision of Charlos Drift is again suggested by the bifurcated lobate pattern of the end moraines.

The northern lobe consists of two end moraines which join to form a continuous, low lateral moraine paralleling the northeasterly course of Roaring Lion Creek for a short distance. This lateral is breached by the stream and continues on the opposite bank, joining the mountain front at an elevation of 4800 ft.

The end moraines in the northern lobe are truncated on the south at a high angle by an east-trending, low lateral moraine. Granite weathering ratios on the moraines in the northern lobe range from 2-98-0 to 10-90-0, while values determined for the east-trending lateral range from 4-86-10 to 10-90-0. Hand-dug pits reveal no discernable difference in the character of the Ward paleosol on these moraines.

As previously discussed, the south lateral moraine of Charlos Drift in Roaring Lion Creek flanks and overlaps the type deposit of the Judd Drift. This lateral moraine terminates abruptly downslope at an elevation of about 3840 ft and merges with an irregular belt of scattered erratic boulders and cobbles interspersed with shallow, discontinuous bogs. This zone seems to mark the former terminus of a southern ice lobe bounded on its northern flank by the cross-cutting lateral moraine.

If correctly interpreted, the moraines of the northern lobe belong to the Lower Member of the Charlos Drift, whereas the lateral moraines and erratic zone of the southern lobe represent the Upper Member of the Charlos Drift.

Both moraine lobes terminate at the head of a large, arcuate outwash-fan complex, and are overlapped in their upper regions by fresher, higher moraines of the Lost Horse Drift.

Moraines along Bear Creek

The moraines at the mouth of Bear Creek form a sequence of nested, arcuate loops spreading laterally from the canyon mouth (Fig. 8). On the north and south the lateral moraines of the Charlos Drift overlap the eroded edges of the Dutch Hill terrace. The end moraines lie at the head of a broad outwash-fan complex which lies from 30 to 120 ft below the dissected remnants of the Dutch Hill terrace.

The distal slopes of two prominent end moraines are conspicuously bouldery and steep. In contrast, the proximal slopes of faces are much smoother and more gently sloping. These moraines also apparently reflect the effects of wave erosion of glacial Lake Missoula. Numerous hand-dug pits on the proximal slopes reveal stratified sands and gravels which, like the moraines, have the Ward paleosol developed upon their surface. Modification of the moraines, as at Lost Horse Creek, took place largely before the formation of the

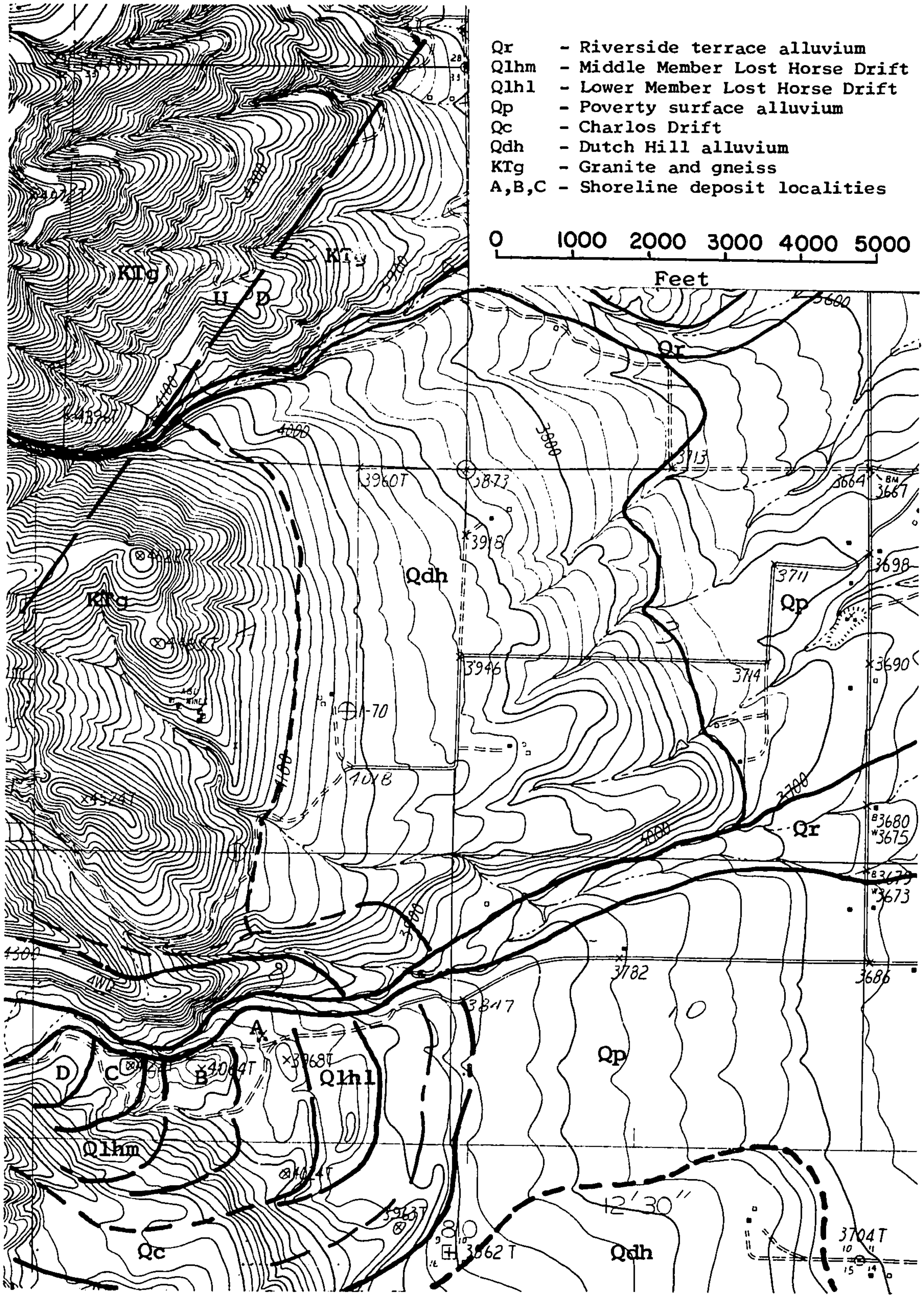


Figure 8 - Drift deposits at Bear Creek.

Ward paleosol.

The outermost moraine extends to an elevation of 3840 ft. The upper moraine is overlapped by moraines of the succeeding Lost Horse Drift at an elevation of 3910 ft.

Granite weathering ratios for the outer moraines are very consistent and range from 4-96-0 to 4-94-2 (Table 2). Roadcuts and hand-dug pits reveal no differences in the internal stratigraphy of the two Charlos moraines and no obvious cross-cutting relationships were detected. Consequently, both moraines are provisionally assigned to the Lower Member of the Charlos Drift.

Hamilton terrace

The Hamilton terrace is named for Hamilton, Montana (sec. 25, T.6 N., R.21 W.), where it occupies an intermediate position in the terrace sequence of the Bitterroot Valley.

In the upper valley the terrace consists of paired remnants approximately 20 ft above the Bitterroot River. In this section of the trunk valley the terrace commonly extends into the tributary valleys and is approximately 30 ft above the floodplain of the tributaries. In the tributary valleys the terrace heads at the Charlos moraines.

In the lower valley the Hamilton terrace merges downvalley with the Riverside terrace. It is best expressed on the east side of the Bitterroot River in this segment of the valley, and cannot be traced as a morphologic unit much farther than five miles beyond Corvallis.

The terrace is composed of interbedded cobble gravels and sands, commonly crudely stratified, with cut-and-fill structures and cross bedding well developed in many exposures. The outwash comprising the terrace is of variable thickness, but reaches at least 30 ft in the upper valley. Nowhere is the base of this terrace exposed, so the total thickness of sediment is not known. Numerous water wells drilled in the lower valley indicate that as much as 90 ft of outwash overlies truncated Bozeman "lake beds" (McMurtrey and others, 1956).

Drill logs do not indicate the presence of buried paleosols or significant stratigraphic variation in the gravels beneath the Hamilton terrace. Furthermore, truncated bedrock is exposed in the Dutch Hill terrace scarp at several localities in the upper valley. Therefore, because the Hamilton terrace lies as much as 120 ft below the dissected remnants of the Dutch Hill terrace, and approximately 90 ft of gravel underlie the Hamilton terrace, as much as 210 ft of valley erosion occurred after the development of the Dutch Hill terrace and before the interval of aggradation represented by the gravel underlying the Hamilton terrace.

Roadcuts, gravel pits, and hand-dug pits reveal that the grainsize of the outwash decreases downstream from Charlos moraines. The west-side terrace remnants consist almost entirely of quartz monzonite and gneiss, whereas the east-side remnants include varying percentages of locally derived meta-quartzite, chert, sandstone, and granite. Soils developed upon these deposits are correlated with the Ward paleosol.

The Hamilton terrace is graded to moraines of Charlos Drift and therefore is broadly contemporaneous with them. The outwash may represent both the Lower and Upper members of the Charlos Drift. However, neither the internal stratigraphy nor morphology of the terrace permits definitive correlation with the two members.

Poverty surface

One of the most striking geomorphic features of the front of the Bitterroot Range is the nearly continuous piedmont alluvial plain developed at an intermediate level throughout much of the lower valley. North of Roaring Lion Creek in the lower valley, broad outwash fans radiate from the outermost moraines of Charlos Drift.

The Poverty surface is named for outwash fans at Poverty Flat (sec. 10 & 11, T.7 N., R.21 W.) near the mouth of Bear Creek (Fig. 8). There the surface lies 30 to 120 ft below remnants of the Dutch Hill terrace and 5 to 15 ft above lower terrace remnants inset into its surface. The surface descends from the mountain front at 80 to 160 ft/mi towards the trunk stream where it is truncated abruptly approximately 30 ft above the floodplain.

West of the Woodside River crossing to Corvallis, the Poverty surface and the Hamilton terrace are juxtaposed. At this locality the Hamilton terrace truncates the Poverty surface and lies approximately five feet below it. A few hundred yards away the Poverty surface reaches the level of the Hamilton terrace.

Ward Paleosol

The Ward paleosol is here defined as the moderately developed zonal soil found on Charlos Drift. In all localities the soil remains as a relict paleosol, maintaining a characteristic degree of development relative to the other soils of the region. The Ward paleosol is stratigraphically distinct, in that it maintains a constant landscape association, occurring only on Charlos Drift or on deposits erosionally truncated subsequent to the development of the Indian Prairie paleosol.

The Lost Horse Drift and the channels in which it occurs bear a soil whose profile characteristics are more immature than those of the Ward paleosol. Therefore, even though the Ward paleosol may still be undergoing some degree of development, it attained its dominant megascopic profile characteristics in the soil-forming interval preceding deposition of the Lost Horse Drift.

The Ward paleosol is named for Ward Mountain (sec. 24, T.5 N., R.22 W.). The type locality of the Ward paleosol is on the crest of the outermost end moraine of the Upper Member of the Charlos Drift in the valley of Lost Horse Creek (NE ¼ sec. 9, T.4 N., R.21 W.). There the paleosol is developed upon till of Charlos Drift and is exposed at the surface as a relict paleosol (Ruhe, 1965). At the type locality the paleosol is a zonal soil member of the Gray Wooded great soil group. Elsewhere, the Brown and Chestnut great soil groups are represented in the facies variation of the Ward paleosol. Mapped soil series grouped in the Ward paleosol include the Como, Clark Fork, Gransdale, Hamilton, Lone Rock, and Victor soils (Soil Survey Staff, 1959).

The following is a typical Gray Wooded soil facies profile:

Type locality of the Ward paleosol,
NE ¼ sec. 9, T.4 N., R.21 W.

Oo	1 to 0 in, partly decomposed needle litter.
A1	0 to 3 in, light-brownish-grayish-brown (10YR 3/2), compact, coarse sandy loam; weak crumb structure; medium acid.
A2	3 to 13 in, light-brownish-gray (10YR 6/2), compact, gravelly coarse sandy loam to loamy sand; medium acid.

B2	13 to 25 in, light-brownish-gray (10YR 6/2), gravelly coarse sandy loam to loamy sand; irregular, weakly cemented, dark-brown (10YR 4/3), subangular blocks; medium acid.
C	25 to 40 in, grayish-brown (10YR 5/2), friable, quartz monzonite and gneiss cobbles and pebbles in coarse-grained, arkosic sand matrix; cobbles moderately weathered.

The Chestnut soil facies of the Ward paleosol is widespread in the lower valley of the Bitterroot River. Commonly it is restricted to remnants of the Hamilton terrace and the Poverty surface on the west side of the Bitterroot River where it is developed upon quartz monzonite- and gneiss-rich outwash gravels from the Bitterroot Range.

The following is a typical Chestnut soil facies profile:

Profile of Ward paleosol,
Poverty Flat
SE ¼ SE ¼ sec. 12, T.7 N., R.21 W.

A1	0 to 10 in, very-dark-grayish-brown (10YR 3/2), friable loam; weak, fine granular structure; neutral reaction.
B21	10-15 in, dark-grayish-brown (10YR 4/2), friable loam; weak granular structure; slightly acid.
B22	15 to 22 in, brown (10YR 5/3), very friable, coarse sandy loam; slightly acid.
C	22 to 30 in, light-yellowish-brown (10YR 6/4), loose, unweathered quartz monzonite and gneissic cobbles and pebbles in a coarse- to medium-grained arkosic sand matrix.

The Brown soil facies of the Ward paleosol occurs on remnants of the Hamilton terrace and Poverty surface on the east side of the Bitterroot River, and is developed upon calcareous silts and gravels of mixed origin. Soils developed upon fans of the Poverty surface reflect the diversity of bedrock exposed along the flanks of the Sapphire Mountains, whereas soils found on alluvium of the Hamilton terrace reflect the blending of both Sapphire and Bitterroot Range lithologies.

The following is a typical Brown soil facies profile:

Profile of Ward paleosol,
Hamilton terrace,
NE ¼ NE ¼ sec. 30, T.6 N., R.20 W.

Ap	0 to 7 in, very-dark-gray (10YR 3/1), friable loam; fine crumb structure; slightly alkaline; clear boundary to B2 horizon.
B2	7 to 16 in, dark-grayish-brown (10YR 4/2), friable loam; weak subangular blocky structure; alkaline; clear transition to Cca horizon.
Cca	16 to 24 in, light-brownish-gray (2.5Y 6/2), friable loam; contains scattered granite pebbles; highly calcareous.
C	24 to 35 in, light-yellowish-brown (10YR 6/4), loose, unweathered quartz monzonite, gneiss, granite, metaquartzite, dolomite, and chert cobbles and pebbles in a coarse-grained sandy matrix.

The distribution of clay-size sediment in these soil profiles is shown in Figure 4.

Lost Horse Drift

Lost Horse Drift in the Bitterroot Valley includes till and outwash gravel. Locally these deposits intertongue with, or are overlapped by, lake deposits of glacial Lake Missoula.

The Lost Horse deposits lie upstream or upslope from, and locally overlap or occur within channels cut in, the Charlos Drift. The deposits characteristically bear the Moose Creek paleosol, whose facies include immature Gray Wooded, Humic Gley, and alluvial soils (Soil Survey Staff, 1959), and locally either are overlapped by younger deposits or are cut by channels containing such deposits.

Within the tributary canyons, moraines of the Lost Horse Drift were the last to be deposited at, or near the canyon mouth, and lie 7 to 15 mi downvalley from much fresher moraines in or near cirques along the crest of the Bitterroot Range. Moraines of the Lost Horse Drift therefore represent the last major glaciation in the Bitterroot Range.

Definition

The Lost Horse Drift (Fig. 7) is named for Lost Horse Creek where till of this age underlies high, fresh, bouldery moraines (sec. 8, 9, 16, 17, & 18, T.4 N., R.21 W.). The crest of the lowermost moraine, altitude 4060 ft, is about a mile upstream from the lower limit of Charlos till, and lies in a valley which dissects the moraines and associated outwash of this earlier glaciation.

The till of the type area consists of relatively fresh, poorly sorted, subrounded to angular cobbles and boulders of quartz monzonite and gneiss in a loose matrix of very silty, arkosic sand. Boulders and cobbles are very common on the surface of the moraines. Erratic boulders measuring from 3x4x6 to 14x21x30 ft are common on the surface of these moraines; the gneissic boulders are typically frost shattered or split by tree roots.

Undrained kettle depressions as deep as 20 ft are found locally on the moraine surface. Some kettles contain perennial water. The relative freshness of these moraines is also suggested by the abundance of perched erratic boulders on the slopes of the lateral moraines. In particular, the left lateral moraines of the Lost Horse Creek glacier near the end moraine zone reflect this freshness and are expressed as delicately poised boulder lines on the steep valley slope. Both left- and right-lateral moraines can be traced as high as 5200 ft where they merge with the valley walls.

Granite weathering ratios range from 32-68-0 on the outermost moraine of this deposit to 74-26-0 for moraines in the upstream portion of this deposit (Table 2). In all, 10 terminal moraines and associated lateral moraines are developed in the type area, ranging in elevation from 4060 ft to 6480 ft. The progressive variation in the granite weathering ratios of these moraines may reflect a combination of factors.

The advancing glaciers in Lost Horse time very likely scoured, reworked, and perhaps remolded Charlos Drift, thereby incorporating previously weathered debris in the outer moraines. This inference is indirectly supported by the especially massive nature of the outermost moraine of the Lost Horse Drift, standing approximately 120 ft above its corresponding outwash terrace, and by the direct juxtaposition of till of both ages at the toe of the outermost Lost Horse moraine.

The range in altitude (2400 ft) of the Lost Horse Drift also introduces the factor of differing climatic zones, and hence differing weathering rates as expressed in the granite weathering ratios. Although no specific meterologic data are available, casual observation points to a much more rigorous frost climate in the higher portions of the Bitterroot Range, as evidenced by massive taluses and extensive frost-riven terrain.

The nine lower moraines (4060 to 4220 ft) are developed in a relatively narrow belt along approximately two miles of the valley floor and are capped by the Gray Wooded soil facies of the Moose Creek paleosol. This group of moraines lies 7 miles from the uppermost end moraine in the North Fork of Lost

Horse Creek. Ground and air-photo reconnaissance of both the main and South forks of Lost Horse Creek has revealed scattered drift but no well-defined end moraines such as found in the North Fork; however, the threshold of the main cirque in each of these tributaries lies at an elevation of approximately 6600 ft, closely corresponding in elevation to the North Fork moraine. Granite weathering ratios for this moraine average 72-28-0 and, thus, are compatible with other values obtained on Lost Horse Drift. A hand-dug pit on the crest of the end moraine revealed an A-C soil profile with no suggestion of a cambic B horizon.

Despite the gradational nature of the granite weathering ratios and the general similarity of the Moose Creek paleosol developed upon the lower moraines, the lower moraines can be subdivided into two groups.

The outer five moraines of the Lost Horse Drift are somewhat more dissected than the remaining upstream moraines. The lower moraines are breached by a 400- to 500-ft wide cut containing a complex of low discontinuous terraces and the present floodplain, whereas the upper moraines abut the floodplain of the axial stream. In the lower valley of Lost Horse Creek, however, remnants of only one outwash terrace - the Riverside terrace - are preserved below the Hamilton terrace.

The sixth moraine, which appears to comprise the outer moraine of a second group of Lost Horse moraines, is a massive, high ridge similar to the outermost Lost Horse moraine. The intervening moraines, as well as the moraines upstream from the sixth moraine, are less prominent. The crest of the more-massive sixth moraine lies near an elevation of 4220 ft, and rises above a belt of dead-ice moraine.

These relationships appear to indicate waxing and waning of the ice; the second group of Lost Horse moraines repeat the pattern of the first group. Viewed together, these morphologic criteria provide a basis for subdivision of the Lost Horse Drift into three members, designated Lower, Middle, and Upper. A similar pattern of moraine development is found in other tributary drainage basins.

Moraines along Rock Creek

The moraines of the Lost Horse Drift in Rock Creek form a mile-long sequence of six nested, arcuate loops along the valley floor (Fig. 7). They lie between altitudes of 4100 ft and approximately 4200 ft, where they meet the waters of Lake Como, a natural moraine-impounded lake raised by an earth-fill dam for irrigation purposes. Above the dam, at least one set of lateral moraines merges with the level of the lake. Along both sides of the valley Lost Horse lateral moraines can be traced some 2.5 mi upstream from the outermost end moraine, to approximately 5240 ft, where they merge with ice-eroded features on the valley walls.

The outermost three moraines of the sequence cannot be traced within 400 ft of the axial stream. Throughout this wide belt flanking the stream the moraines have been breached and partially buried by later outwash. Stream-bank exposures in this segment of the valley commonly reveal bouldery till capped by a variable thickness of rounded cobble gravel. No fossil soil was seen between these units. These relationships are similar to those of the Lower Member of the Lost Horse Drift in the type area, and on this basis a correlation is inferred.

The three moraines just below Lake Como do not differ appreciably from lower moraines of the sequence, except that they are not as greatly dissected. The weathering characteristics of the moraines are comparable and show a gradation in granite weathering ratios from 28-72-0 on the outermost moraine to 46-54-0 on the moraines just below the dam and on the lower lateral moraines. The Moose Creek paleosol attains similar development on all Lost Horse moraines. Therefore, it appears that both the Lower and Middle members of the Lost Horse Drift are present in the valley of Rock Creek.

Moraines along Roaring Lion Creek

Moraines of the Lost Horse Drift are well developed at the mouth of Roaring Lion Creek (Fig. 5). The outer five moraines comprise a nested sequence joining on a common left-lateral moraine, which in turn is overlapped by the higher, more-massive sixth end moraine in the sequence. Thus, the outer group of five moraines is set apart as a distinctly earlier group of moraines, followed by subsequent readvance of the ice resulting in the deposition of the sixth and later moraines in the sequence. These moraines are correlated with the Lower and Middle members of the Lost Horse Drift, respectively.

Granite weathering ratios for these moraines range from 12-88-0 on the outermost ridge to 30-70-0 for moraines upstream. The moraines are composed largely of quartz-monzonite cobbles and boulders in a loose, arkosic sand matrix. Developed upon these deposits is an immature, zonal Gray Wooded soil facies of the Moose Creek paleosol.

The crest of the outermost end moraine rises to approximately 3900 ft. The distal slope of this and the remaining moraines of the Lower Member of the Lost Horse Drift is very abrupt and bouldery in sharp contrast to the gently sloping proximal slope. Roadcuts and hand-dug pits reveal the presence of stratified sand and gravel of glacial Lake Missoula beneath the proximal slopes, whereas the distal slopes commonly are devoid of these deposits and apparently are truncated by wave erosion. Many of the sands are remarkably well sorted and mineralogically mature. These deposits vary greatly in thickness and overlie the till with an abrupt contact. No soil was found at this contact. However, a soil is developed upon the sand and gravel and shows no significant difference from the soil formed on the Lost Horse till; therefore, the soil is considered to be correlative with the Moose Creek paleosol.

Roaring Lion Creek, which currently occupies a moderately deep valley, flows northeast immediately upon leaving the confines of the canyon. The stream breaches the left-lateral moraines of both the Lost Horse and Charlos drifts and occupies a position marginal to the northern lobe of Charlos till. No terraces occur along this stream beneath the level of the Poverty surface. Lost Horse outwash is also conspicuously absent immediately downslope from the morainal loops. Owing to the lack of an axial stream, Lost Horse moraines along Roaring Lion Creek show no apparent differences in degree of dissection.

Moraines along Bear Creek

Lost Horse glacial deposits along Bear Creek are more complex than those in other valleys because of the relationship of the moraines and terrace remnants to the axial stream.

Till of the Lower Member forms three end moraines ranging in elevation from 3900 ft at the crest of the outermost end moraine, to 4020 ft where the till is overlapped by drift of the Middle Member. Moraines of the Lower Member are slightly more dissected than those of the Middle Member. Locally as many as five nonpaired terrace remnants are inset in the steep-sided valley cut through the end moraines of the Lower Member.

These terraces are discontinuous and show downvalley divergence, apparently reflecting the effects of a rising Lake Missoula. A massive sand deposit of glacial Lake Missoula is developed conspicuously at the head of the largest of these terrace remnants.

Downstream from the outer moraines, remnants of a low terrace standing some 5 to 7 ft above the modern floodplain extend through the breach in the Charlos moraines and cross the Poverty surface 8 to 10 ft below its level. The terrace is probably correlative with the Riverside terrace along the Bitterroot River and is capped with a weakly developed, very cobbly alluvial soil facies of the Moose Creek paleosol.

Granite weathering ratios average 14-86-0 on the outermost moraine of the Lower Member and reach 28-72-0 on the innermost moraines of the Middle Member. The characteristics of the Moose Creek paleosol do not vary significantly on moraines of the Lower and Middle members of the Lost Horse Drift. Locally sand and gravel occur on the proximal slopes of the moraines and, as at Roaring Lion Creek, are capped with the Moose Creek paleosol.

Riverside Terrace

The Riverside terrace is named for Riverside, Montana (E ½ sec. 13, T.6 N., R.21 W.), where it constitutes the lowest terrace along the Bitterroot River.

In the upper valley the paired terrace remnants stand approximately 12 ft above the Bitterroot River. In this section of the trunk valley the terrace can be traced a short distance up the tributary valleys where it rises rapidly and may stand as high as 20 ft above the modern floodplain of the tributaries. The terrace is developed in the channels entrenched within the outwash of the Hamilton terrace and occupies a position approximately 10 to 14 ft below the general level of the older terrace. The development or preservation of the Riverside terrace is very poor in the tributary valleys and the terrace cannot be traced directly to moraines in the canyon mouths. The channels in which the terrace is developed are, however, the channels which dissect the Charlos moraines. Therefore, the deposition of the outwash of the Riverside terrace is inferred to have been contemporaneous with deposition of the Lost Horse moraines.

In the lower valley, the Riverside terrace converges downvalley with the floodplain of the Bitterroot River. The terrace is best expressed on the east side of the Bitterroot River where it attains a maximum width of slightly more than a mile. Just north of Hamilton the terrace lies 13 to 14 ft below the Hamilton terrace and 22 to 36 ft below truncated segments of the Poverty surface.

From Corvallis north to Stevensville, the terrace lies approximately five feet above the modern floodplain. Dissection of the terrace by the sinuous Bitterroot River in this section of the valley has produced a multitude of low alluvial island remnants within the floodplain proper.

The terrace is composed of an interbedded assemblage of fresh, moderately well-rounded, crudely stratified cobble gravels and sands. Exposures on terrace risers reveal that the sediment comprising the Riverside terrace is at least 20 ft thick in the upper valley and perhaps also as thick in the lower valley. Examination of numerous natural exposures and hand-dug pits disclosed no features that permit internal stratigraphic subdivision of the terrace sediments.

The relative paucity of Lost Horse outwash along many of the glaciated tributary valleys is probably a result of fluctuations of glacial Lake Missoula in the Bitterroot Valley. Stratigraphic and morphologic relationships indicate that shortly after deposition of Lost Horse outwash began the Bitterroot Valley was flooded by the waters of Lake Missoula and the normal patterns of glacio-fluvial deposition were interrupted.

The facies of the Moose Creek paleosol developed upon outwash of the Riverside terrace reflect local variations in lithology, sorting, and relative age of the parent material. In the lower valley the complex mosaic of soil patterns on the dissected remnants of the Riverside terrace mainly reflects local variations in drainage (Soil Survey Staff, 1959).

Moose Creek Paleosol

The Moose Creek paleosol is here defined as the immature zonal soil developed upon the Lost Horse Drift and locally on older deposits. In all localities the soil remains as a relict paleosol, maintaining a characteristic degree of development relative to the other soils of the region.

The Moose Creek paleosol is geomorphically distinct, in that it maintains a constant landscape association, occurring only on Lost Horse Drift or on older deposits truncated after the development of the Ward paleosol. Deposits formed or truncated after the deposition of the Lost Horse Drift bear no soil or at best an incipient A-C profile. Thus, even though this paleosol may still be undergoing development, it acquired its dominant profile characteristics in the soil-forming interval preceding the development of the present floodplain-landscape association.

The type locality of the Moose Creek paleosol is on the crest of the outermost moraine of the Lower Member of the Lost Horse Drift in Lost Horse Creek (W ¼ sec. 9, T.4 N., R.21 W.) near the small tributary of Moose Creek, for which the paleosol is named. There an immature Gray Wooded zonal soil facies of the paleosol is developed on stony till. Elsewhere, Gray Wooded, Humic Gley, and Alluvial soil facies of the Moose Creek paleosol are developed upon outwash and lake sediments of the Lost Horse Drift. Mapped soil series grouped in the Moose Creek paleosol include the Woodside, Cherette, Gallatin, Poverty, St. Joe, Slocum, Chamokane, and Kenspur soils (Soil Survey Staff, 1959).

The following is a typical Gray Wooded soil facies profile:

Type locality profile of the Moose Creek paleosol,
W ½ sec. 9, T.4 N., R.21 W.

Oo	0.5 to 0 in, partly decomposed needle litter.
A1	0 to 1 in, dark-grayish-brown (10YR 4/2), loose, sandy loam; weak fine crumb structure; slightly acid.
A21	1 to 2.5 in, yellowish-brown (10YR 5/6), loose, sandy loam; weak medium subangular blocky structure; medium acid.
A22	2.5 to 10 in, light-yellowish-brown (10YR 6/4), loose, sandy loam; weak medium subangular, blocky structure; medium acid.
B2	10 to 18 in, yellowish-brown (10YR 5/4), loose sandy loam; weak medium subangular blocky structure; medium acid.
C	18 to 48 in, white (10YR 8/2), loose, quartz-monzonite and gneiss cobbles and pebbles in coarse-grained arkosic sand matrix; cobbles fresh.

The distribution of clay-size sediment in this profile is given in Figure 4.

The characteristics of the intrazonal Humic Gley soil facies of the Moose Creek paleosol vary widely through very short distances. The soil is widespread on the Riverside terrace along the trunk stream, and in low swales and interfingering channels inset within the sediment of the Poverty surface. The soils have very thick to thin surface organic mats overlying mottled grayish-brown subsoils.

The following is a typical Humic Gley soil facies profile:

Profile of Moose Creek paleosol,
Riverside terrace,
SW ¼ sec. 18, T.7 N., R.20 W.

Oo	2 to 0 in, organic mat, mainly roots.
A1	0 to 9 in, black (5Y 2/2), friable loam; weak medium granular structure; neutral reaction.
B2	9 to 14 in, dark-grayish-brown (2.5Y 4/2), friable, gravelly loam; numerous mottles of gray (2.5Y 5/0) and olive brown (2.5Y 4/4).
C	14 to 28 in, light-yellowish-brown (2.5Y 6/4), loose unweathered quartz monzonite and gneiss cobbles and pebbles in a coarse-grained sandy matrix; faint mottling.

The Alluvial soil facies of the Moose Creek paleosol is excessively drained, sandy and gravelly. The facies is developed widely in the lower valley on the Riverside terrace and on islands within the main channel. The parent material commonly is crudely stratified and soil horizons are difficult to distinguish from original stratification.

The following is a typical Alluvial soil facies profile:

Profile of Moose Creek paleosol,
Riverside terrace,
NE ¼ sec. 12, T.6 N., R.21 W.

A1	0 to 4 in, very-dark-grayish-brown (10YR 3/2), friable, fine sandy loam; weak crumb structure; neutral reaction.

B2	4 to 12 in, grayish-brown (10YR 5/2), friable to loose, fine sandy loam; neutral reaction.
C	12 to 26 in, pale-brown (10YR 6/3), friable to loose; weakly stratified; fine sandy loam.

Deposits of Glacial Lake Missoula

Introduction

Within the Lake Missoula Basin the erosional effects of this glacial lake are ubiquitous; the depositional record is not. In the northern and central valleys which comprise the lake basin the lake deposits consist chiefly of two types: benches of compact, pinkish, rhythmically bedded silt, judged to be of Bull Lake age; and soft, yellowish-brown, more-massive deposits on or near the valley floor, which are considered Pinedale in age (Richmond and others, 1965). Locally these deposits are overlain by coarse-grained, poorly sorted gravels. Pardee (1942) interpreted these gravels, as well as many denuded surfaces, as recording huge, vigorous currents developed within the lake as it drained rapidly following failure of the ice dam at the mouth of the Clark Fork Valley. Occasional reference has been made to the occurrence of beach and delta deposits within the lake basin (cf. Beaty, 1962; Pardee, 1942; McMurtrey and others, 1965), but the total volume of such deposits apparently is small.

The relative abundance and type of lake deposits in the Bitterroot Valley arm of Lake Missoula differ from that in other valleys comprising the lake basin. Lacustrine silt deposits are notably lacking. Pardee (1942, p. 1579) and Alden (1953, p. 156) observed that laminated lake silts extend only a short distance into the Bitterroot Valley, and occur below an elevation of 3200 ft.

Sieja (1959), on the basis of limited clay-mineralology data, agreed with Pardee (1942) and Alden (1953) who assumed, largely upon physiographic grounds, that silts in the adjoining Missoula Basin were derived from glaciers in the upper Blackfoot River drainage basin. The heavily glaciated Bitterroot Range apparently did not supply as much silt as the Blackfoot drainage, and McMurtrey and others (1965, p. 13) suggested that "most of the detritus of the Bitterroot glaciers was dumped directly into the lake and there was less opportunity for sorting than in the headwaters of the Clark Fork and Blackfoot drainages."

Although lake silts are absent in the Bitterroot Valley, deltaic and beach deposits commonly are interbedded with, or overlie, moraines of the Bitterroot Range. Unlike the silts, these shoreline deposits demonstrate multiple, quasi-equilibrium, maximum lake levels. Furthermore, the immediate juxtaposition of these shoreline deposits with the sequence of moraines in the Bitterroot Range, permits comparison of lake-level fluctuations with fluctuations of the alpine glaciers.

Scattered ice-rafted erratics are common throughout the Bitterroot Valley and may be locally abundant on north- and northwest-facing strandlines. The erratics seem to comprise the bulk of the sediment found upon the multitude of narrow, wave-cut strandlines so common in the Lake Missoula Basin. Pardee (1910, p. 379) reported a veneer of sand and waterworn pebbles on strandlines in the northern portion of the Bitterroot Valley, but much of the fine strandline sediments examined during the present study may be colluvium.

The slight amount of wave modification of the delicate closely spaced strandlines has been noted by several authors (Pardee, 1910, 1942; Alden, 1953). The maximum elevation usually cited for the development of these strandlines is 4200 ft, and within 1000 ft of this limiting elevation as many as 40 strandlines have been counted (Pardee, 1942, p. 1581). The multiplicity and close spacing of these delicate strandlines makes long-distance tracing or correlation difficult, and whether the strandlines record the effects of isostatic adjustment and regional tectonics is presently unknown.

Erosional Evidence

Strandlines

Within the Bitterroot Valley a multitude of delicately etched strandlines are developed along the flanks of the

Sapphire Range and occasionally along the front of the Bitterroot Range. These strandlines are cut upon a wide variety of lithologies including the crystalline rocks of the Idaho Batholith, metamorphic quartzites and argillites of the Precambrian Belt Supergroup, and unconsolidated to weakly consolidated sediments of the Bozeman Lake Beds.

The best developed strandlines are commonly found on north- and northwest-facing slopes, particularly in the wider portions of the valley. Pardee (1942, p. 1581) made similar observations and concluded that this pattern of strandline development probably reflected prevailing winds from the north and west during the Pleistocene. As this is consistent with present prevailing wind patterns in the regions the explanation seems reasonable.

The altitudinal range of the strandlines in the Bitterroot Valley is nearly 1000 ft, the highest and lowest strandlines observed occurring at 4240 ft and 3260 ft, respectively. They are very nearly uniform in development and, therefore, provide no direct evidence that Lake Missoula maintained any particular level for a long span of time. The number and close spacing of the strandlines was used by Alden (1953, p. 155) to infer frequent fluctuations of lake level in response to fluctuations of the glacial dam, as well as erosion of the bedrock floor of any ice-marginal channels used as spillways. In addition, the multitude of strandlines developed may relate, in part, to multiple floodings of the Lake Missoula basin as well as lake fluctuations during a single cycle of lake expansion.

Any single strandline may be the product of multiple occupation of that lake level for the strandlines are developed nearby equally on the different lithologies comprising the lake shore. Some of the best-developed strandlines in the Bitterroot Valley are cut upon granite and granite gneiss approximately five miles southeast of Hamilton (Fig. 9). Although these strandlines are cut on firm, crystalline rock, their development is equal to, or better than, that of the strandlines cut on softer Tertiary and Pleistocene sedimentary rocks. The strandlines cut on these soft rocks are only slightly modified by subsequent mass-wasting. The observed degree of development of the strandlines on the crystalline bedrock therefore may represent multiple occupation of these strandlines by a lake that fluctuated through a given range of elevations.

Drainage Texture and Regolith Discontinuity

Air-photo reconnaissance of the Bitterroot Valley along the flank of the Sapphire Range discloses a striking contrast in the character of the drainage networks and regolith above and below the highest strandline (Fig. 10). The well-integrated, dendritic drainage pattern displayed on the air photo in Figure 10 is common to the terrain above the highest lake level. This drainage texture discontinuity commonly occurs at an elevation of 4200 ft, but appears somewhat higher on steeper slopes, as a result of greater mass-wasting and erosion on these slopes.

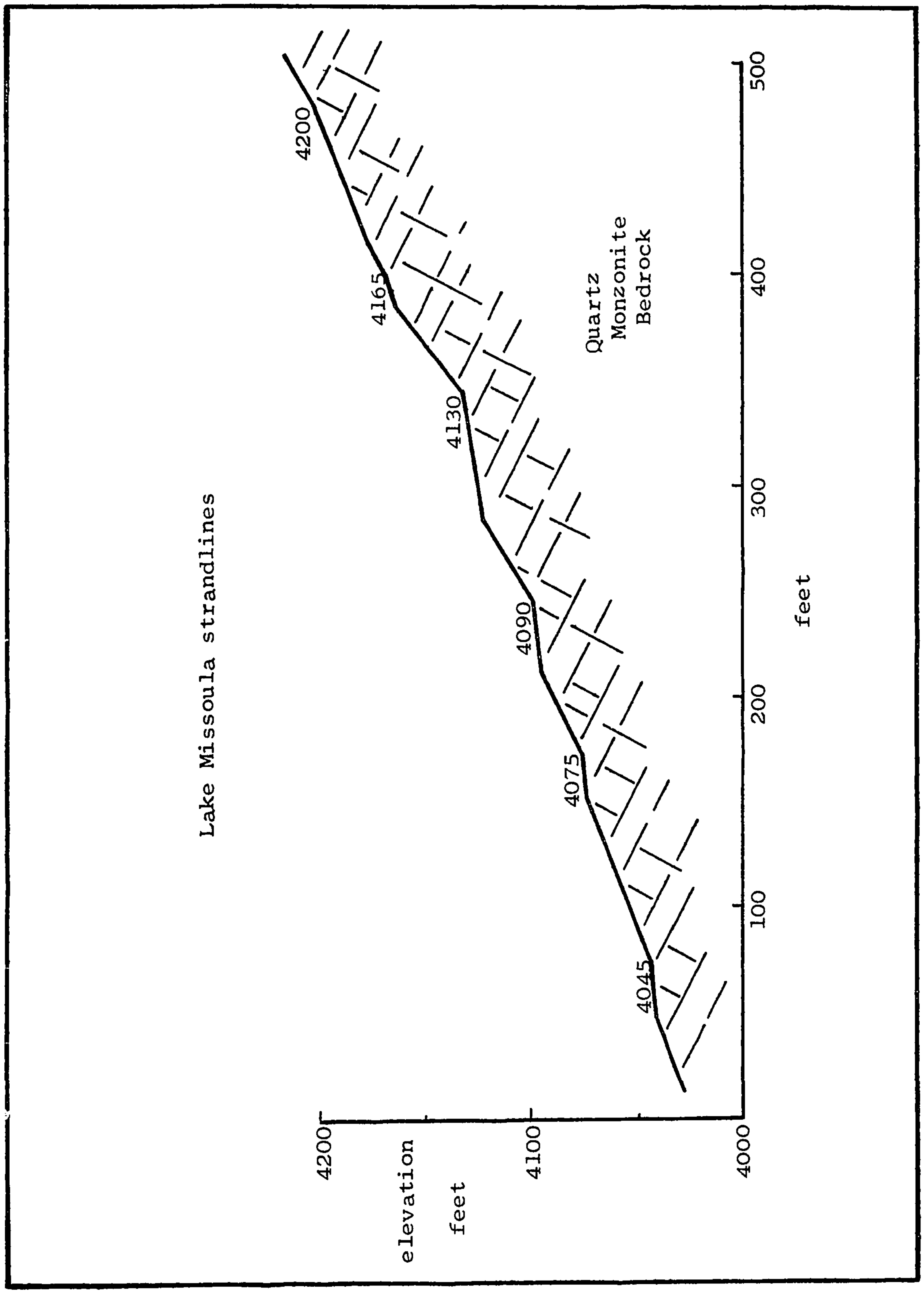


Figure 9 - Prominent strandlines of glacial Lake Missoula southeast of Hamilton, Montana.

Figure 10 - Regolith and drainage texture discontinuity at the 4200 ft strandline of glacial Lake Missoula. Area shown in air photo is 6 mi SE of Hamilton, Mont.

Accompanying the drainage texture discontinuity is a very noticeable change in the character of the regolith above the highest strandline. This contrast is partly due to stripping of the soils and weathered debris from the steeper slopes beneath the upper limit of submergence, and partly to deposition of loess on the uplands above maximum lake level. The Skaggs, Cooney, and Gird soil series reflect this contrast. They occur only above 4200 ft, and are developed on 2 to 6 ft of loess that rests on bedrock (Soil Survey Staff, 1959, p. 25). A similar contrast in soil development above and below maximum lake level was noted elsewhere in the Lake Missoula Basin by Alden (1942, p. 1575).

Deposits of Birch Creek

Detailed reconnaissance has not disclosed the presence of fossil invertebrates or other organic debris associated with strandlines along the flank of the Sapphire Range. Consequently, the absolute ages of these strandlines are unknown. However, an apparently isolated occurrence of fossil gastropods interbedded in an alluvial fill was discovered along the course of Birch Creek, a tributary stream draining the Sapphire Range.

The fossil locality lies approximately 5.5 mi northeast of Corvallis (SW ¼ NW ¼ sec. 18, T.7 N., R.19 W.). Several specimens of the terrestrial gastropod *Polygyra* cf. *Ptychophora* (specimen no. 39978) and a single specimen of *Physa* sp. (specimen no. 39977), a fresh water genus were collected from the sandy silt comprising the valley fill. Also included in the deposit are scattered, unidentified bone fragments. All fossil gastropod shells have been deposited in the collections of the Geology and Paleontology Division of the Thomas Burke Memorial Washington State Museum, University of Washington.

The alluvial valley fill of Birch Creek cannot be traced with certainty below an elevation of approximately 3780 ft and may relate to a lake cycle at approximately that elevation. Because the valley of Birch Creek is cut largely in highly calcareous Bozeman lake beds, dating of the shell material has not been attempted owing to possible complications of a "hard-water" effect.

A short distance from the gastropod locality, a small amount of charcoal was found incorporated within the same deposit and this ultimately may provide a date for the low lake level.

Beach and Deltaic Deposits of the Bitterroot Range

The stratigraphic record of the existance and fluctuations of glacial Lake Missoula is recorded in the sequence of beach and deltaic sediments interbedded with, or overlying, till of the Bitterroot glaciers. The thickness, areal extent, and degree of preservation of these beach and deltaic deposits varies widely in the individual tributary valleys of the Bitterroot

Range reflecting, directly and indirectly, such local conditions as postglacial stream incision, steepness of slope, the original depositional environment, and the glacial regimen at the time of deposition. Local facies variation inhibits detailed correlation of the internal stratigraphy of these sand and gravel units, but their altitudinal position and relationship to glacial stratigraphic units permit correlation and formulation of a stratigraphic sequence.

The most striking and characteristic feature of these lake-margin deposits is the remarkably high degree of textural sorting and mineralogical maturity of the sand units. Grainsize analyses give a mean diameter of 2.2ϕ, with a skewness of only +0.29 (Folk, 1961). Microscopic examination indicates that the sands typically are composed of 82% quartz, 13% feldspars, and 5% mica.

The regional stratigraphic pattern of intertonguing and overlapping beaches, deltas, and moraines is illustrated by geologic cross sections in Figure 11. Several of these lake margin deposits occur at the same, or very nearly the same, elevation; others appear unrelated to regional altitudinal levels.

The internal structure of these deposits consists of a complex interbedded sequence of small-scale topset and foreset beds, truncated by large-scale cut-and-fill structures. These deposits seem to reflect a fluctuating, yet gradual rise of

Lake Missoula to an elevation approximated by the highest level of the individual deposit. The mouths of the glaciated canyons of the Bitterroot Range are not continuously mantled below high-lake level with beach and deltaic sediments, so a strong argument can be made for each lake margin deposit representing a nearly-stable lake level, a condition also implied by the textural and mineralogical character of the beach sands. The systematic relationship of these sand and gravel units to the morainal stratigraphy suggests that these lake margin deposits represent more than fortuitous preservation of outcrops.

On this basis, nine lake cycles have been recognized and correlated with the Lost Horse Drift (Table 3). One or possibly more lake cycles can be inferred, largely on indirect evidence, to have occurred during earlier glaciations. Because an absolute chronology is lacking for all but the lowest lake cycle and because definitive stratigraphic evidence of draining of Lake Missoula was not found, the full significance of each lake cycle cannot at present be evaluated. Therefore, a chronology of sudden lowering of lake level, and of consequent downstream flooding, is not possible at the present time.

Rock Units		Lake Cycle (elev)	Shoreline Deposits			
			Rock Creek	Lost Horse Creek	Roaring Lion Creek	Bear Creek
Lost Horse Drift	Middle Member	3700 ft	Strandline cut at 3700 ft and peat and gyttja deposits(?) in the valleys of Skalkaho Ck., Burnt Fork, and Bitterroot River			
		3935 ft				Beach sand oversteps terrace remnant of Upper Member
		4106 ft				Beach sand overlaps 3rd moraine
		4088 ft			Beach and deltaic sands overstep outermost moraine	Beach and deltaic sands intertongue with second moraine
		4144 ft	Deltaic sand intertongue with outermost moraine	Beach sand overlaps front of outermost moraine	Beach sand overlaps front of outermost moraine	
	Lower Member	4040 ft				Beach and deltaic sands intertongue with uppermost moraine
		4017 ft			Beach sands intertongue with fourth moraine	
		4110 ft	Beach sand overlaps front of 2nd moraine	Beach and deltaic sand overlap front of 2nd moraine		
		4040 ft		Beach and deltaic sand intertongue with outermost moraine		
Charlos Drift		4200 ft	Strandlines cut at 4200 ft or above			

Table 3 - Cycles of glacial Lake Missoula.

Character of the Lake-Shore Deposits

Rock Creek

Within the confines of the Rock Creek drainage basin, lake-shore deposits are exposed at two localities (Fig. 11). Stratigraphic sections of these beach and delta units are given in Figure 12.

The lowest unit exposed (Fig. 12A) overlaps the front of the outermost moraine of the Lower Member of the Lost Horse Drift and appears to extend a short distance into the axial breach of this moraine, thus overlapping the second moraine in this sequence. The deposit is poorly exposed, but seems to consist of a basal, angular, outwash gravel which grades upward into a fine-grained beach sand that can be traced no higher than 4110 ft. The deposit is capped by a soil considered an equivalent of the Moose Creek paleosol. This deposit is thought to represent a lake cycle culminating at 4110 ft.

The sands and gravels of the upper locality (Fig. 12B) appear to be largely deltaic. The deposit overlaps the front of the outermost moraine of the Middle Member of the Lost Horse Drift. The deposit can be traced to a maximum elevation of 4144 ft. The interbedded sequence of topset and foreset beds which comprise the bulk of the deposit are abruptly overlain by coarse-grained sandy alluvium which, in turn, is capped

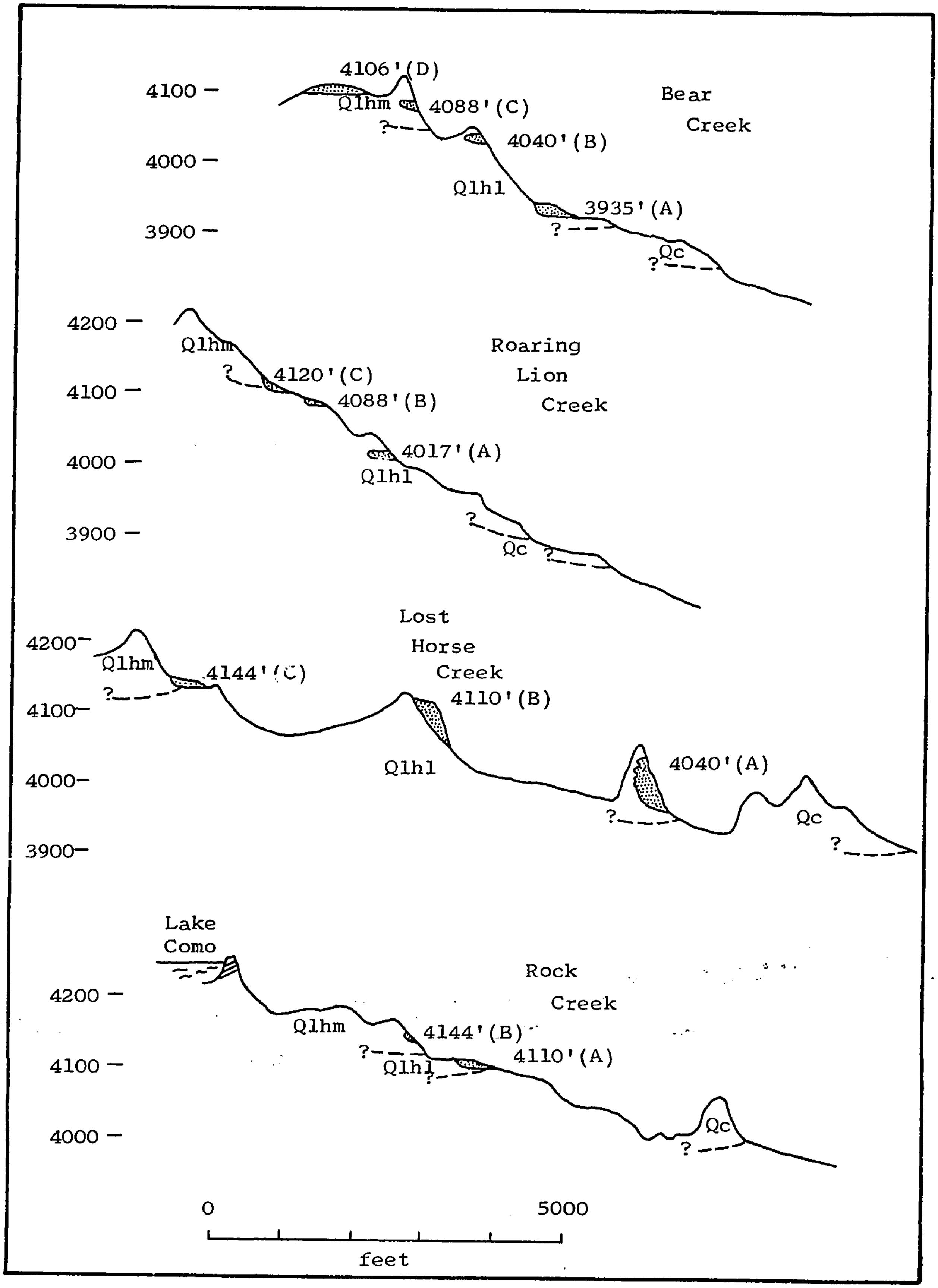


Figure 11 - Relationship of Bitterroot Range moraines to the shoreline deposits of glacial Lake Missoula. Charlos Drift, Qc; Lower Member Lost Horse Drift, Qlhl; Middle Member Lost Horse Drift, Qlhm.

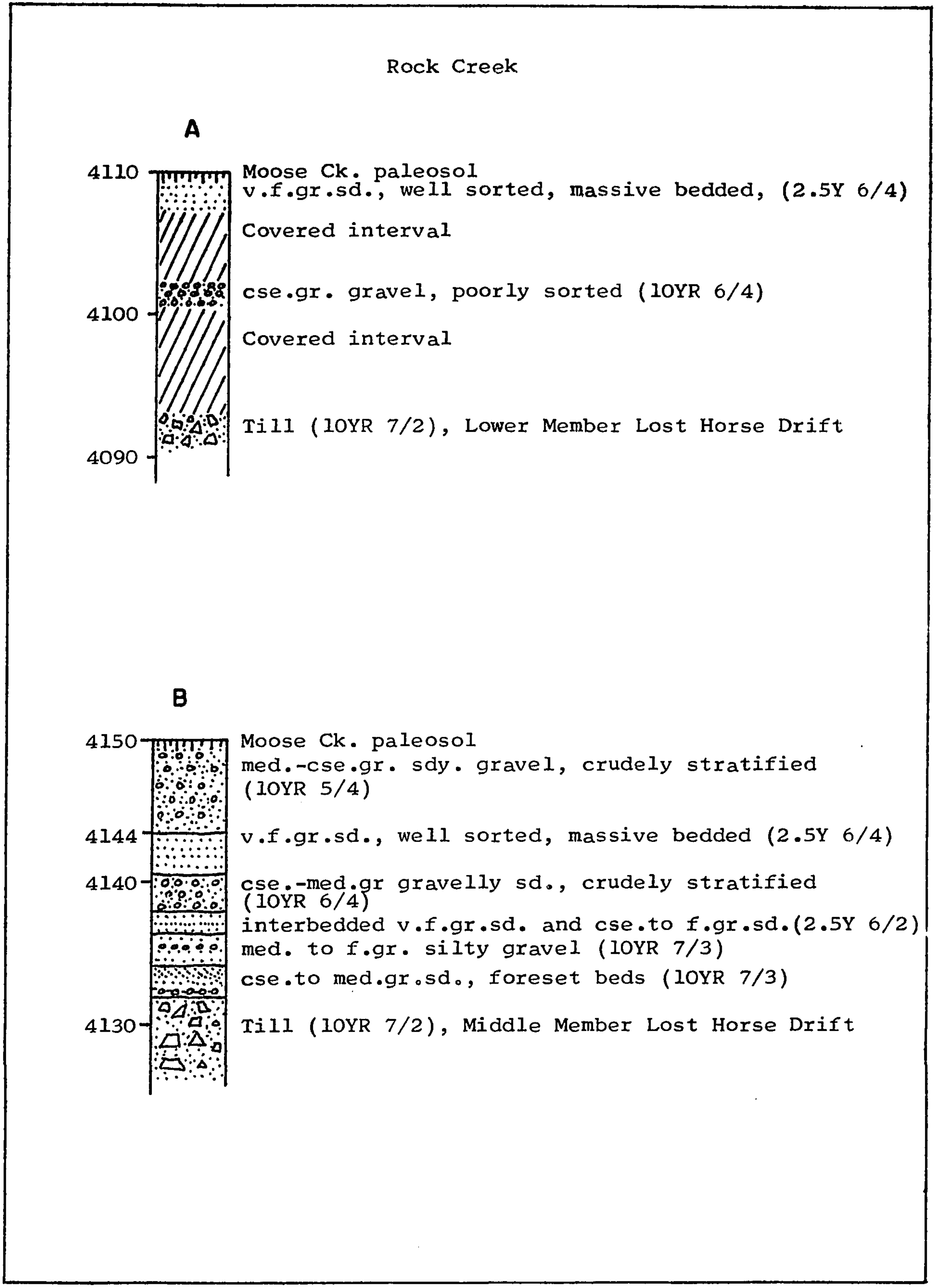


Figure 12 - Stratigraphic sections, shoreline deposits in Rock Creek. Location of sections indicated in Figs. 6 & 10.

by the Moose Creek paleosol. The abruptness of the contact between the deltaic beds and the overlying alluvium may suggest a rapid lowering of Lake Missoula from the 4144 ft cycle.

Lost Horse Creek

Three shoreline units are exposed in the valley of Lost Horse Creek (Fig. 11). Stratigraphic sections of these beach and deltaic deposits are shown in Figure 13.

The lowest deposit exposed in the valley of Lost Horse Creek intertongues with the outermost moraine of the Lower Member of the Lost Horse Drift (Fig. 13A). The sand unit has a total thickness of approximately 80 ft, and constitutes one of the most massive shoreline deposits examined. The deposit consists of very fine-grained sand which grades into coarse sand and rounded pebbles in the upper 1.5 ft of the deposit. These coarse sediments immediately below the contact with the till at 4040 ft represent a drop in lake level or a glacial readvance. However, as the sand unit pinches out within the end moraine, the overlying till represents a minor glacial readvance, therefore probably indicating a drop of the lake surface from the 4040 ft level.

Proceeding upvalley, the next shoreline unit encountered consists of a relatively massive accumulation of sand with minor amounts of gravel. The deposit is exposed near the north wall of Lost Horse Creek, overlapping the front of the

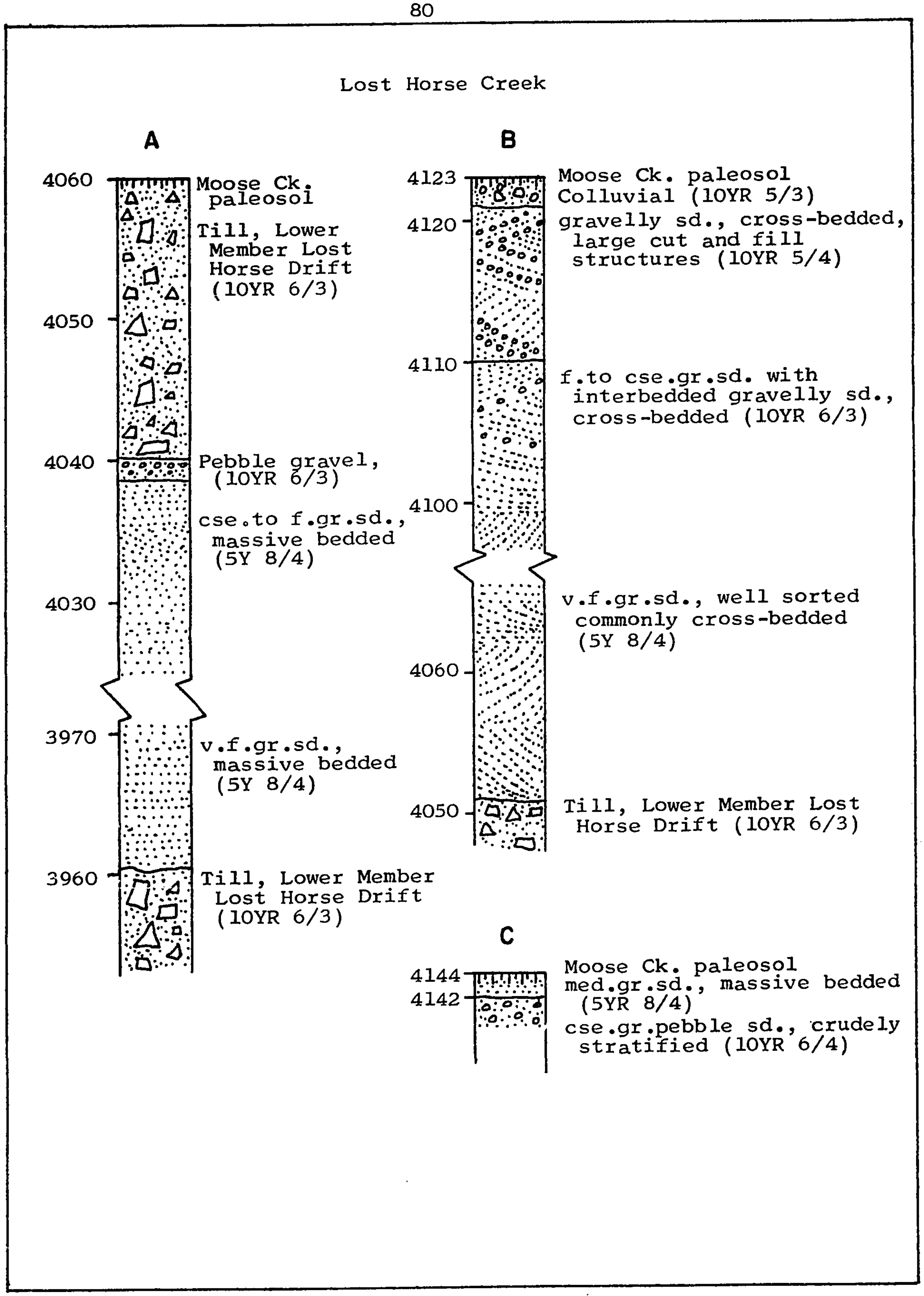


Figure 13 - Stratigraphic sections, shoreline deposits in Lost Horse Creek. Location of sections indicated in Figs. 6 & 10.

second moraine of the Lower Member of the Lost Horse Drift (Fig. 13B). A barrow pit on the south side of the deposit has exposed as much as 60 ft of sand. U.S. Forest Service drilling logs indicate that the base of the deposit lies at an elevation of 4051 ft, and that the deposit is 70 ft thick (U.S.F.S., Open File Report, 1969).

Detailed examination of the internal stratigraphy of this deposit indicates an unconformable contact at 4110 ft between the deltaic sediments and the overlying very gravelly alluvium. This unconformity may indicate a recession of Lake Missoula from a 4110 ft level.

The highest shoreline sand exposed in the valley of Lost Horse Creek reaches an elevation of 4144 ft and overlaps the front of the outermost moraine of the Middle Member of the Lost Horse Drift (Fig. 13C). This unit is only two feet thick and is capped by the Moose Creek paleosol. It appears to correlate with the sand unit at 4144 ft in Rock Creek, and together they represent deposits of the highest lake cycle attained during Lost Horse time.

Strandlines that reach 4200-4240 ft on the opposite side of the valley along the western flank of the Sapphire Range, must have been cut during pre-Lost Horse time. As mentioned previously, rounding and modification of the moraines of the Charlos Drift took place largely prior to the development of the Ward paleosol. Therefore, it can be inferred that a 4200 ft lake level was attained at least once during Charlos time.

Roaring Lion Creek

Three shoreline units are exposed in the valley of Roaring Lion Creek (Fig. 11). Stratigraphic sections of these beach and deltaic deposits are given in Figure 14.

The lowest beach deposit exposed along Roaring Lion Creek intertongues with the fourth moraine of the Lower Member of the Lost Horse Drift (Fig. 14A). In its lower portion the nine-foot-thick sand unit intertongues with a cobbly outwash gravel. The deposit contains a few pebbles and cobbles in its uppermost portion, but is abruptly overlain by till at 4017 ft. This deposit pinches out within the moraine unit; this relationship probably indicates a fall of lake level, as at Lost Horse Creek. Of the sands which correlate with the Lower Member of the Lost Horse Drift, this unit intertongues with the youngest moraine of the sequence, and, therefore, probably it represents a discrete lake cycle culminating at an elevation of 4017 ft.

The next shoreline unit encountered upvalley lies at an elevation of 4088 ft and consists of a relatively thin accumulation of massively bedded sand overlain by a thin bed of deltaic foresets. Charcoal samples, as yet undated, were collected from the sand immediately beneath these foreset beds, and from the gravelly sandy colluvium which locally overlies disconformably the foreset beds (Fig. 14B).

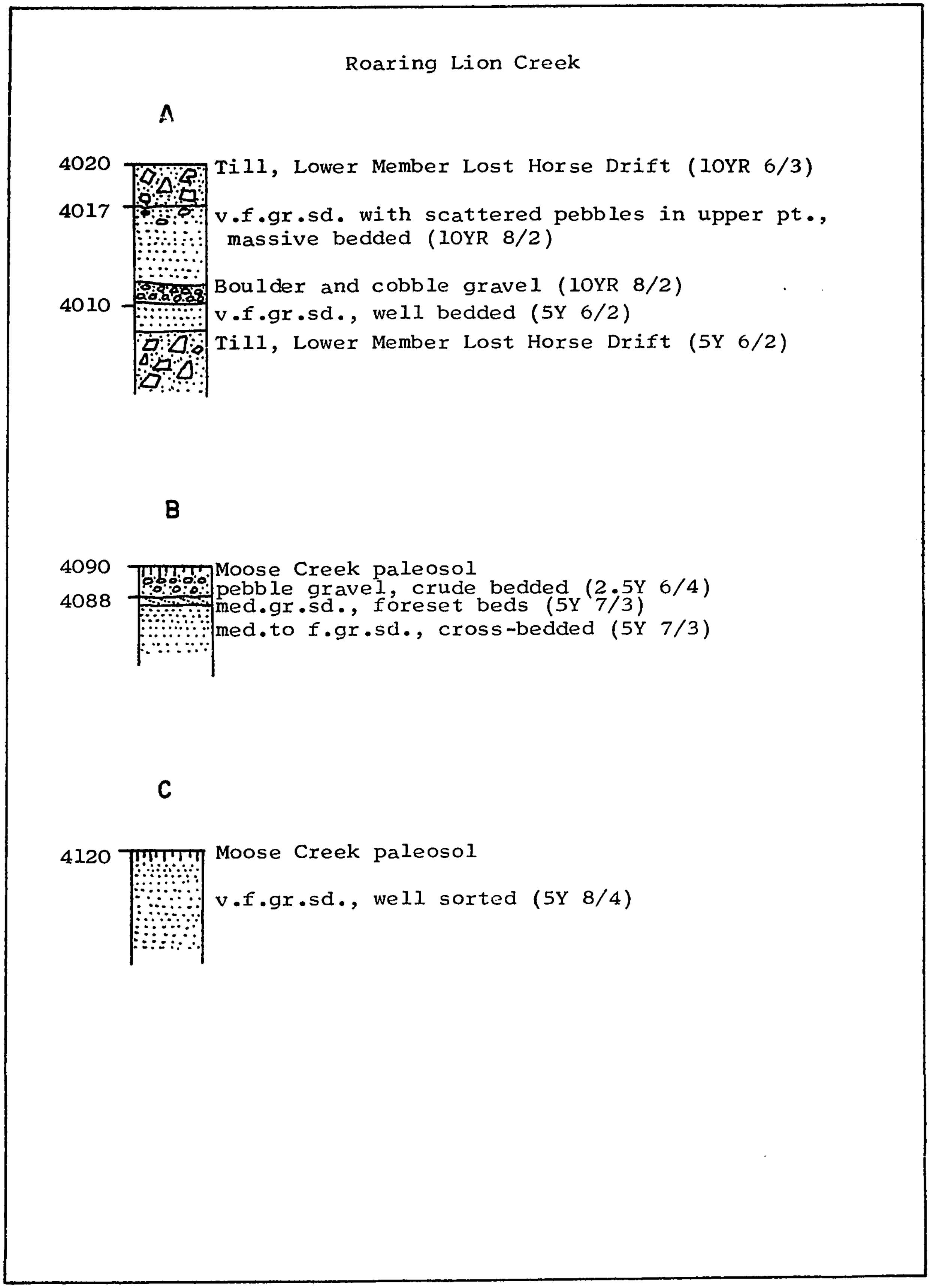


Figure 14 - Stratigraphic sections, shoreline deposits in Roaring Lion Creek. Location of sections indicated in Figs. 4 & 10.

The deposit forms a small delta flanking a breach in front of the outermost moraine of the Middle Member of the Lost Horse Drift and, like the moraine, is capped by the Moose Creek paleosol. The sand is correlated with a sand unit in the valley of Bear Creek which intertongues with the second moraine of the Middle Member of the Lost Horse Drift at a similar elevation of 4086 ft. Therefore, the sand is thought to represent a cycle of the lake culminating at an elevation of approximately 4088 ft.

The uppermost beach sand exposed in the valley of Roaring Lion Creek lies at an elevation of 4120 ft and overlaps the front of the outermost moraine of the Middle Member of the Lost Horse Drift (Fig. 14C). The base of this sand is not well exposed, and the unit could not be traced to an elevation lower than 4110 ft. The Moose Creek paleosol is developed upon the deposit. It is not certain that this deposit was truncated by erosion prior to soil formation, but despite the difference in elevation, it occupies a stratigraphic position similar to the sands of the 4144 ft lake level in Lost Horse and Rock creeks. Thus, tentative correlation of this upper sand unit in Roaring Lion Creek is made with the 4144 ft lake level.

Bear Creek

Four shoreline deposits are exposed in the valley of Bear Creek (Fig. 11). Stratigraphic sections for these beach and deltaic deposits are given in Figure 15.

The lowest deposit exposed in the valley of Bear Creek lies at an elevation of 3935 ft, unconformably overlying till of the Lower Member of the Lost Horse Drift. A barrow pit in the deposit exposes the upper five feet of the unit which consist of massively bedded beach sands. The lower portion of the deposit is poorly exposed, but several hand-dug pits indicate that it consists of thin-bedded sands and silty sands which abruptly overlie the till (Fig. 15A).

The beach deposit occupies a wave-cut notch in the front of the third moraine of the Lower Member of the Lost Horse Drift and extends laterally to overlap a portion of one of the discontinuous, divergent terraces of the Middle Member of the Lost Horse Drift which extend through the breach in the moraine. The deposit is interpreted as representing a lake cycle culminating at 3935 ft.

Farther upvalley, the next shoreline unit intertongues with the uppermost moraine of the Lower Member of the Lost Horse Drift. This beach deposit consists of 10-15 ft of sand, interbedded with thin sandy gravel, and is overlain abruptly by till at an elevation of 4040 ft (Fig. 15B). The deposit may represent a second stand of Lake Missoula at 4040 ft, the earlier being recorded in Lost Horse Creek by the intertonguing of shoreline sands with the outermost moraine of the Lower Member of the Lost Horse Drift. It is also possible, that the deposits are

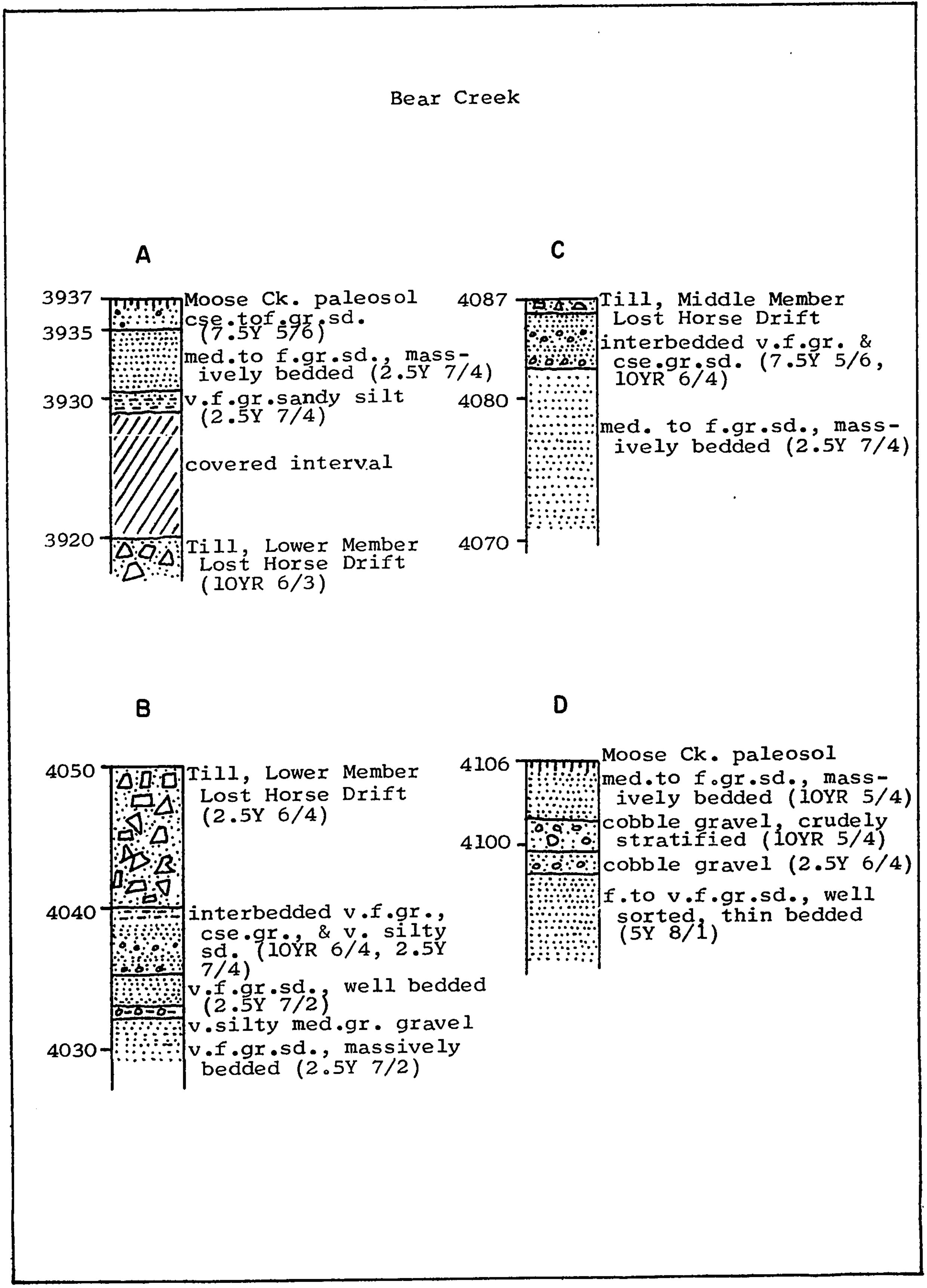


Figure 15 - Stratigraphic sections, shoreline deposits in Bear Creek. Location of sections indicated in Figs. 7 & 10.

correlative and, therefore, that the Bear Creek glacier had reached a maximum somewhat earlier than the Lost Horse glacier.

Sands and gravels at the third locality intertongue with the second moraine of the Middle Member of the Lost Horse Drift (Fig. 15C). These sediments pinch out within the end moraine; the overlying bouldery till abruptly truncates the beach deposit at an elevation of 4086 ft. As previously mentioned, this deposit occupies a stratigraphic position very similar to that of the beach and deltaic sands of Roaring Lion Creek representing the 4088 ft cycle of Lake Missoula, and the Bear Creek sand-and-gravel unit is tentatively correlated with the 4088 ft lake stand.

The uppermost shoreline unit developed in Bear Creek unconformably overlies the third moraine of the Middle Member of the Lost Horse Drift (Fig. 15D). The unit is composed of an interbedded succession of fine-grained beach sands and boulder-cobble outwash. The deposit is approximately 14 ft thick and is capped by the Moose Creek paleosol at an elevation of 4106 ft. The deposit is not overlapped by any of the previously described units, and it occurs farther upvalley in the sequence of moraines comprising the Middle Member of the Lost Horse Drift than the other shoreline units of similar elevation. Therefore, this deposit is inferred to represent a cycle of Lake Missoula which culminated at about 4106 ft.

Other Deposits

Within the valley of the Bitterroot River and many of the large, low-gradient tributaries draining the Sapphire Range, accumulations of peat and gyttja are found in a cross-valley belt at elevations ranging from 3690-3780 ft. The thickest deposits occur near Ward (sec. 26, 35, T.5 N., R.21 W.) in the upper Bitterroot Valley near the former state fish hatchery (sec. 9, T.5 N., R.20 W.) along Skalkaho Creek and approximately three miles east of Stevensville (sec. 32, T.9 N., R.19 W., and sec. 5, 6, T.8 N., R.19 W.) along the Burnt Fork of the Bitterroot River. Local borings have disclosed approximately 20 ft of gyttja and overlying peat in the Ward deposit but thicknesses of 5-6 ft are more common in the other deposits (Soil Survey Staff, 1959). In each of these deposits a lack of a local downstream barrier or dam favoring ponding conditions suggests these deposits may represent the limnic and terrestrial shoreline organic sediments that accumulated when Lake Missoula stood at an elevation of near 3700 ft. Pardee (1910, p. 380-381) observed that the 3700-ft strandline "is more than ordinarily prominent", and that it seemed to reflect "a comparatively long" halt of Lake Missoula at that level.

At the Ward locality a drainage ditch through the center of section 26 exposes a sequence of interbedded peat, silt, and gyttja (Fig. 16). The basal gyttja at this locality has a radiocarbon age of 7483 ± 130 years BP (UW - 183). The

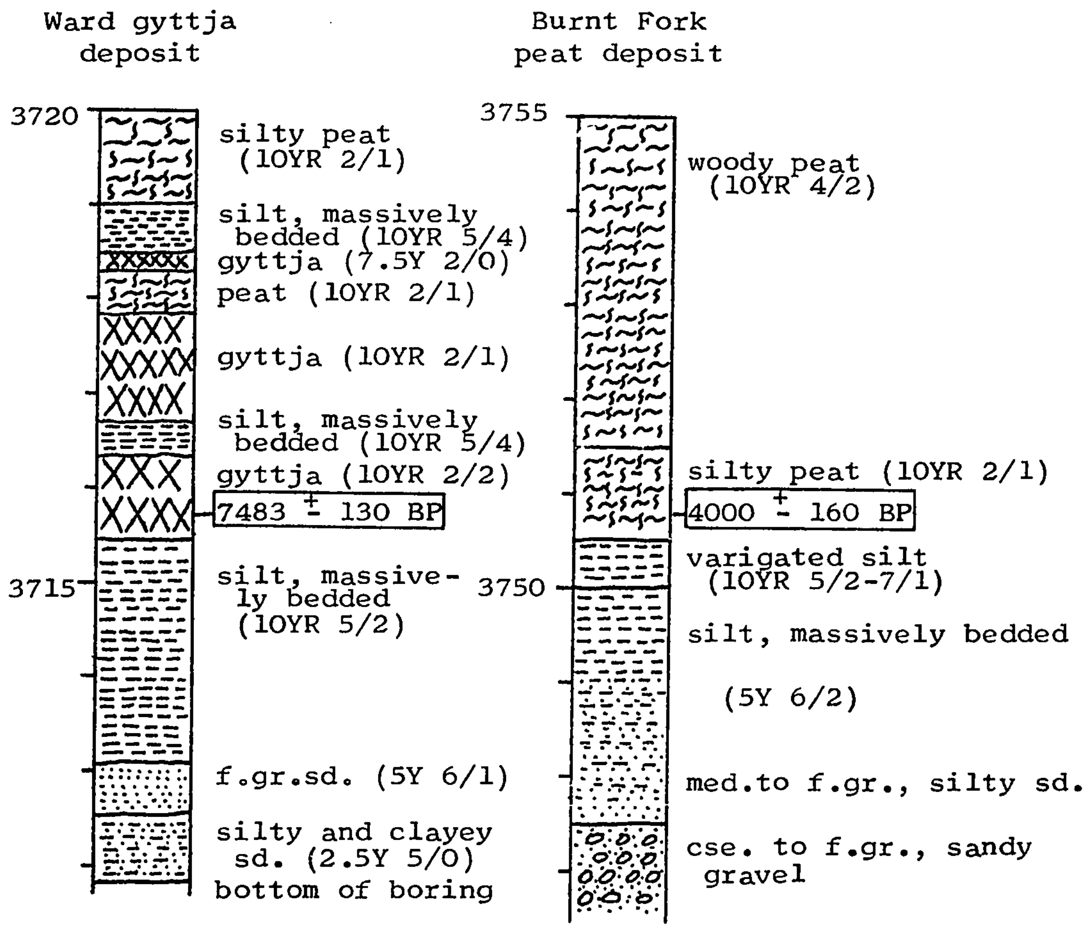


Figure 16 - Deposits near the 3700 ft strandline of glacial Lake Missoula.

section from which the gyttja was collected lies at an elevation of 3720 ft in an area that was stripped for the overlying peats; thus, the thickness of the upper peat is not known. The basal gyttja locally rests on an alternating sequence of shoreline sands and silts which in turn disconformably overlie cobble gravels of the Hamilton terrace; elsewhere, however, these intervening deposits may be absent (Soil Survey Staff, 1959).

The Burnt Fork deposits consist of a variable thickness of terrestrial peat resting on silts and sands that disconformably overlie gravel of the Hamilton terrace (Fig. 16). The peat is best exposed in a drainage ditch along the boundary between sections 5 and 6 (T.8 N., R.19 W.) at an elevation of 3755 ft. Wood and twig fragments are common in this peat deposit which is inferred to have formed above the high water level of the lake. Basal peat at this locality has a radiocarbon age of 4000 ± 160 years BP (UW - 182).

The Ward and Burnt Fork dates should establish a minimum limiting age for the occupation of the strandline near 3700 ft. However, a limiting date of at least 12,000 years for the final draining of Lake Missoula has been established by the presence of Glacier Peak ash both in flood channels of the Channeled Scablands (Bretz, 1969) and overlying till and lacustrine deposits in the northern part of the Lake Missoula Basin (Konizeski and others, 1963). Similar evidence is provided by a single radiocarbon date on peat from the base of a bog deposit near Kootenai Lake, B.C. which indicates that the Lake Pend Oreille lobe had retreated far to the north of the ice-dam site at the mouth of the Clark Fork River prior to 10,270 years BP (GSC - 719; Fulton, 1968). Thus, the Ward and Burnt Fork dates appear to be much too young. Furthermore, the dates appear to be too young to reflect only the effects of possible contamination of the deposits by modern carbon. It is possible that these deposits may represent previous local ponding or drainage conditions, the nature of which is not readily apparent from the present field relationships.

Until further evidence is gathered the gyttja and peat deposits near the 3700 ft strandline are inferred to correlate with the Middle Member of the Lost Horse Drift.

CORRELATION

Inferred correlations of Pleistocene deposits of the Bitterroot Valley is summarized in Table 4.

The generalized glacial stratigraphy of Alden (1953) offers many problems for correlation because it was based largely upon vaguely defined morphostratigraphic units which were inferred to correlate with similar units elsewhere in the northern Rocky Mountains.

In general, I agree with Alden on the number and sequence of deposits found within the Bitterroot Valley, but disagree with his relative-age assignments. Drift on the high interfluves

<table>
<tr><th colspan="2">Bitterroot Range
(Alden, 1953)</th><th colspan="3">Bitterroot Range
This report</th><th colspan="3">Rocky Mountains
(Richmond, 1965)</th></tr>
<tr><td colspan="2" rowspan="7">Wisconsin stage of glaciation</td><td colspan="3">Moose Creek soil</td><td colspan="3">Altithermal interval</td></tr>
<tr><td rowspan="6">Lost Horse Drift</td><td rowspan="3">Upper Member</td><td rowspan="3"></td><td rowspan="6">Pinedale Glaciation</td><td colspan="2">Late Stade</td></tr>
<tr><td colspan="2">Interstade</td></tr>
<tr><td colspan="2">Glacier Peak Ash</td></tr>
<tr><td rowspan="2">Middle Member</td><td rowspan="3">Riverside terrace</td><td colspan="2">Middle Stade</td></tr>
<tr><td colspan="2">Interstade</td></tr>
<tr><td>Lower Member</td><td colspan="2">Early Stade</td></tr>
<tr><td rowspan="6">Intermediate stage of glaciation</td><td rowspan="6">? ? Third Terrace
"Great bouldery fans"</td><td colspan="3">Ward soil</td><td colspan="3">Interglacial</td></tr>
<tr><td rowspan="5">Charlos Drift</td><td rowspan="4">Upper Member</td><td rowspan="5">? ? Hamilton terrace
Poverty surface</td><td rowspan="5">Bull Lake Glaciation</td><td rowspan="3">Late Stade</td><td>2nd episode</td></tr>
<tr><td>Nonglacial</td></tr>
<tr><td>1st episode</td></tr>
<tr><td colspan="2">Nonglacial</td></tr>
<tr><td>Lower Member</td><td colspan="2">Early Stade</td></tr>
<tr><td colspan="2">Second terrace</td><td colspan="3">Indian Prairie soil</td><td colspan="3">Interglacial</td></tr>
<tr><td colspan="2">Early Pleistocene(?) stage of glaciation</td><td colspan="2">Judd Drift</td><td>Dutch Hill terrace</td><td colspan="3">Sacagawea Ridge Glaciation</td></tr>
</table>

Table 4 - Correlation of stratigraphic and geologic climate units of the Bitterroot Range.

assigned an "early" Pleistocene (?) age by Alden (1953, p. 67) generally appear to consist of lateral moraines of the Charlos and Lost Horse drifts. The apparent antiquity of these deposits is due largely to high percentage of weathered gneiss in the moraines. However, at localities where a pre-Charlos age seems to be indicated, Alden's "early" Pleistocene (?) deposits have been assigned to the Judd Drift.

Alden (1953, p. 68) believed the "second terrace" was formed by an interglacial stream, and was older than the (classical) Wisconsin and probably older than an "intermediate stage" of glaciation. The "second terrace", here redefined as the Dutch Hill terrace, is inferred to be an outwash facies of the Judd Drift, based largely on correlation of soil-stratigraphic units and a similar physiographic position beyond the limits of the Charlos Drift.

The "intermediate stage" of glaciation is represented by the outermost end moraines in tributary canyons of the Bitterroot Range. They were inferred by Alden (1953, p. 165) to correlate with moraines of the "Bull Lake stage of glaciation" recognized by Blackwelder (1915, p. 323-325). The exact age assignment intended by Alden is in some doubt, however, for he correlated moraine remnants both stratigraphically younger and older than "second terrace" with Bull Lake ("Illinoian or Iowan") moraines (Alden, 1953, p. 100, 165). The Mission moraine which comprises the outermost moraine complex of the Flathead Lobe of the Cordilleran Ice Sheet is also correlated by Alden (1953, p. 94) with the "Bull Lake stage of glaciation" (Fig. 17). The Charlos Drift appears to correlate with Alden's "intermediate stage" deposits.

The "great bouldery fans" (Alden, 1953, p. 86) and remnants of the lower, or third terrace are correlated with moraines of the "intermediate stage" of glaciation, and, therefore, are correlative with the Poverty surface and Hamilton terrace of this paper.

The "Wisconsin stage of glaciation" in the Bitterroot Range consists of "well-defined moraines" that lie upstream from those of the "intermediate stage" of glaciation (Alden, 1953, p. 97-103). This assignment of a late Wisconsin age for these deposits appears to be based largely upon the fact that these moraines lie in valleys 100 ft or more beneath the "second terrace" (Alden, 1953, p. 98). The description of these moraines and outwash-terrace remnants in the Bitterroot Range corresponds generally with the Lost Horse Drift. The Polson moraine of the Flathead Lobe of the Cordilleran Ice Sheet also is correlated by Alden (1953, p. 117) with the "Wisconsin stage of glaciation" (Fig. 17).

Regional Correlations

Since 1957, Richmond has published nearly a dozen papers on the glacial history of the Northern Rocky Mountain Province.

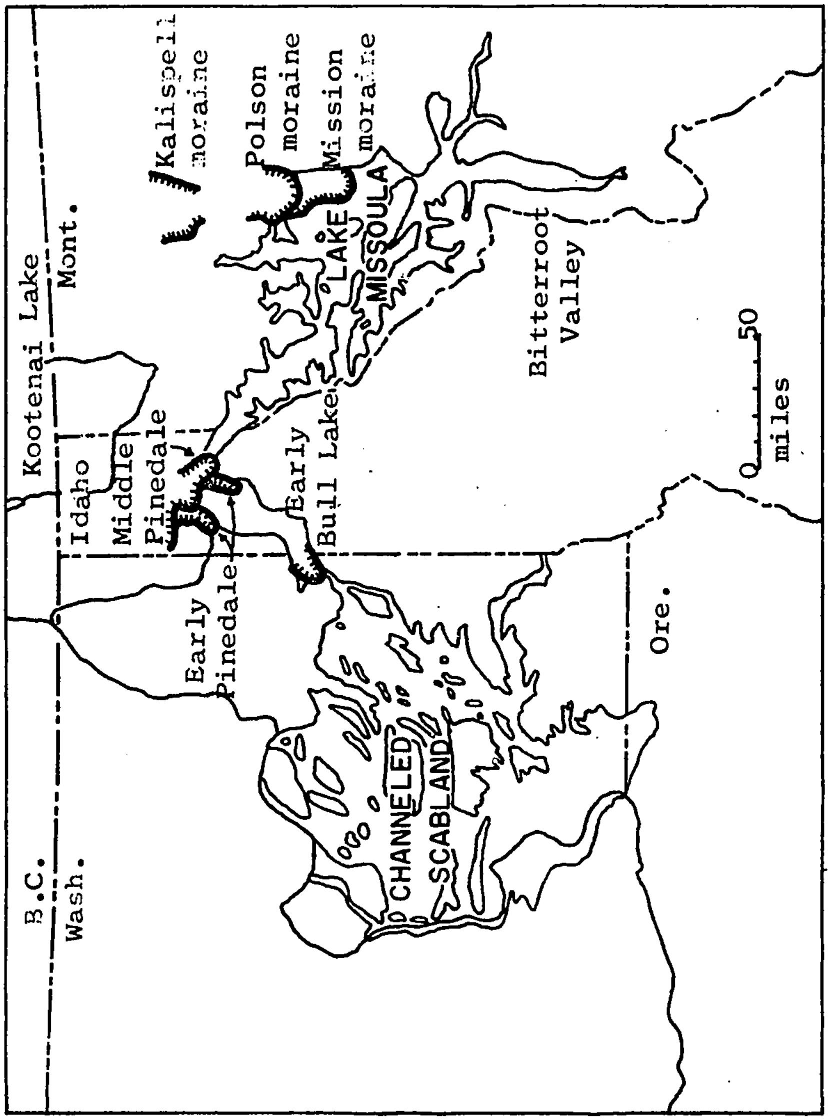


Figure 17 - Map showing relation of moraines of the Flathead and Lake Pend Oreille lobes to Lake Missoula and Channeled Scablands. (after Thornbury, 1965, and Richmond and others, 1965).

The alpine glacial stratigraphy which has evolved from these investigations is based largely upon the morainal sequence of the Wind River Mountains, Wyoming (Richmond, 1965a), and has been extended widely throughout the Rocky Mountains. Deposits of the Cordilleran Ice Sheet flood debris in the Channeled Scablands of eastern Washington, and lacustrine and flood debris within the northern portion of the Lake Missoula Basin have been correlated with this standard alpine glacial stratigraphy (Bretz, 1969; Richmond and others, 1965). Therefore, it is appropriate to suggest correlations of Rocky Mountain glacial episodes established by Richmond, with Pleistocene deposits of the Bitterroot Valley (Table 4).

Surface morphology, degree of dissection, and weathering characteristics of the moraines of Lost Horse and Charlos Drift appears to be broadly similar in character to those of Pinedale and Bull Lake moraines, respectively (Richmond, 1965a). The relative degree of development and geologic succession of soils in the Bitterroot Valley also appear consistent with this interpretation (Richmond, 1962, 1965a).

Correlation of the Judd Drift with a pre-Bull Lake glaciation is based largely on the position of the drift near the canyon floor, beyond the limit of readily distinguishable moraines, and on the strongly developed Indian Prairie paleosol capping the drift. Beyond this, however, local stratigraphic evidence is presently insufficient to infer a more detailed correlation of the Judd Drift with a specific pre-Bull Lake glaciation.

Flathead Lobe

Apparently general agreement exists among previous workers that the Mission and Polson moraines (Fig. 17) were built during Bull Lake and Pinedale advances of the Flathead Lobe (Alden, 1953; Richmond and others, 1965). Evidence of a third, or pre-Bull Lake glaciation may be represented by isolated deposits of highly oxidized drift found south of Kalispell (Richmond and others, 1965).

Richmond and Fryxell (1965) correlate drift of the Flathead Lobe near the Joco River with an early stade of the Bull Lake Glaciation; the Mission moraine, 10 miles to the north, with the late stade of the Bull Lake Glaciation; the Polson moraine, south of Flathead Lake, with both the early and middle stades of the Pinedale Glaciation; and the Kalispell and Corum moraines, north of Flathead Lake, with the late stade of Pinedale Glaciation (Fig. 17).

In the Flathead River valley, beyond the limit of the Polson moraine, exposures of three tills, inferred to be of Bull Lake age, are separated by lacustrine silts and sands. Thus, it appears that three advances of Bull Lake ice were followed by three separate rises of Lake Missoula (Richmond and others, 1965; Richmond and Fryxell, 1965). In the Bitterroot

Valley, moraines of both the Upper and Lower members of the Charlos Drift were rounded and smoothed by wave action prior to soil formation, and thus, indirectly may reflect these Bull Lake fillings of Lake Missoula.

The compound Polson moraine was formed subaerially and subsequently covered by the rising waters of Lake Missoula (Nobles, 1952). Delicate strandlines are cut upon the distal face of the moraine, and shallow cuts on the crest of the moraine (near 3400 ft) expose fine, ripple-marked sand (Alden, 1953). Nearby two Pinedale lacustrine silts can be found as high as 3200 ft, which is the apparent upper limit of strandlines north of the Polson moraine. Thus, Alden (1953, p. 122) concluded that the higher stages or cycles of Lake Missoula, those between 3200 and 4200 ft, occurred before the Flathead Lobe had melted back from the Polson moraine. During this early and middle Pinedale interval nine cycles of Lake Missoula are recorded in the Bitterroot Valley at elevations ranging from 4144 to 3700 ft.

Konizeski and others (1968) present evidence suggesting that after the retreat of the Flathead Lobe from the Polson moraine, Lake Missoula expanded north inundating the entire Kalispell Valley to an elevation of 3400 ft. Lacustrine silts reportedly interfinger and overlap the Kalispell moraine of the late stade of Pinedale Glaciation at an elevation of 3100 ft (Richmond and others, 1965).

Fryxell (in Konizeski and others, 1968, p. 8) concluded that the presence of Glacier Peak ash at the contact between drift or lacustrine deposits and dune sand approximately 30 miles north of the Polson moraine provides:

> "1. A limiting date of more than 12,000 years for retreat of the Flathead Lobe from its maximum at Polson;
>
> 2. A limiting date of 12,000 years for draining of Glacial Lake Missoula;
>
> 3. Evidence that retreat of the Flathead Lobe was approximately synchronous with recession of the Okanogan Lobe from the Columbia Plateau to the west, where ash from the Glacier Peak eruption also lies north of the terminal moraines (Fryxell, 1965); and
>
> 4. Support for previous correlation of the maximum advance of the Cordilleran Ice Sheet during Pinedale time with the middle stade of the Pinedale glaciation (Richmond and others, 1965)."

It was thought previously that silts interfingering with the Kalispell moraine at 3100 ft probably formed in an ancestral Flathead Lake of late Pinedale age retained by the moraines at Polson (Richmond and others, 1965). However, Glacier Peak ash on drift and lacustrine silts behind the Kalispell moraine at elevations as low as 3030 ft suggests that the ice retreated from the Kalispell moraine and the lake drained to a level lower than the moraine some 1000-2000 years before late Pinedale time. Therefore, a middle Pinedale age also appears to be indicated for the Kalispell moraine, as well as for a stand of Lake Missoula at approximately 3400 ft.

Detailed stratigraphic studies of Lake Missoula sediments exposed along the Clark Fork River west of Missoula have revealed two sedimentary sequences separated by a well-developed caliche horizon (Chambers and Alt, 1971). These sedimentary deposits are inferred to correlate with the Bull Lake and Pinedale glaciations and presumably correspond to the pink and yellowish-brown silt deposits of previous authors.

The Pinedale sedimentary sequence is subdivided into at least 37 stratigraphic units, each of which consists of stream deposited silts which grade upward into rhythmically bedded lacustrine silts. Weathered zones appear to be developed on some of the rhythmically bedded silts. Approximately the same number of strandlines are reported to be developed on the hillsides near the deposit.

Chambers and Alt (1971) suggest that this sedimentary sequence records at least 37 major fluctuations of Lake Missoula during Pinedale time. The shoreline deposits of the Bitterroot Valley record only 9 fluctuations of Lake Missoula during the same time interval and, therefore, the significance of multiple silt deposits is difficult to evaluate until they are correlated more precisely with the regional stratigraphic framework.

Lake Pend Oreille Lobe

The Lake Pend Oreille Lobe of the Cordilleran Ice Sheet (Fig. 17) extended southwest as far as Spokane, Washington during the Bull Lake Glaciation and impounded Lake Missoula at the mouth of the Clark Fork River (Weis and others, 1965). Only one advance of Bull Lake ice has been recognized (Richmond and others, 1965).

Kame terraces interpreted as representing an early Pinedale maximum are found south of Cococalla Lake, Idaho where they are truncated by coarse flood gravel from Lake Missoula (Richmond and others, 1965, p. 72). Kame terraces inferred to be of the same age also are found as high as 4200 ft on the rim above Lake Pend Oreille and are thought to mark the outlet for Lake Missoula during early Pinedale time.

Moraines of the Lake Pend Oreille Lobe, inferred to be of middle Pinedale age, lie athwart the path of Lake Missoula floods and lack flood-scour features or a mantle of flood debris. Therefore, they are thought to postdate the catastrophic flooding of the Columbia Plateau (Richmond and others, 1965, p. 72). The latest flood from Lake Missoula is inferred to have occurred shortly after the early Pinedale maximum.

Pardee (1942) noted that Lake Missoula strandlines are cut upon deltaic flood deposits indicating that the lake rose again to nearly 4200 ft after being drained. If events are correlated correctly, this post-flood rise must have occurred during middle Pinedale time, and resulted in shoreline deposits as high as 4144 ft in the Bitterroot Valley. A subsequent gradual drop of lake level is inferred to explain the absence of flood scour features on the middle Pinedale moraines of the Lake Pend Oreille Lobe (Richmond and others, 1965).

A maximum limiting date of 32,700 ± 900 years (UW - 9) for the youngest flood recognized in the Channeled Scablands was obtained from reworked peat fragments incorporated in flood gravels of inferred late Pinedale age (Fryxell, 1962). If the peat and associated wood fragments were reworked from an interglacial bog, the last flood may have occurred between about 15,000 and 25,000 years ago.

Radiocarbon dates from a conformable sequence of nonglacial deposits near Kootenai Lake, British Columbia (Fig. 17) indicate that the Purcell Trench was not occupied by ice from at least 43,800 years BP (GSC - 740) until after 25,840 years BP (GSC -715; Fulton, 1968). The chronology is based on eight radiocarbon dates that, if valid, preclude the presence of the Lake Pend Oreille Lobe damming Lake Missoula until after 25,840 years ago. This date is in good agreement with Fryxell's estimate of 15,000-25,000 years BP for the last Lake Missoula flood. Therefore, 25,840 years BP may provide a maximum limiting date for the cycles of Lake Missoula correlative with the Lower Member of the Lost Horse Drift. Furthermore, this limiting date is compatible with the inferred correlation of the Lower Member of the Lost Horse Drift with the early stade of the Pinedale Glaciation.

Flood Deposits on the Columbia Plateau

A detailed review of the Channeled Scablands and the Lake Missoula floods was given by Bretz (1969). The voluminous evidence indicates that between 3 and 8 floods have crossed the Channeled Scablands. Richmond deduced the occurrence of Lake Missoula floods at the close of Sacajawea Ridge Glaciation, late stade of the Bull Lake Glaciation, and early stade of the Pinedale Glaciation. Seven or eight floods were recognized by Bretz (1969). Both Pardee (1942) and Bretz (1969) concluded that the number of floods on the Columbia Plateau need not correspond to the number of fillings of Lake Missoula. Alden (1953, p. 155) suggested that adjustments in the ice and bedrock channel of the outlet stream, if sudden, might result in floods, even if Lake Missoula were only partly drained.

The multiple cycles of Lake Missoula recorded in the shoreline deposits of the Bitterroot Valley may reflect this type of delicate adjustment of the Lake Missoula outlet stream to advance and retreat of the Lake Pend Oreille Lobe, as well as to erosion of ice-marginal channels.

The presence of the Glacier Peak ash on the Columbia Plateau and in the Lake Missoula Basin provides a minimum limiting date for the latest Lake Missoula floods. This ash is interbedded with the deposits of Soap Lake in the southern part of the Grand Coulee, indicating that the last flood terminated before the Glacier Peak ash fell some 12,000 years ago (Bretz, 1969).

Relationship of the Glacial Succession of the Bitterroot Range to Fluctuations of Lake Missoula

Stratigraphic studies of the glacial deposits of the Bitterroot Range and the shoreline deposits of Lake Missoula reveal that lake fluctuations are generally synchronous with the oscillations of the alpine glaciers. Figure 18 illustrates the interrelation of the glacial and lake fluctuations established on the basis of local and regional correlation of stratigraphic units. Deposits of lake maxima at 4040, 4017, 4144 and 4088 ft, which correlated with the Lost Horse Drift, intertongue with end moraines and, therefore, are synchronous with the alpine glacial fluctuations. Deposits of the remaining lake maxima recognized in this study overlap moraine or outwash deposits and either do not correspond with alpine glacial fluctuations or correlate with alpine glacial fluctuation recorded above the elevation of the lake maxima. Shoreline deposits of lake maxima at 4144 and 4088 ft and possibly at 4040 ft do not maintain a constant stratigraphic relationship from valley to valley with the morainal sequence. This may reflect the lack of absolute synchroniety between valleys of minor glacial fluctuations.

The fluctuations of the Lake Pend Oreille Lobe at the mouth of the Clark Fork River must have been broadly similar

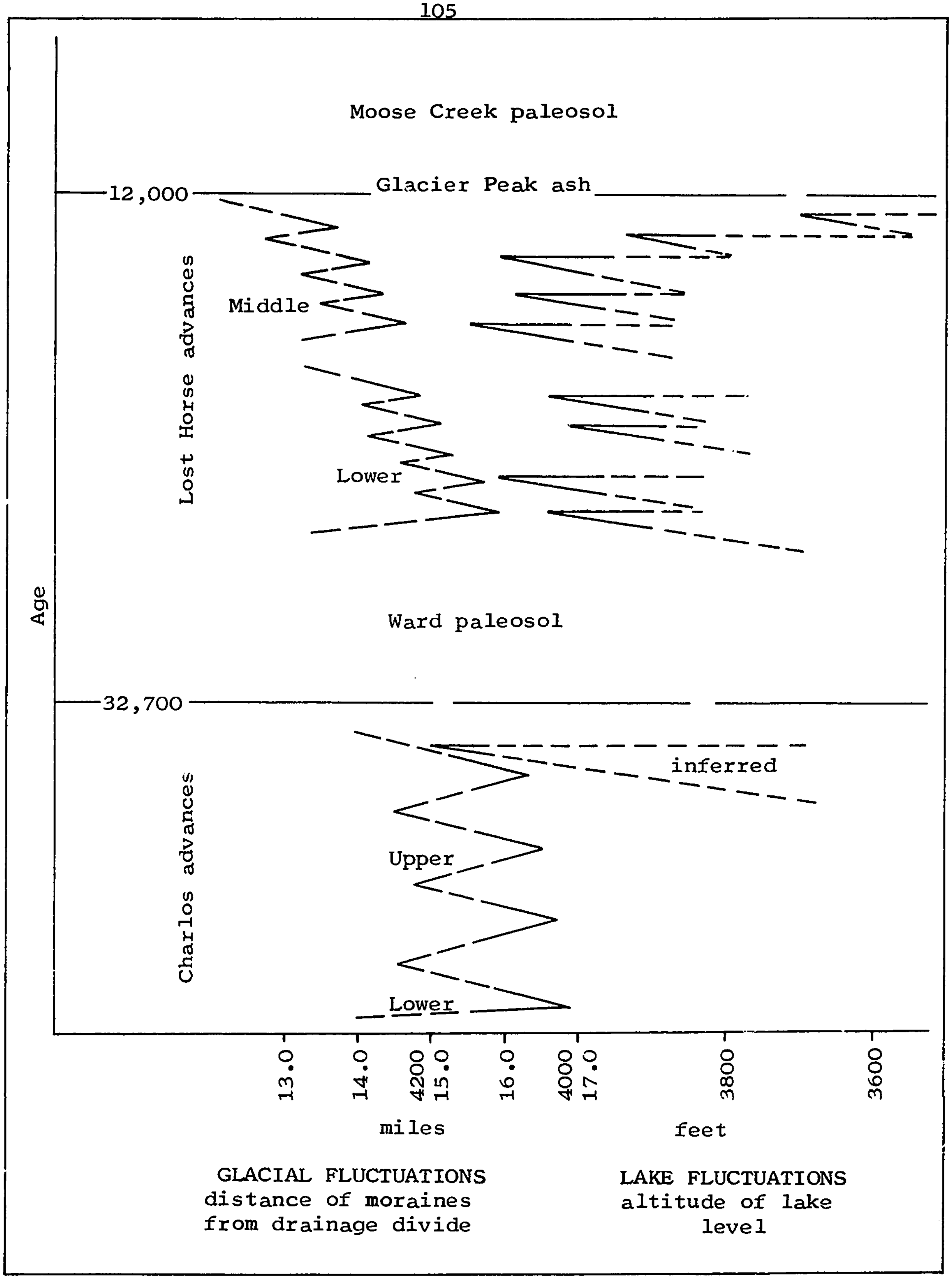


Figure 18 - Comparison of the glacial fluctuations of the Bitterroot Range with lake cycles of Lake Missoula.

and contemporaneous to the fluctuations of the alpine glaciers of the Bitterroot Range to yield the general correspondence of glacial and lake fluctuation observed.

REFERENCES CITED

Alden, W.C., 1932, Physiography and glacial geology of eastern Montana and adjacent areas: U.S. Geol. Survey Prof. Paper 174, 133 p.

__________, 1953, Physiography and glacial geology of western Montana and adjacent areas: U.S. Geol. Survey Prof. Paper 231, 200 p.

Beaty, Chester B., 1962, Topographic effects of glacial Lake Missoula - a preliminary report: California Geographer, v. 3, p. 113-122.

Blackwelder, Eliot, 1915, Post Cretaceous history of the mountains of central western Wyoming: Jour. Geology, v. 23, p. 97-117; 193-217; 307-340.

__________, 1931, Pleistocene glaciation in the Sierra Nevada and Basin Ranges: Geol. Soc. America Bull., v. 42, p. 865-922.

Bretz, J H., Smith, H.T.U., and Neff, G.E., 1956, Channeled Scabland of Washington, new data and interpretations: Geol. Soc. America Bull., v. 67, p. 957-1047.

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

Chambers, R.L., and Alt, D., 1971, Bull Lake and Pinedale Glacial Lake Missoula sediments: Geol. Soc. America Abs. with Programs, v. 3, no. 2, p. 94.

Folk, R.L., 1961, Petrology of sedimentary rocks: Hemphills, Austin, Texas, p. 40-46.

Fryxell, Roald, 1962, A radiocarbon limiting date for scabland flooding: Northwest Sci., v. 36, p. 113-119.

__________, 1965, Mazama and Glacier Peak volcanic ash layers; relative ages: Sci., v. 147, p. 1288-1290.

Fulton, R.J., 1968, Olympia interglaciation, Purcell Trench, British Columbia: Geol. Soc. America Bull., v. 79, p. 1075-1080.

Jenny, Hans, 1941, Factors of soil formation: New York and London, McGraw-Hill Book Co., Inc., 281 p.

Konizeski, R.L., Brietkrietz, A., and McMurtrey, R.G., 1968, Geology and ground water resources of the Kalispell Valley, Northwestern Montana: Montana Bu. Mines and Geol. Bull. 68, 42 p.

Langton, C.M., 1935, Geology of the northeast part of the Idaho Batholith and adjacent region in Montana: Jour. Geology, v. 43, no. 1, p. 27-60.

Lemke, R.W., Laird, W.M., Tipton, M.J., and Lindvall, R.M., 1965, Quaternary geology of northern Great Plains, in Wright, H.E., and Frey, D.G., eds, The Quaternary of the United States: Princeton, Princeton Univ. Press, p. 15-27.

Lindgren, W., 1904, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: U.S. Geol. Survey Prof. Paper 27, 128 p.

McMurtrey, R.G., and Konizeski, R.L., 1956, Progress report on the geology and ground water resources of the eastern part of the Bitterroot Valley, Montana: Montana Bu. Mines and Geology, Inf. Circ. 16, p. 1-8.

McMurtrey, R.G., Konizeski, R.L., and Brietkrietz, A., 1956, Geology and ground water resources of the Missoula Basin, Montana: Montana Bu. Mines and Geology Bull 47, p. 1-18.

Nobles, Laurence H., 1952, Glacial sequence in the Mission Valley, western Montana: Geol. Soc. America Bull., v. 63, p. 1286-1287 (Abs).

Pardee, J.T., 1910, The glacial Lake Missoula, Montana: Jour. Geology, v. 18, p. 376-386.

____________, 1913, Coal in the Tertiary lake beds of southwestern Montana: U.S. Geol. Survey Bull. 531, p. 229-244.

____________, 1942, Unusual currents in glacial Lake Missoula, Montana: Geol. Soc. America Bull., v. 53, p. 1569-1600.

____________, 1950, Late Cenozoic block faulting in western Montana: Geol. Soc. America Bull., v. 61, p. 359-406.

Richmond, G.M., 1962, Quaternary stratigraphy of the La Sal Mountains, Utah: U.S. Geol. Survey Prof. Paper 324, 131 p.

______________, 1965, Glaciation of the Rocky Mountains, *in* Wright, H.E., and Frey, D.G., eds., The Quaternary of the United States: Princeton, Princeton Univ. Press, p. 217-230.

Richmond, G.M., and Fryxell, R., 1965, Advances of the Cordilleran Ice Sheet and their relations to glacial Lake Missoula, *in* Schultz, C.B., and Smith, H.T.U., eds, Northern and Middle Rocky Mountains: INQUA Guidebook, Field Conf. E., p. 65-73.

Richmond, G.M., Fryxell, R., Neff, G.E., and Weis, P.L., 1965, The Cordilleran Ice Sheet of the Northern Rocky Mountains, and related Quaternary history of the Columbia Plateau, *in* Wright, H.E., and Frey, D.G., eds, The Quaternary of the United States: Princeton, Princeton Univ. Press, p. 231-242.

Ross, C.P., 1950, The eastern front of the Bitterroot Range, Montana: U.S. Geol. Survey Bull. 974 E, p. 135-175.

Ruhe, R.V., 1965, Quaternary paleopedology, *in* Wright, H.E., and Frey, D.G., eds, The Quaternary of the United States: Princeton, Princeton Univ. Press, p. 755-764.

Sieja, Donald M., 1959, Clay mineralogy of glacial Lake Missoula varves, Missoula County, Mont: Univ. Montana, unpub. MS thesis.

Soil Survey Staff, 1959, Soil Survey, Bitterroot Valley Area, Montana: U.S. Dept. Agriculture, Series 1951, no. 4, 128 p.

U.S. Forest Service, 1969, Drilling - Lost Horse sand source, Bitterroot National Forest: 7700 transportation system, Open File Report, Aug. 18., 19 p.

Weis, P.L., and Richmond, G.M., 1965, Maximum extent of late Pleistocene Cordilleran glaciation in northeastern Washington and northern Idaho: U.S. Geol. Survey Prof. Paper 525-C, p. 128-132.