Physiography and Glacial Geology of Western Montana and Adjacent Areas

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By W. C. ALDEN

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A study of glacial features in the intermontane valleys and the drainage area of the upper Missouri and Columbia Rivers

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By William C. Alden

ABSTRACT

Western Montana, as described in this paper, constitutes all that part of the State between the Rocky Mountain front on the east and the Montana-Idaho line on the west. Of this area (fig. 1) about 24,700 square miles are drained by the Missouri River and about 500 square miles drain to Hudson Bay; that part west of the Continental Divide, about 25,000 square miles, is drained to Columbia River by the Pend Oreille River, the Clark Fork, and the Kootenai River. With the exception of the Beartooth Mountains and the northern part of the Absaroka Range, all of western Montana is included in the Northern Rocky Mountains province and is characterized by many mountain ranges, some very rugged, and by intermontane valleys or basins, parts of which are 10 to 15 miles in width.

In the northern half of the region, the bedrock formations are mostly pre-Cambrian sedimentary rocks of the Belt series, with some of Paleozoic and Mesozoic age. In the southern half there are also large areas of Belt rocks and much gneiss and schist of Archean type, overlapped by folded and faulted Paleozoic and Mesozoic rocks. Intruded into them are granitic rocks of the Idaho and Boulder batholiths and outlying intrusives. Tertiary volcanic rocks overlie old eroded surfaces in many places, particularly in and near Yellowstone National Park. These volcanic rocks range in age from Eocene to upper Miocene and later, and have undergone uplift, some deformation, and faulting in the orogenic movements that produced the mountain ranges. The glacial and other Cenozoic deposits lie mostly in the intermontane basins.

The Eocene epoch probably was characterized especially by erosion in this region; and during it the uplands were largely reduced to areas of moderate relief. However, no actual remnants of so old an erosion surface are known to be preserved uncovered in western Montana. Volcanic eruptions in and near the Yellowstone National Park area made great deposits of lava, tuffs, and breccia, and some noteworthy stream deposits were laid on old worn-down erosion surfaces that are now high on mountain crests in and northwest of Yellowstone Park. The Sphinx conglomerate forms the upper part of Sphinx Mountain between 7,000 and 10,840 ft above sea level on the Madison Range. The coarseness, thickness, and height of this erosion remnant indicates that considerable elevation and a vast amount of erosion have occurred since this material was deposited upon the Livingston formation (Upper Cretaceous and Paleocene).

A deposit of bouldery gravel on top of the Gravelly Range west of the Madison Valley, part of which has been described by H. W. Scott as glacial till, is possibly of Eocene age, inasmuch as it overlies Mesozoic sand and shale and is overlain by volcanic deposits of supposed Oligocene age.

Unlike the plain in eastern Montana where the deposits of the Oligocene and Miocene epochs were entirely eroded, in many of the intermontane valleys of western Montana both east and west of the Continental Divide there are considerable deposits of clay, sand, and sandstone, many containing volcanic ash with beds of lignite and some interbedded, fine to coarse bouldery gravel. They include the so-called Bozeman "lake beds". Much of the material seems to have been deposited in lakes and ponds, or slack-water streams, with ash transported by winds from volcanic eruptions in nearby areas. The lignite was formed in marshes and the coarse gravel and boulders were probably swept out into the basins by torrential wash from adjacent mountain gulches. These strata are largely of Tertiary age. In many places remains of vertebrate animals have been found; some, such as Titanotheres, of Oligocene age. In places, Oligocene(?) beds underlie similar beds containing fossils, including plant remains, of Miocene or Pliocene age.

At many of the exposures the strata are faulted and tilted, frequently toward the mountains from which much of the material was derived by erosion. Evidently there was then considerable relief in this region, and the hills and mountains were in much the same positions as they now are, but perhaps not rising so high above the intervening valley floors at first. The disturbed condition of the Tertiary strata and the abruptness of some of the adjacent mountain slopes suggest faulting and lagging of the loaded valley floors while the whole region was being elevated by recurrent orogenic forces.

A deposit of bouldery gravel near the Beaverhead River north of Armstead and old gravel deposits on the flanks of the Anaconda and Flint Creek Ranges are possibly of Tertiary (Oligocene or Miocene) age.

Remnants of gravelly alluvial fans, stream terraces and benched spurs are found at several places in the Missouri River basin, above the Gates of the Mountains near Helena, at considerable heights above the main streams. The characters and relations of these features suggest that they are correlatives of similar remnants of the high benches, (No. 1 terrace) bordering the east front of the Rocky Mountains. The most noteworthy border the Madison River south of Three Forks at heights of 1,000 to 1,200 ft above the stream. They are capped with quartzite cobblestone gravel which overlies the eroded surface of the so-called Bozeman "lake beds" (Oligocene and Miocene). Since their formation a great deal of erosion has been accomplished. The Missouri and its tributaries have not only cut broad valleys in the friable Tertiary deposits but at many places, they have cut deep gorges in the older and more resistant sedimentary and crystalline rocks. The renewed down cutting seems to be largely the result of regional uplift in late Tertiary and Quaternary time. Certain bouldery benchlands and numerous piedmont spurs capped with glacial morainal drift are perhaps to be correlated with the well-marked high-terrace remnants. Possibly similar features in several of the valleys west of the Continental Divide also are to be correlated with them. These features are grouped with benched interstream ridges in the western part of Glacier National Park, which appear to be erosion remnants of a piedmont bench underlain very largely by Tertiary "lake beds" and capped with bench gravel and glacial drift. It is quite possible that in some parts,

such as the narrow gorge (Eddy Narrows) east of the mouth of Thompson River, the Clark Fork deepened its valley 800 to 1000 ft, in Pliocene and/or early Pleistocene time.

Some conspicuous smooth tracts on the Beaverhead Range and Pioneer Mountains may be upland remnants of old erosion surfaces of Pliocene(?) age. However, there are few indications of the development of a widespread peneplain at this time in western Montana.

It seems probable that in northern Idaho and adjacent parts of western Montana the Purcell Trench and adjacent valleys had been deepened in Oligocene and Miocene time by faulting and erosion far below the mountain tops and other uplands. This is inferred from the fact that deposition of the lake beds of the Latah formation and the overlying Columbia River basalt (upper Miocene) extended up the broad Spokane Valley and occupied the Purcell Trench west and north of Coeur d'Alene, Idaho, to places within eight miles of the present south end of Pend Oreille Lake basin. These deposits also had been very largely removed by erosion before this part of the Trench was first invaded by the Rathdrum lobe of the Cordilleran ice in Pleistocene time prior to the Wisconsin stage.

It seems probable on a priori grounds, that there were as many distinct stages of glaciation in western Montana and northern Idaho as have been demonstrated as occurring in the central part of the upper Mississippi basin. The extensive reconnaissance studies by the writer in the intermontane valleys west of the front ranges revealed but little definite evidence of early Pleistocene glaciation either by local mountain glaciers or by lobes of the Cordilleran ice. Certain deposits have been found that may reasonably be regarded as representing one or more early glaciations. They are mostly of relatively small extent and lie both east and west of the Continental Divide. They include very old drift near Pioneer, northwest of Deer Lodge, and the till near Grace, southeast of Butte, that was described by Atwood.

Some extra-morainal boulders at numerous places may perhaps be of an early glacial stage. Those on high-terrace remnants at the south side of the Castle Mountains, 50 to 60 miles north of Livingston, have previously been cited. Others lie on high-bench remnants in the upper Madison Valley; still others appear to have been dropped from floating ice during later stages.

In most of the intermontane valleys south of Missoula and the Blackfoot River, both east and west of the Continental Divide, are extensive erosion remnants of terraces that correspond to the second set of terraces and benchlands (thought to be early Pleistocene) east of the Rocky Mountains front. They were formed much later than the highest terrace remnants on the Madison River and correlated features, which are regarded as of either Pliocene or very early Pleistocene age. During the Wisconsin stage some mountain glaciers extended down into valleys, 100 to 200 ft or more in depth, that transect these main piedmont terraces. It seems clear that these remarkable terraces are of pre-Wisconsin, probably of Yarmouth interglacial age, although perhaps not earliest Pleistocene. They seem to be near correlatives of Blackwelder's "Circle terraces" in the Wind River Range and Jackson Hole, Wyoming.

Many of these terraces are underlain by tilted and faulted Tertiary "lake beds" and volcanic rocks thought to be of Oligocene and Miocene age. These beds are beveled off as though by lateral-shifting streams issuing from the mountain gorges. They are capped with coalescing alluvial fans heading at the numerous gorges. The fans are composed of sand and gravel, largely cobblestones and with some boulders. In places these alluvial deposits, which slump readily, are so thick (50 to 100 ft or more) that the underlying strata are not well exposed in the sides of the transecting gulches. The surfaces of the constituent fans are in many places creased by small, radiating channels, but the surfaces of most of them are remarkably smooth over many square miles except where trenched by the erosion of steep-sided later gulches.

The more extensive remnants, such as those in the Madison and Beaverhead Valleys, appear to merge with the lower terraces which slope downstream. The eroded edges of these terraces form lines of river bluffs that rise 50 to 100 ft or more above the lower terraces and bottom lands. The superficial aspect of these conspicuous terraces is much the same as that of the pediments of the southwestern states. There may be legitimate differences of opinion as to whether or not these features should be correlated throughout the several intermontane basins south and east of Missoula, but their character and relations are so similar both east and west of the Continental Divide that such a tentative correlation seems to be warranted as indicating a fairly definite stage of topographic development. Some small remnants of terraces west, northwest, and north of Missoula may perhaps represent this stage of development, but they are generally less well preserved and have been less carefully studied.

South of Flathead Lake and outside of the Polson moraine, which seems to be of late Pleistocene (Wisconsin) age, a sheet of glacial till extends southward to the hills north of the Jocko River. This drift comprises the Mission moraine of the Flathead glacial lobe and drift outside of it. It does not show evidence of much greater age than that of the Polson moraine. It is possible that this drift of the Mission moraine is a correlative of the outer drift of the Keewatin glacier on the plains of eastern Montana and northwestern North Dakota. It has been tentatively suggested that the latter drift may have been deposited either at a late phase of the Illinoian stage of glaciation or when the Iowan drift of the Keewatin ice sheet was laid down in northern Iowa and adjacent States. The writer is inclined to regard the Mission moraine as the product of an advance of the Flathead glacier distinctly older (but not greatly older) than that which formed the Polson moraine and associated deposits. There are exposures of this older till at several places in the sides of the inner gorge of the Flathead River between the outlet of Flathead Lake and Dixon on the south.

Perhaps also to be correlated with the drift of the Mission moraine are remnants of somewhat worn-down moraines outside of, but near, some of the well-defined terminal moraines (Wisconsin) of local mountain glaciers of the Bitterroot, Flint Creek, Beaverhead, and other ranges. Similar drift is found on the upper Blackfoot River in the region of Helmville and Lincoln. The outer moraine of the Yellowstone glacier southwest of Livingston, and certain drift deposits in the upper Madison Valley near West Yellowstone, Mont., are perhaps also to be correlated with these deposits. All seem to be near correlatives of the moraines of Blackwelder's "Bull Lake Stage of glaciation" in the Wind River Range and Jackson Hole, Wyoming.

During the Wisconsin and earlier stages of glaciation there was probably an extensive ice cap covering most, possibly all of the Yellowstone Park plateau and the Absaroka Range and Beartooth Mountains to the north and northeast, from which glacial tongues extended down the several gorges. Farther north, northwest, and west, between the Park, the Idaho-Montana State line, and the Canadian boundary, there were many local glaciers, some of them large, heading in the cirques that scallop the upper slopes of the highest mountain ranges both east and west of the Continental Divide. Some of the glaciers, especially those in and south of Glacier National Park, were so large that they extended for miles out onto the adjacent piedmont benchlands.

So great was the amount of ice in British Columbia that some geologists have used for it the name Cordilleran ice sheet. For convenience, this name is used in the present paper. So thick was the ice at the maximum stages that it appears to have almost, if not entirely, submerged the Purcell and Selkirk Mountains near the 49th parallel in northwestern Montana and northern Idaho. Large tongues of the Cordilleran ice extended far to the south along the Rocky Mountain Trench and the several valleys to the west. A sublobe of the ice in the great Purcell Trench extended southeastward from the Pend Oreille Lake basin and completely blocked the Clark Fork at the Montana-Idaho State line, so that water was impounded in the branching valley for a maximum distance of about 250 miles above a 2500-foot ice dam, forming glacial Lake Missoula. As indicated by the shorelines, there were many fluctuations of the water level in this lake and it is probable that at each stage of deglaciation, the lake basin was entirely drained. The relations of the glacial, glaciolacustrine, and glaciofluvial deposits are described.

As shown on the topographic maps, there are 65 or 70 small glaciers in Glacier National Park. They lie in high cirques at altitudes between 6,500 and 10,000 ft above sea level. The largest, the Blackfoot Glacier, consists of 3 or 4 sq mi of ice. There are two small glaciers on the Flathead Range south of Nyack, and one or two on the Mission Range and the Cabinet Mountains at altitudes above 6,500 ft. There are also two or three small glaciers on the Crazy Mountains at altitudes of 9,000 to 10,000 ft, and on the mountains east and northeast of Yellowstone National Park at altitudes above 10,000 ft. There are several small glaciers on the Bighorn Mountains in northern Wyoming at altitudes above 11,000 ft. Examinations of several of the glaciers in Glacier National Park at different times between the years 1900 and 1940 show progressive decrease in the size of some of the glaciers. These glaciers have been described in other papers.

Between the lines of river bluffs in western Montana, there are many remnants of one or more lower gravelly terraces of Wisconsin and post-Wisconsin age. In some places there are several such terrace steps at heights 10 to 50 ft apart. Such lower terraces are less extensive than the piedmont terraces and are generally confined between the main lines of river bluffs, which are one to several miles apart. In places they are well developed in tributary gulches transecting the piedmonts. They seem to mark minor substages of cutting downward and incipient lateral planation. Although well preserved, they do not generally show up clearly on the topographic maps. Some of the terrace gravels may be composed of outwash from mountain glaciers of the Wisconsin stage. On the maps in this paper these lower terraces are not differentiated from the later flood plain deposits or the broad valley bottom lands with which they merge in places. Generally distinct from the gravel terraces west and north of Missoula are terraces composed of laminated silt deposited in glacial Lake Missoula.

INTRODUCTION

FIELD STUDIES

The study of the physiography and glacial geology of western Montana started with work in 1911–13 in Glacier National Park and the Blackfeet Indian Reservation and was continued in 1921, 1922, and 1923 with a preliminary check across the intermontane valleys in the region of Bozeman, Townsend, and Helena, Mont. to correlate the results with those of similar studies by J. T. Pardee on the upper Missouri River and on the tributaries of the Clark Fork of the Columbia River. In the summers of 1927 to 1931 and 1936 to 1938 inclusive, regional studies were made throughout the intermontane valleys and the borders of the mountains in western Montana, northern Idaho, and eastern Washington to the valley of the Okanogan River and the eastern front of the Cascade Range in the region of Lake Chelan and Wenatchee, with some observations along the Columbia River as far west as Portland, Oreg. The total area traversed is one of great extent. It is therefore evident that the studies were, in general, a reconnaissance and that the interpretations and correlations are of a tentative character. In most places the examinations of the intermontane basins in Montana and Idaho were extended to the foot of the bordering mountain ranges or up the gorges to the terminal moraines of the mountain glaciers of the last or Wisconsin stage of glaciation.

Except during the two seasons, 1911 and 1913, when the writer and his assistants were working with M. R. Campbell's party on a more detailed survey in Glacier National Park, the higher slopes and crests of the mountains were traversed only in some places accessible from automobile roads. The discussions of high mountain tracts presented in this paper are based mostly on the examination of topographic maps and aerial photographs where such have been available, and on published reports of other geologists who have worked in this region. In general, the interpretations do not deal with features as old as early Cenozoic—that is, Paleocene time. The geomorphologic development of the mountains and the valleys as we see them today in this region appears to have been accomplished mostly since Paleocene deposition in Montana.

In 1914 Eugene Stebinger and C. S. Corbett, who had been the writer's assistant in 1913, continued the geologic mapping of Glacier National Park. To them the writer is indebted for the use of their unpublished notes, maps, and photographs. The same is true of the results of Stebinger's work in the Flathead Indian Reservation in 1911 and of his observations in the valley of the Clark Fork in Montana in June 1914. So greatly is the writer indebted to the studies of J. T. Pardee in various parts of this whole region and so considerable have been Mr. Pardee's contributions to the mapping of the deposits and to the interpretation of their relations, that it is a pleasure to acknowledge his collaboration in the preparation of this paper. The following persons, mostly enthusiastic students of geology, rendered considerable assistance in field examinations in western Montana and adjacent areas: J. H. Alden, L. M. Alden, R. E. Bates, D. B. Clapp, C. L. Gazin, M. A. Harrell, P. T. Jenkins, G. D. Johnson, G. E. Manger, E. F. Richards, J. R. Sandidge, and O. L. Tweto.

Topographic surveys have been made of large parts of western Montana and adjacent parts of northern Idaho and eastern Washington. The designations and distribution of the topographic maps published and for sale by the U. S. Geological Survey are shown on index maps for these states. Most of the maps are on a scale of one-half inch per mile (1:125,000). Frequent references are made to these maps in this paper and interested readers will find them of much assistance in study of the physical features of the region.

GENERAL FEATURES OF WESTERN MONTANA

Western Montana, as treated in this paper, embraces that part of the State west of the eastern front of the Rocky Mountains (fig. 1 and pl. 1). In this same physiographic province are included the adjacent mountainous parts of Idaho and northeastern Washington. From the Wyoming boundary, near the west

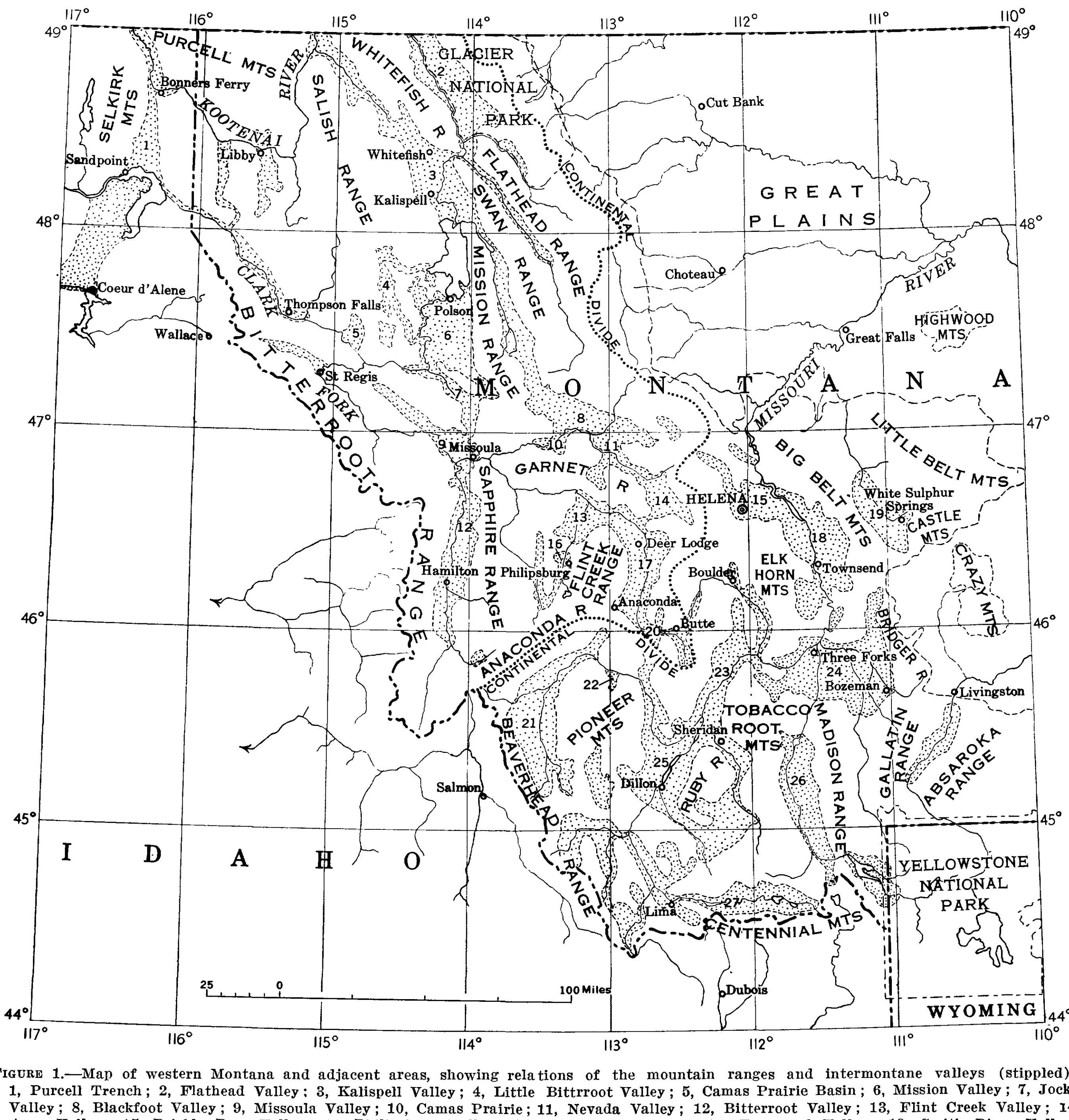

FIGURE 1.—Map of western Montana and adjacent areas, showing relations of the mountain ranges and intermontane valleys (stippled): 1, Purcell Trench; 2, Flathead Valley; 3, Kalispell Valley; 4, Little Bittrroot Valley; 5, Camas Prairie Basin; 6, Mission Valley; 7, Jocko Valley; 8, Blackfoot Valley; 9, Missoula Valley; 10, Camas Prairie; 11, Nevada Valley; 12, Bitterroot Valley; 13, Flint Creek Valley; 14, Avon Valley; 15, Prickly Pear Valley; 16, Philipsburg Valley; 17, Deer Lodge Valley; 18, Townsend Valley; 19, Smith River Valley; 20, Silver Bow Valley; 21, Big Hole Basin; 22, Vipond Park; 23, Jefferson Valley; 24, Gallatin Valley; 25, Beaverhead Valley; 26, Madison Valley; 27, Centennial Valley.

line of Yellowstone National Park, northwestward to the vicinity of the 116th meridian, the Montana-Idaho State line follows the irregular crests of a succession of practically continuous mountain ranges. These ranges have, severally, the following names[1] and approximate lengths as scaled roughly on a map; the Henrys Lake Mountains (pl. 1) extending in a broad curve west to Red Rock Pass, 45 miles from the Wyoming State line in Yellowstone National Park; the Centennial Mountains westward to the canyon of Beaver Creek and the pass near Monida, about 55 miles; the Beaverhead Range between Monida on the southeast and the Nez Perce Pass (about 25 miles southwest of Darby, Mont.) on the northwest, a distance of about 230 miles; the Bitterroot Range extending from the Nez Perce Pass northward and northwestward to a point east of Pend Oreille Lake, Idaho, near latitude 48° N., longitude 116° W., a distance of nearly 250 miles (the name "Bitterroot Range" is sometimes used as far southeast as Monida); thence northward to the international boundary, a distance of about 70 miles, the Montana-Idaho State line is parallel to and about 2½ miles west of the 116th meridian. In this part it crosses the Clark Fork, the western part of the Cabinet Mountains, the Kootenai River, and a part of the Purcell Mountains.

From a point on the 49th parallel near longitude 113°35′ W. the east front of the Rocky Mountains is abrupt and fairly regular, trending southeastward nearly 200 miles to the Missouri River above Great Falls. East of the Missouri the north ends of the Big Belt Mountains and the Little Belt Mountains rise from the plains along a nearly continuous front extending eastward to southeastward for 120 miles to the Judith Gap near the 110th meridian.

North and east of the Little Belt Mountains are several relatively small isolated mountain groups, which are generally included in the Great Plains province. In the Plains province also might be included two abrupt and high mountain groups of relatively small areal extent, the Castle Mountains and the Crazy Mountains, which stand within a great reentrant in the main Rocky Mountain front between the Little Belt Mountains on the north, the Big Belt Mountains and the Bridger Range on the west, the north end of the Gallatin Range on the southwest, and the northern part of the Absaroka Range south and east of the Yellowstone River. The Crazy Mountains are very largely the product of Eocene igneous intrusions into the Livingston formation and underlying Cretaceous deposits of the plains, which nearly surround them and are otherwise not greatly disturbed.

The north front of the Absaroka Range is generally abrupt and high for some distance east of the vicinity of Livingston; beyond this it is continuous with the similar front of the Beartooth Mountains trending from southeast to south in the vicinity of Red Lodge, Mont. Thence southward across the State line it continues to be abrupt to and beyond Cody in Wyoming. The Absaroka Range, the Beartooth Mountains, and most of the area of Yellowstone National Park are included in the middle province of the Rocky Mountains system. Separated by the Cody Basin and the valley of the Clarks Fork of the Yellowstone River from the mountain front described above, and east of it, are the Pryor Mountains and the Bighorn Mountains. These mountains, which are separated by the narrow canyon of the Bighorn River, and the Cody Basin are also generally included in the Middle Rocky Mountains province.

The northern Great Plains rise gradually westward to altitudes of 5,000 to 6,000 ft above sea level at the foot of the Rocky Mountains. The mountain front in general rises abruptly from the plains and a short distance back from the front are peaks rising to altitudes of 9,000 to 10,000 ft in and south of Glacier National Park, and 11,000 to 13,000 ft and more in the Bighorn Mountains and the more rugged parts of the Beartooth Mountains, northeast of Yellowstone National Park.

Western Montana, as a whole, is characterized by a succession of distinct mountain ranges and intervening valleys. In general, the intramontane basins are not so wide as the intervening mountain belts but some are as wide as or wider than the adjacent mountains. The distribution, but not all of the names, of these several ranges are shown on the map, plate 1. North of the latitude of Helena and Missoula (46°30′ to 47°) the general trend of these features is northwest, or nearly parallel to the east front of the Rockies. South of this latitude the general trend is more northerly, but the mountains are considerably more irregular and the basins are somewhat broader.

The rocks in the northern area are mostly of the pre-Cambrian sedimentary Belt series, but some Paleozoic and Mesozoic strata are present, mostly in the eastern part; only small areas of Tertiary extrusive rocks are found. In the southern half there are rather large areas of sedimentary rocks of the Belt series, notably in the Big Belt and Little Belt Mountains, the Pioneer and the Sapphire Mountains, Flint Creek, Beaverhead, and Anaconda Ranges. Much gneiss and schist of Archean type forms the mountain cores from the Beartooth Mountains on the east to the Tobacco Root Mountains and Ruby Range on the west. Bordering these masses of gneiss and schist and in many other parts of the south half of the region are upturned, folded, and faulted Paleozoic and Mesozoic sedimentary rocks. Granitic rocks of the Boulder batholith intrude all these rocks in the region of Helena and Butte; and similar rocks of the northeastern part of the great Idaho batho-

[1] In this paper the usage of geographic names conforms to the decisions and recommendations of the United States Board on Geographic Names.

lith are found in that part of the Bitterroot Range adjacent to the Bitterroot Valley, in the Sapphire Mountains, and in the Anaconda, and Flint Creek Ranges. At many places in the south half of western Montana, Tertiary volcanic rocks overlie old eroded surfaces, with markedly unconformable relations in the region of Yellowstone National Park and elsewhere. These volcanic rocks range in age from Eocene to late Miocene or later, and all have been uplifted, deformed, and faulted by the orogenic movements that produced the mountain ranges essentially as they are now.

In setting forth the results of the regional reconnaissance study of the physiographic and glacial history of western Montana, we may well consider the headwater drainage of the Missouri River system. Figure 1 and plate 1 show how large the part of western Montana east of the Continental Divide is as compared with that which lies west of the Continental Divide and drains to the Columbia River. As is well known, the Divide in Montana does not generally lie along the crest of the most easterly ridges of the Rockies. In Glacier National Park, for 12 miles south of the international boundary, the Divide is along the crest of the Livingston Range, 15 to 20 miles west of the mountain front. It then jogs eastward to and southward along the crest of the Lewis Range, keeping to the west of the headwaters of the Hudson Bay drainage basin. Branching off northeastward at Triple Divide Peak, the Hudson Bay divide shuts off the Milk River drainage from that of Saint Mary River, a branch of Belly River tributary to the South Saskatchewan River. From Triple Divide Peak southward to Theodore Roosevelt Pass the Missouri River system heads in the Lewis Range, but farther southeast from the pass to a point within 20 miles of the Missouri River the divide is along a crest 6 to 20 miles back of the most easterly of the longitudinal mountain ridges. About 35 miles southwest of Great Falls the Missouri River issues from the mountains and from this point southward a great deal of the area comprising the Rocky Mountain ridges and intermontane basins is drained by the Missouri River. Near Butte the Continental Divide is about 70 miles west of the crest of the Bridger Range, north of Bozeman, and a few miles farther south it shifts westward another 70 miles in a broad curve to the southwest boundary of the State on the crest of the Beaverhead Range near longitude 114° W. It is near this same meridian that the Divide crosses the international boundary and enters Glacier National Park from Canada. That part of Montana west of the Divide is approximately 25,000 sq mi in extent.

From the headwaters of the South Fork of Dearborn River northward to the Hudson Bay divide in Glacier National Park the mountainous belt drained by tributaries of the Missouri encompasses about 1,500 sq mi. Smith River drains the basin bounded by the Big Belt, Little Belt, and Castle Mountains, an area of about 1,800 sq mi, and enters the Missouri above Great Falls; Shields River drains to the Yellowstone most of the basin between the Bridger Range and the Crazy Mountains, an area of about 900 sq mi. The Yellowstone also takes to the Missouri the drainage of the mountains north and northeast of Yellowstone National Park, an area of about 2,700 sq mi.

About 1,300 sq mi on the north and south flanks of the Little Belt, Castle, and Crazy Mountains, which are drained to the Missouri River by way of several different streams, might also be included under the name "Western Montana", as used in this paper.

The total of these areas in Montana between the east foot of the Rocky Mountains and the Continental Divide, which is drained by the Missouri River system, is about 24,700 sq mi. If to this amount is added about 500 sq mi in and adjacent to Glacier National Park, which drain to the South Saskatchewan River, the total area east of the Continental Divide in the Rocky Mountains of Montana is about 25,200 sq mi—that is, a little more than the area west of the Divide within this State.

The characteristic sedimentary deposits in the bottoms of these drainage basins are, so far as definitely known, of post-Eocene age. The early Tertiary deposits, although they overlie unconformably the upturned folded and faulted Paleozoic and Mesozoic rocks, and are clearly of post-Cretaceous age, are nevertheless integral parts of the higher hills and mountains and were involved in the movements that produced the mountains. This is true of both sedimentary and volcanic rocks of Eocene age.

PALEOCENE AND EOCENE EPOCHS

LIVINGSTON FORMATION AND SPHINX CONGLOMERATE

During Paleocene and Eocene time large quantities of volcanic material were ejected in the form of lava flows and volcanic breccias in the Yellowstone National Park region. This material formed a nearly continuous cover over the old land surface that had been developed by long erosion of the folded and faulted Paleozoic and Mesozoic sedimentary rocks. A good deal of volcanic material was spread far to the east and northeast, contributing to the upper part of the Livingston formation on the plains. The upper part of the Livingston formation grades eastward into beds typical of the Fort Union formation of the plains and in places contains fresh-water shells and plant remains. Thus the upper part of the Livingston is regarded as of Paleocene age.

From the Little Belt Mountains northward to the international boundary the only deposits near the eastern mountain front that have been regarded as of possible Eocene age are those of the Willow Creek and Saint Mary River formations and the Horsethief sandstone. These deposits were involved in the major orogenic movements and were upturned and faulted in a belt bordering the Rocky Mountain front, in the Blackfeet Indian Reservation, and in part in the basin of the Sun River.

A few miles east of East Rosebud Creek, in Carbon County, is a small remnant of the Linley conglomerate which Calvert (1917) found to overlie the Fort Union formation unconformably. This conglomerate is tilted slightly northeastward.

Twenty to twenty-two miles northwest of the northwest corner of Yellowstone National Park is a peak in the Madison Range known as Sphinx Mountain whose upper part is composed of conglomerate. Peale (1896, p. 3) describes the peak as follows:

> In the Sphinx Mountain, which reaches an elevation of 10,840 feet in the central part of the Madison Range, is found a group of beds which once may have spread over an extensive area of the country, although at present occupying only an area of about 2 square miles. This remnant is between 2,000 and 3,000 feet in thickness, made up of reddish sandstones and coarse conglomerates of limestone pebbles and bowlders cemented with a reddish sand. The entire mass of the peak is composed of these beds, which are horizontal in position and distinctly stratified, the rugged and steep slopes of the mountain rendering evident the gigantic scale of the erosion which has left it in this district the only monument of this group of beds. So far as observed the strata are nonfossiliferous, the character of the beds precluding the preservation of fossils. They are, therefore, somewhat arbitrarily referred to the Eocene, but they form a group certainly younger [2] than the Bozeman beds and older [3] than the Livingston formation.

The Sphinx conglomerate overlies unconformably a considerable thickness of andesitic volcanic material which Peale correlated with the Livingston formation and which in turn, unconformably overlies upturned faulted and folded Cretaceous strata. The Sphinx conglomerate was evidently deposited on a worn-down land surface, but its present extent is too limited to show that the surface was definitely a peneplain. It is considered to be of Eocene age.

Certain deposits of gravel and boulders observed in the vicinity of Black Butte, 25 to 30 miles southwest of Sphinx Mountain, are described, inasmuch as they are very suggestive of topographic conditions in the region of the Madison River in early Tertiary time.

BOULDERY DEPOSITS AND EOCENE(?) TILL ON THE GRAVELLY RANGE

The Gravelly Range is south of Virginia City and Old Baldy Mountain between the Ruby River on the west and Madison Valley on the east and borders Centennial Valley on the south. In the Three Forks quadrangle this range was mapped as the southern part of the "Jefferson Range", a name that has been abandoned in this area. Deep valleys, tributary to the rivers on the east and west, gash the flanks of the Gravelly Range. Black Butte, an abrupt conical hill composed of basalt (in T. 11 S., R. 2 W.) is the culminating peak of the range, rising hundreds of feet above the adjacent surface and about 10,850 ft above sea level. Parts of the crest of the range that are traversed by a Forest Service road are narrow and composed of upturned siliceous rock and limestone strata. Other parts, especially where underlain by shale and sandstone (Cretaceous) both north and south of Black Butte, are smoothly rounded and grassed and look like remnants of an old erosion surface; they are about 8,000 to 9,500 ft above sea level. In places, these smooth surfaces are sprinkled with cobblestones and boulders, some of gneiss 3 to 6 ft in diameter.

Bare scarps formed by slumping at the heads of tributaries to East Fork Ruby River expose 10 to 30 ft of bouldery gravel overlying red clay. The stones include angular to subangular blocks of buff sandstone and angular to well-rounded cobbles and boulders of gneiss 1 to 6 ft in diameter. Much of the deposit is also of well-rounded white quartz cobbles and some of quartzite. This gravel is unconsolidated and many such stones are scattered over the smooth grassed surfaces. The gneiss boulders seem to be unweathered.

Four to five miles north of Black Butte another landslide scarp, about 30 to 50 ft high, at the west side of Ruby Creek exposes coarse reddish gravel, partly cemented to conglomerate. No pebbles or boulders of gneiss were noted in this deposit, but boulders of gneiss 1 to 6 ft in diameter and well-rounded quartzite cobbles are sprinkled on the smooth surface along the road near and above the crest of the scarp.

A detailed examination of the crest and flanks of the Gravelly Range south of the Three Forks quadrangle has not been made by the writer. However, there are some indications of faulting north and east of Black Butte, as shown on a map by Condit, Finch, and Pardee (1928, pl. 12). As seen from the east side of Madison Valley, a rather definite benching of the east flank of this part of the Gravelly Range suggests that the belt of pre-Cambrian gneiss and schist along this flank may have been lowered somewhat by downfaulting when the intermontane basin between the Madison and Gravelly Ranges was formed, during and after the deposition of the Bozeman "lake beds" and of the rhyolitic lava flows. No direct evidence of glaciation was noted at the exposures examined, but some of the boulders on the surface ar 3 to 6 ft in diameter and their source is not clearly evident. Only the east base of Black Butte was visited by the writer in 1938. H. W. Scott (1938), however, examined the environs of Black Butte in 1935 in connection with studies for the Montana Bureau of Mines and Geology and revisited the locality in 1936 and 1937. He gives the following description of a de-

[2] *younger* should be *older*.
[3] *older* should be *younger*.

posit of ancient glacial till found at the western border of the basalt of Black Butte.

Description of the till

The type locality of the till is on the southwest side of Black Butte * * * a prominent physiographic feature that rises 1,000 feet above the surrounding area. It is composed chiefly of columnar basalt. In places around the margin of the butte white unconsolidated tuff attains a thickness of 200 feet or more. The tuff underlies and is therefore older than the basalt. At some points the basalt rests directly upon Mesozoic sands and shales. Isolated remnants of the volcanics occur throughout Gravelly Range.

The glacial deposit is unconsolidated and is composed of rocks ranging in size from clay particles to boulders 5 feet in diameter. The large pieces are mixed with fine sand and silt, the whole representing typical heterogeneous glacial till. Irregular, faceted stones and beautifully striated pebbles and cobbles are present. Striated specimens are most frequently found at the south end of the deposit. Water-worn pebbles and cobbles are common and most prevalent near the base of the formation, but these contain some of the best striations. Cobbles of quartzite seem to be most commonly striated and, interestingly, some of the rounded and polished specimens contain the deepest and most numerous striations. * * *

The till contains igneous, metamorphic, and sedimentary material. It is made up of the following in the approximate order of their abundance: white-to-pink quartzite, dark-gray quartzite, pegmatite quartz, chert, gneiss, red quartzite, sandstone, orthoclase, porphyry, and yellow quartz. Limestone and basalt are entirely absent. The material has been derived primarily from the pre-Cambrian metamorphics. Any Paleozoic limestones which may have been incorporated in the till have been completely leached. * * *

The Paleozoic and Mesozoic rocks in Gravelly Range were uplifted and folded during the Laramide orogeny. Dissection was continuous throughout the uplift, and in some places thousands of feet of sediments were removed. As dissection went on it is safe to presume that glaciers existed in many of the higher areas. A reconstruction of the old profile of Gravelly Range suggests that the east side of that range attained an elevation of approximately 12,000 feet. It is certain that the source of the Black Butte till was to the east and north of its present position.

The age of the Black Butte till must be determined through a study of the overlying and underlying formations. The till rests upon an erosional surface which truncates rocks that were tilted and folded during the Laramide orogeny. * * * This makes it evident that the till is Eocene or younger. The overlying formations consist of extrusives, tuffs, basalts, and the determination of their exact age is the most important problem in determining the age of the Black Butte glaciers. There is some indirect paleontological evidence concerning the age of these volcanics.

The tuffs on the upland areas were probably formed contemporaneously with the white ash in the basal part of the Bozeman beds. Oligocene and Miocene fossils, mainly vertebrates, have been found in these 'lakebed' deposits. Therefore, the age of the tuffs overlying the Black Butte till is certainly mid-Tertiary, probably Oligocene, as indicated by the relationship of the tuffs to the lower Bozeman beds which contain Oligocene fossils. Physiographic studies throughout the Rocky Mountains by many workers show that no mountain ranges existed in Oligocene time comparable in elevation to the earlier Rockies. The Black Butte till should, therefore, belong to the Rocky Mountain generation of Eocene time and is probably to be correlated with the Ridgway glacial stage of Colorado.

If the pre-Cambrian rocks along the east flank of the Gravelly Range have been down faulted, as suggested above and have also been considerably lowered by post-Eocene erosion, it is quite possible that in Eocene time these rocks composed a mountain crest where the east flank of the Gravelly Range is now located. This crest may have been sufficiently high to have generated one or more local glaciers, which, together with attendant torrential flows of water, could have transported westward the glacial till found by Scott at Black Butte and the erratic cobbles and boulders seen by the present writer and could have deposited them in the places which are now on the crest of the Gravelly Range. Such Eocene(?) glacial transportation and deposition would be quite in harmony with the deposition of the Ridgway till and similar deposits found in the region of the San Juan Mountains, Colo., as reported by Atwood and Mather (1932, pp. 16–17). There undoubtedly were many valleys and hills and there may have been mountains of considerable height.

West and north of Madison County, in Beaverhead, Silverbow, and Jefferson Counties, the only rocks thought to be of early Tertiary age are lavas, largely andesitic, which unconformably overlie upturned, folded, and faulted Paleozoic and Mesozoic rocks. These lavas occur at both high and low levels and not only were deposited on uneven eroded surfaces, but have since been subjected to orogenic movements, elevation, and faulting. There is little evidence in hand to show the progress of the uplift in this region during Eocene time.

BOULDERY GRAVEL NEAR ARMSTEAD AND ANACONDA

Near Clark Canyon, 3 miles north of Armstead, the Beaverhead River has cut a gap which is barely wide enough for the stream, the east-side road, and the railroad bridge, so that the newer highway (U S 91) was graded across the low spur west of the river and above the railroad. Cuts made in grading at this place exposed a deposit that suggested the presence of a glacial moraine to some persons. Nothing else in this vicinity, however, indicates that there was Pleistocene glaciation at this place. The loose material exposed is probably a part of the deposits laid down in Tertiary time and later tilted and eroded. The deposit appears to be distinct from, and unconformably overlapping a northeast-dipping conglomerate interbedded with buff sandstone, which is exposed in the bluff west of the road and a quarter of a mile to half a mile to the south. A railroad cut in the lower east end of the spur exposed loose sandy material containing many smoothly worn boulders, mostly of reddish quartzite, with some of disintegrating gneiss and limestone and some of rhyolite. The 5- to 15-ft road cut on the highway showed a loose, unsorted, till-like mixture of pebbles, cobbles, and boulders embedded in finer sandy material. Many of the boulders are several feet in diameter; one of quartzite measured 4 by 6 by 8 ft. Such scratches as were seen on the boulders appear to have been made artificially in grading. A belt of cobbles and boulders also extends from the highway northwestward up the slope to the edge of the upland, 600 or 800 ft above the river; there the weathered surface of the upturned beds of fossiliferous Paleozoic limestone is strewn with similar loose pebbles and boulders. Part way up the side of a gulch at the south side of this boulder belt there are big broken masses (or ledges) of very hard, gray, siliceous rock and on the nearby slope are numerous fragments of silicified fossil wood. In the bottom of the gulch ledges of conglomerate are exposed in which the pebbles are mostly limestone but with many cobbles and boulders of sandstone and reddish quartzite 1 to 2 ft long. These quartzites, however, are mostly not like the pink and red, cross-bedded quartzites, such as are numerous among the loose boulders on the adjacent slopes, and it is doubtful if the latter were derived from this conglomerate. They resemble the quartzites of the Belt series, but the nearest known exposures of Belt rocks are 15 miles or more to the west and northwest of this locality. This bouldery material appears also to extend up onto a high bench east of the Beaverhead River, south of Clark Canyon. The deposit as a whole may be a torrential stream deposit or, possibly (?), a glacial deposit of early Tertiary age or associated with the Bozeman "lake beds" and later upturned. Further study is needed to determine its origin and whether or not it is of greater age. It is evidently not a Pleistocene glacial deposit. The nearest mountains on which Pleistocene glaciers formed are the Pioneer Mountains near the head of Rattlesnake Creek, 20 miles or more to the northwest. It is surprising to find such large boulders in this place.

Above the old road the steep slope at the south side of the Clark Canyon also is strewn with large and small boulders. The lower part of this canyon is cut in lava and some exposures at the north side show gray to pinkish-white tuff and tuff breccia. Eastward and about a mile below the Anderson ranch a side gulch is cut into a bed of conglomerate, which dips toward the northwest and which appears to extend thence up to the upland on the northeast. This conglomerate consists of well-rounded cobblestones and 1- to 3-ft boulders of quartzite. What may be part of the same deposit is well exposed in the upper part of the opposite bluff south of the Anderson ranch (in or near sec. 12, T. 10 S., R. 10 W.). It forms a dark-red buttressed cliff below the smoothly rounded upland (7,600 ft above sea level) near the head of the canyon of Horse Creek, east of Armstead. The smoothly water-worn pebbles, cobbles, and 1-ft boulders in the upper part of the cliff are largely of reddish quartzite, some white, and there are some etched pebbles of dark-gray limestone. Whether or not this conglomerate formation is continuous southeastward along the range of hills between Red Rock River on the west and Sage Creek on the east has not been determined. If it is continuous, it may be the immediate source for the quartzite cobbles and boulders widely scattered over slopes and crests and capping terrace remnants as far south as the valley of Red Rock River east of Lima.

North of the Big Hole Basin and about 6 to 12 miles southwest of Anaconda a large area on the southeast flank of the Anaconda Range is underlain by somewhat consolidated gravel which was regarded by Calkins as probably to be correlated with gravel in the valley of Warm Springs Creek west of Anaconda. The gravel deposits are not known to be as old as Eocene. They may be of Oligocene or Miocene age. This deposit which was mapped as "earlier gravel" is described in part (Calkins and Emmons, 1915, p. 10) as follows:

> The gravels on the top of Grassy Mountain lie 8,000 feet above sea level, and their thickness on the east side of the mountain appears to be at least 500 feet. The areal distribution of the gravel clearly indicates that it overlies the tuff.
>
> The gravel area is characterized by landslides. Some of them, notably one just east of the point where Sixmile Creek leaves the quadrangle, are expressed by the contours. The eastern face of Grassy Mountain is a landslide escarpment and affords one of the best exposures of the gravels, which are here somewhat consolidated. The pebbles and boulders, the largest 2 feet but most of them less than 1 foot in diameter, are only fairly well rounded, and not well graded as to size. They here consist mostly of Spokane and Newland rocks [of the Belt series] and various Paleozoic limestones but comprise quartzite, horny metamorphosed sedimentary rocks, and an intrusive porphyry. The general scarcity of granitoid rocks in these gravels stands in striking contrast to the predominance of such rocks in the moraines and outwash aprons and serves to distinguish the Tertiary deposits from the glacial material. Thin beds of cream-colored, pink, and brownish clay and sandstone are interstratified with the gravels.
>
> Some of the gravel near the southern boundary of the quadrangle consists almost exclusively of boulders of red sandstone like that which is typical of the upper part of the Spokane formation. These boulders are in general not well rounded and the largest have diameters of as much as 5 feet. This remarkably homogeneous gravel is shown by a cutting to be at least 15 feet thick. Its source is not known but is evidently different from that of the gravel on Grassy Mountain.

OLIGOCENE AND MIOCENE EPOCHS

The relations at the mountain front in Oligocene to early Miocene time are described in Professional Paper 174 (Alden, 1932, pp. 4–10). It might be expected that examination of the intermontane basins of western Montana would show the highest terraces and benchlands therein to be of Oligocene or Miocene age. Lake and stream deposits of such age are found underlying the several terraces on the upper Missouri River and its tributaries, but almost invariably, so far as has been determined, these deposits have been tilted and faulted in places so as to dip toward, instead of away from the adjacent mountains from which the sediments in beds were very largely derived. After being thus displaced, the beds seem to have been truncated by stream erosion so as to form extensive piedmont terraces (pl. 1) similar to the so-called pediments found in the arid and semi-arid regions of the southwestern part of the United States. The silt, sand, and gravel, which are so generally spread over these piedmont terraces in the form of coalescent alluvial fans, appear to be mostly of Pleistocene and Recent age, and there is nothing to indicate that any of the terrace remnants in the intermontane basins under consideration are older than Pliocene age. Although the relations are not conclusively demonstrated, the following inferences appear to be warranted:

The stream deposits east of the mountains were elevated concurrently with the rise of the mountains in Miocene and Pliocene time; also the so-called Tertiary "lake beds" in the intermontane basins were probably raised to higher levels but with the significant difference that the bottoms of the basins tended to lag in the upward movement and broke into blocks that became displaced and tilted, in some places toward the adjacent mountains. The net topographic effect was as though the bottoms of the basins had actually dropped to lower levels, as indeed they may have done, while the mountain ridges had gone up. It is not thought that any of the terraces now preserved in these basins on the upper Missouri River and its tributaries are as old as the Cypress plain (Oligocene and early Miocene) east of the front ranges.

When the streams at the east front of the Rockies had cut away nearly all of the Oligocene and Miocene deposits in that region and were cutting deeply into, and planing off the upturned edges of the underlying folded and faulted Paleozoic, Mesozoic, and early Tertiary rocks, the streams in these basins west of the front ranges were still, in large part, eroding the thick Oligocene and Miocene lake and stream beds and included volcanic ash. These so-called lake beds and correlated deposits are also found throughout much of western Montana in extensive undulating or hilly areas whose eroded surfaces are not now in the form of definite pediments or terraces.

TOWNSEND VALLEY

In connection with his studies of the geology and ground-water resources of the Townsend Valley, Mont., Pardee (1925, pp. 17–34) summarized the literature on these intermontane Tertiary deposits and to that paper reference can conveniently be made. Pardee's description of the Tertiary of the Townsend Valley (Pardee, 1925, pp. 22–31) may be summarized briefly as follows:

He found numerous exposures of a lower series of beds, an extensive deposit of light colored clay, largely composed of volcanic ash or tuff, and more than 500 ft in thickness. In this were some thin layers of diatomaceous earth and some thin beds of coal. In what were identified as the Toston beds, he states that Douglass found remains of White River (Oligocene) mammals including horses, tapirs and rhinoceroses.

In the bluffs along Beaver Creek northeast of Winston and adjacent parts of Missouri River Pardee found exceptionally thick deposits comprising a local lens, a generalized section of which included volcanic ash or tuff (800 ft) and volcanic conglomerate (1200 ft) overlying 700 ft of volcanic ash with buff clay poorly exposed below it.

In some places in Townsend Valley he also found an upper series which he described as follows:

> The upper or Miocene series of Tertiary beds of this area is poorly exposed. Apparently it lies in valleys eroded in the lower (Oligocene) series and is of less extent than that series. It occupies a small area south of Deep Creek and a comparatively large one north of Confederate Creek and probably extends over part of the benchland and area on the west side of the valley south of Winston. The series attains a thickness of at least 500 feet and consists chiefly of incoherent sand and gravel derived from the older rocks that compose the neighboring mountains. Presumably it yielded the Miocene fossils listed. * * *

Concerning the structure of the Townsend Valley, Pardee states:

> When newly deposited the beds of clay and other fine sediments must have lain horizontal or nearly so. Possibly the layers of stream-deposited gravel had a slight inclination, and the coarser volcanic products in the Beaver Creek section may have assumed a considerable dip. In general, however, the beds are regarded as having been essentially flat-lying at first, their present attitude which commonly departs 20° or more from the horizontal, being the result of subsequent movements within the crust of the earth. The outstanding structural features are a zone of anticlines that extends northwestward across the valley from the neighborhood of Toston to the Spokane Hills and a monocline or persistent dip toward the northeast shown over most of the area east of this zone. Less prominent features include synclines and steplike faults that, locally at least, cause the outcrops of the different beds to be repeated. * * *

MADISON RIVER VALLEY

In his description of the geology of the Three Forks quadrangle, A. C. Peale (1896, p. 3) wrote in part as follows:

> Toward the end of [Neocene time] a series of fresh water lakes had been formed along the courses of nearly every stream in the western part of Montana. At first these lakes were probably more numerous and more distinct from one another than during their later stages. The deposits found in the lower part of the basins show by their character that they were derived from the land areas of closely adjacent shores. After their deposition there followed a period during which immense showers of fine volcanic dust, evidently wind carried, fell upon the surfaces of the lakes and upon the land. In the former they quietly settled to the bottom as pure white sediments in which no traces of foreign material are found. These beds occur in the central portions of the large valleys and upon them, spreading out over wider areas, rest undisturbed beds of a rusty color although composed of the same pumiceous dust which was evi-

dently washed into the lakes from the surrounding country. The beds of pure white dust in the Gallatin-Madison Lake have a total thickness of only about 20 feet, while above them the beds of rearranged dust attain a thickness of over 1,000 feet * * *.

Bozeman lake beds.—There were two principal lakes within the limits of the Three Forks sheet. The larger of these was the Gallatin Lake, which was undoubtedly connected with another larger lake that occupied the Jefferson Valley, lying mainly within the area mapped on the Dillon sheet [an advance sheet never published as a topographic map], directly west of the Three Forks sheet. It was also connected with the lake of the north Boulder Valley, which extends northward beyond the limits of the map, and which was itself connected with the Jefferson Lake. The Gallatin Lake also extended a short distance northward beyond the limits of the map, along the west side of the Bridger Range and to the eastward in the area of the Livingston sheet [east] of Bozeman, the town from which the beds have been named on account of the good exposures in its vicinity. * * *

The beds in the main basin have a dip of a few degrees to the eastward or northeastward, causing the slope noticeable in the surface of the plateau that lies between the Madison and Gallatin rivers. If continued this dip would carry the beds there visible below those exposed in the hills east of Bozeman, and make the total thickness of the deposits more than 2,000 feet. At no one place, however, can a complete or continuous section be obtained. * * *

In the Madison Valley, 12 to 15 miles above Three Forks, a section 800 to 1,000 feet thick is shown, and if these beds are lower, as they apparently are, than those near Bozeman, from which they differ, the total thickness would be nearer 2,500 than 2,000 feet. * * *

In the summit of the Madison Bluffs, in a layer of gray conglomerate sandstone, numerous fragments of fossil bones were found, which were identified as the same as those found at other localities in the Pliohippus beds of Marsh. In the sandstones below the fossil horizon immense quantities of opalized wood are found, the logs all presenting evidences of having been waterworn.

The lake that occupied the Upper Madison Valley, although not all included within the limits of the Three Forks sheet, was less extensive than the one just described. * * * The deposits of this lake must be from 1,000 to 1.500 feet in thickness.

The bluff east of the Madison River, 8 miles south of Logan, is 600 ft high and appears to consist wholly of Tertiary deposits dipping eastward at a low angle. The material is mostly fine grained to sandy, is largely of chalky texture and grayish-white color, and contains much volcanic ash. Part way up the bluff numerous fragments of opalized wood and some fragments of bone were found. The bones, J. W. Gidley stated, resemble those of *Merychippus*, a three-toed horse of Miocene age. Overlying the beveled edges of the strata is quartzite gravel, about 100 ft thick, probably of Pliocene age. About 12 miles south of Logan the pre-Cambrian gneiss slopes gradually southward from the Madison Valley toward the north end of the Madison Range, and onto this, and in faulted rocks of a later age the Bozeman "lake beds" overlap in the valleys of both the Madison and Gallatin Rivers. Bozeman "lake beds" are present in the Spanish Creek Basin, 8 to 10 miles southwest of Gallatin Gateway (formerly Salesville), but they have not been found farther south in Gallatin Canyon, nor in Madison Canyon in Tps. 3 and 4 N., below the reservoir. There is a possibility that these two canyons were not eroded to their present depths as early as the deposition of the Bozeman "lake beds." Such beds, however, have been faulted down in the broad Madison Valley, which extends thence for nearly 50 miles south of the reservoir, where they underlie extensive gravel-covered bench lands and terraces.

About 21 miles south of Ennis, near latitude 45° N., these beds are overlain by rhyolitic lava that slopes gradually southward as a rimrock, capping the bluffs in places on each side of the inner valley and partly underlying the dissected bench lands on the east and west. Considerable volcanic ash appears in the friable Tertiary deposits below the lava, and in places stratified clay, sand, and gravel also are exposed. Some of the gravel is coarse and consists largely of waterworn pebbles and cobbles of quartzite, with some of granite and other igneous rocks. There has been considerable sliding in places due to oversteepening of the slopes below the lava rim. The rhyolite rimrock rises gradually southward to the vicinity of Wade Lake and Cliff Lake, and appears to continue rising thence westward on the flanks of the broad-topped southern part of the Gravelly Range. The narrowness of the inner valley of Madison River is probably due to the presence of this rhyolite south of latitude, 45° N. in Tps. 10 and 11 S. To what extent this narrow part of the Madison Valley and the gorge containing Cliff Lake and Wade Lake are due to post-Miocene faulting is not known. Near the south margin of the Three Forks quadrangle (latitude 45° N.) Pleistocene terraces have been cut into the north-dipping lava, but between Wolf Creek and Papoose Creek on the east side and continuing south to Cliff Lake on the west side, what may be a Pliocene or early Pleistocene bench has been preserved on top of the lava high above the river terraces. It seems probable to the writer that this lava is a correlative of the rhyolite of the western part of the Yellowstone Park plateau, and that both are of Miocene age. It also seems probable that the northerly dip of the rhyolite along the Madison Valley, near Hutchins bridge, is due to displacement by faulting and is not the original slope of the flow down this valley. It is possible that this part of the valley is located along a zone of late Tertiary faulting. There has been some very recent or Pleistocene displacement along a fault line a few miles to the east of the river, which borders the west foot of the Madison Range for a distance of 25 or 30 miles or more. From the piedmont benchlands extending up to this fault line the bold west front of the Madison Range rises steeply for 4,000 to 5,000 ft, as along a fault-line scarp, to very rugged mountain peaks whose altitudes range from 10,000 to 11,000 ft or more above sea level. The Gravelly Range west of this part of the Madison Valley is a plateau with a much smoother and more worn-down aspect than the Madison Range on the east or the Snowcrest Range farther west and its northward continuation, the Tobacco Root Mountains. Possibly (or probably) the smoother aspect of much of the Gravelly Range is due to the presence of soft friable Cretaceous sandstone and shale in gentle anticlines with low dips in contrast to the harder and more steeply upturned Paleozoic strata in the more rugged ranges.

TERTIARY "LAKE BEDS" IN THE VALLEY OF THE YELLOWSTONE RIVER

The Tertiary sedimentary deposits, which are well exposed at the White Cliffs along the Yellowstone River south of Emigrant, are described by Horberg (1940, pp. 283–285).

> The most complete section of the "lake beds" in the valley is at "White Cliffs" where 200 feet of bluff clays and silts are overlain by 80 feet of gravel capped by basalt. At this point the "lake beds" were tilted about 6° to the northeast and truncated by erosion prior to the deposition of the gravels. The silts and clays are evenly bedded, noncalcareous, and under the microscope show a high percentage of volcanic shards together with unweathered grains of biotite, amphibole, quartz, and some feldspar. Silicified remains of various vertebrate animals have been collected here and at an exposure along the highway 3 miles to the north. A more tuffaceous facies of the "lake beds" occurs beneath 40 feet of gravel capped by basalt about ½ mile south of Emigrant. Fine-grained deposits are here interbedded with discontinuous zones of rubble derived from the basic breccias to the west. Foreset beds dipping to the east suggest fluvial deposition by streams from uplands to the west. The silts are slightly calcareous and contain abundant shards and small cinders. No vertebrate remains have been found at this locality. A thickness of about 300 feet of silts and clays has been reported from the well at the Northern Pacific Railway quarry 5 miles south of Emigrant.
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> The deposits in Yellowstone Valley contain vertebrate fossils of probable late Miocene-early Pliocene age and are to be correlated with the upper part of the Bozeman beds of the Three Forks and Madison valleys.

The relations of these so-called "lake beds" seem to indicate that they were faulted down, tilted, and beveled off by erosion prior to the deposition of 40 to 80 ft of overlying cobblestone gravel and of the basalt which caps the gravel (Alden, 1932, p. 62 and pl. 24, *B*).

CENTENNIAL VALLEY AND THE VALLEY OF RUBY RIVER

Little or no Oligocene or Miocene sedimentary deposits are seen south of the Henrys Lake Mountains in or around the basin of Henrys Lake in Idaho. The same is true for 10 or 12 miles west of Red Rock Pass along the south side of the Centennial Valley in Montana. Tertiary volcanic rocks are found high on the Centennial Mountains south of this area, sloping thence southward to the Snake River Plain. The north front of this part of the Centennial Mountains is abrupt and high, probably a fault-line scarp, and the broad valley on the north is probably one of the downfaulted intermontane basins. Tertiary "lake beds" have been mapped along the grassy slope to the broad Gravelly Range north of the wide alluvial flat containing the Red Rock lakes. This slope is much dissected by stream erosion. In places on the Recent alluvial fans there is coarse, well-rounded cobblestone gravel that has been washed down from higher levels, and some of the interstream ridge tops, 500 to 1,500 ft or more above Red Rock River, are covered with similar gravel. The smooth pebbles are composed very largely of varicolored quartzite, with some of lava, granite, and gneiss. The largest stones are 1 to 2 ft in diameter. In one small hill beside the road north of Red Rock River, such gravel appears to underlie south-dipping beds of basalt. Farther east rhyolitic lava slopes southward over reddish and whitish clay nearly to the east-west road and it may extend farther south under the flat bordering the Red Rock lakes; it also extends eastward to Cliff Lake and Wade Lake. There are also erosion remnants of the lava in places on the west slope.

West of Lakeview the north flank of the Centennial Mountains is not so abrupt as farther east, and there has been much stream erosion and much landsliding, apparently on Cretaceous clays. Some of the lava exposed near the east-west highway appears to be basaltic and may be of later age than the Tertiary volcanic rocks that have been mapped farther south and west on the Centennial Mountains. At a point about 11 miles west of Lakeview, where the road crosses a low lava-capped ridge, an excavation showed north-dipping beds of grit below a thin bed of lava. This grit, which contains fragments of purplish rhyolite, resembles Tertiary deposits seen elsewhere. No features have been noted in the Centennial Valley or on the bordering slopes that appear to be of Pliocene or early Pleistocene age.

The east flank of the Snowcrest Range above the bluff along upper Ruby River is bordered by what appear to be Pliocene and Pleistocene terraces. They appear to be underlain by Cretaceous shale and sandstone and not by Bozeman "lake beds." In that part of the Ruby River valley, below the narrow gap that is cut through the upturned Paleozoic rocks near the 112th meridian (T. 9 S., R. 3 W.), the inner valley is generally cut into Oligocene and Miocene deposits most of the way northward to the junction with the Jefferson River. These Tertiary Bozeman "lake beds" also extend southward to the Blacktail Creek between the Snowcrest Range on the east and the Ruby Range on the west. In this southern part the Tertiary deposits are much dissected.

About 4 miles southwest of Puller Hot Springs (and 20 miles south of Sheridan) a bare bluff in sec. 9, T. 8 S., R. 5 W., and about 5,900 ft above sea level was examined. There poorly consolidated deposits of sandy-clayey material were exposed, which were brownish, purplish, and gray in color. In them were found very friable fragments of bones and three black-capped molar teeth, each 2 to 3 in. in diameter. They have been identified by C. L. Gazin as remains of a titanothere of lower Oligocene age. No shells or fossil wood were seen at this place. Whitish material included in the section appears to be volcanic ash. At some of the exposures north of Puller Hot Springs the stratified Tertiary deposits dip eastward toward the mountains at a low angle, as the result of displacement by faulting. One exposure on Idaho Creek showed conglomerate and greenish-buff, semi-indurated clay, colored sulphur yellow in spots. The pebbles and cobbles in the conglomerate consist of various crystalline rocks, lava, and quartzite. A light-colored specimen from a thin, flintlike bed exposed at one place in the bluff near the highway was identified by C. S. Ross as volcanic tuff "that appears to have been welded as it fell in a hot plastic condition". On some of the interstream tracts there are well-preserved remnants of gravel-capped terraces, probably of Pliocene and early Pleistocene age, as in the Madison Valley and along the Missouri River.

In the fall of 1905, Earl Douglass (1908–1909, pp. 252–254) passed this way on a geological reconnaissance. He wrote in part as follows:

> Ascending the Ruby River I passed through the lower cañon, where the Ruby cuts through Archaean gneisses and crystalline limestones, to the middle valley of the Ruby River. In the lower portion of this valley and continuing some distance up the Sweetwater to the southwestward are considerable exposures of Lower White River deposits, while overlying these on the east side of the river, and farther up on the west side reaching far up on the flanks of the Crazy Mountains [Ruby Range] are late Miocene sands and gravels. Both formations are very sparingly fossiliferous, though enough teeth and bones of mammals have been found to determine approximately the age of the deposits. I ascended the Ruby River to where Ledford Creek enters from the northwest [south]. This stream issues from cañons in the northern portion of the Snow Crest Range, and then flows through a long narrow grassy-bottomed valley, carved through Miocene sands and gravels. Nearly the whole of the Middle Ruby Valley, in fact, is composed of Tertiary deposits, dissected by many streams and ravines and rising higher and higher toward the elevated narrow ridge of the Snow Crest Range, covering all but the higher portions in its thick mantle of sand and gravel. The road up Ledford Creek ascends quite rapidly, but the benches rise with it. * * *
>
> The next morning I climbed to the top of the high bench which I had crossed the previous evening. The bench was nearly flat, but sloped northward away from the mountains, the dark, sharp, rugged peaks of which rose into the cold sky a little distance to the southward. * * * The Snow Crest Range gives one the impression of being a comparatively recent uplift, and of having carried upward with it in its elevation the Tertiary deposits, which now climb high on its flanks.
>
> In viewing from this elevation the Tertiary deposits, which extend far away between mountain ranges, sometimes almost surrounding them, it was realized how at variance with the facts is the theory that during the deposition of these beds, the valleys of the mountains were occupied by separate lakes, which, like small lakes in the mountains at the present time, are gradually being filled with sediment.
>
> Instead of deposits occupying the isolated valleys, they extend from one valley to another, so that those in the Upper Ruby, Black Tail Deer Creek, Red Rock, Grasshopper, Beaverhead, Big Hole, Deer Lodge, Madison, Gallatin, and Upper Missouri valleys were united, and the Tertiary deposits can be traced almost continuously for hundreds of miles, sometimes occupying the lowest depressions and sometimes occurring on mountain ranges seven thousand or eight thousand feet above sea level.

At the narrows south of Alder, Mont., Ruby River has cut an inner gorge nearly 1,000 ft deep through a transverse ridge of garnetiferous rock. On the top of this ridge are some quartzite cobblestones. At either end of the ridge the slopes rise like the sides of an older and higher valley whose bottom has been trenched. In this gorge a reservoir dam was being constructed in 1938.

The Ruby Range on the west is composed mostly of pre-Cambrian crystalline rocks overlapped in part by Paleozoic rocks and has, in general, a rather worn-down aspect. The Tertiary sediments, where not cut away, extend well up onto its lower flanks. The northern part, however, is quite rugged and high with steep slopes. The Tertiary deposits have been quite largely swept away in the erosion of the broad lower part of the Ruby River valley northwest of the village of Alder.

JEFFERSON AND BEAVERHEAD VALLEYS

Three main tributaries, the Jefferson, Madison, and Gallatin Rivers converge near Three Forks, Mont., to form the Missouri River. Along the Jefferson River west and southwest of Three Forks, a large part of the deposits constituting the Bozeman "lake beds" has been swept away by erosion, but in many places these late Tertiary deposits still overlap the pre-Cambrian rocks and the folded and eroded Paleozoic, Mesozoic, and early Tertiary rocks to altitudes as high as 5,000 or 6,000 ft. Where seen by the author, they consist very largely of whitish to buff semi-indurated clay, sandy clay, and friable sandstone. Considerable volcanic ash is included in places. Along the northern tributaries, Boulder River and Whitetail Creek, these beds are capped with well-preserved remnants of two or more extensive piedmont terraces. The terraces form bluffs 50 to 200 ft above the flats bordering the streams. In many places the deposits of coarse cobblestone gravel at the tops of the bluffs are probably of Pleistocene age. About a mile northwest of Grace, a cut on the Chicago, Milwaukee, St. Paul & Pacific Railroad above Little Pipestone Creek exposes reddish-brown sandy clay (Tertiary?) about 5,800 ft above sea level, or nearly 1,000 ft higher than the river near Whitehall. Above this cut are smooth, grassed upland tracts, probably of late Tertiary or early Pleistocene age developed on the badly decomposed granite. Oligocene and Miocene fossils are reported to have been collected from steeply tilted buff, reddish-brown, and greenish-white Tertiary beds in the vicinity of Pipestone Hot Springs and Whitehall.

From the vicinity of Whitehall southward beyond Twin Bridges, near the place where the Big Hole and Beaverhead Rivers unite to form the Jefferson River, there are extensive piedmont terraces of Pleistocene age. The same is true between Twin Bridges and Sheridan bordering the lower part of Ruby River valley. The Tertiary deposits truncated by the terraces are exposed in places in the eroded bluffs and some of the gulches transecting the piedmont benchlands. These deposits consist of white soft earthy material and are well stratified, with some interbedded sand, gravel, and much volcanic ash. In places the beds are gently tilted.

From the vicinity of Sheridan southwest to Blacktail Creek south of Dillon, the remarkable sloping piedmont terrace, 2 to 8 miles in width, bordering the Ruby Range has been mapped as underlain by the Tertiary "lake beds." Loose sandy clay and grayish to buff, friable sandstone are exposed here and there in the river bluff along the highway at the truncated lower edge of this benchland and in the numerous gulches that transect it. The overlying gravel is thin where it is crossed by the road between Sheridan and Beaverhead Rock, and one gulch exposes white friable beds below the gravel. A sample taken here was identified by C. S. Ross (written communication) as "nearly pure volcanic ash." Farther southwest thicker gravel over the sandy clay and sandstone is exposed in the 75- to 100-ft bluff and this gravel is, in places, cemented to fairly hard conglomerate. The Ruby Range has a generally worn-down aspect, though rugged and high at the north and south. The great dissected piedmont terrace, which borders the range on the west and is underlain by the Tertiary sediments, joins the mountain front about 6,000 to 6,200 ft above sea level, or nearly 1,000 ft above the broad bottom land along the Beaverhead River. The thickness of the late Tertiary and early Pleistocene alluvial deposits capping the "lake beds" near the mountain front is not known to the writer.

The south end of the Ruby Range is separated from a narrow but rugged transverse mountain ridge by the valley of Blacktail Creek. This stream heads at the southeast near the rugged Sawtooth Mountain and the Snowcrest Range; from the vicinity of the pass at the head of Clover Creek it flows northwest to join the Beaverhead at Dillon. The late Tertiary deposits extend far up this valley and also spread around the south part of the Ruby Range in a broad tract as far as the Ruby River west of the Snowcrest Range. It is these deposits, that Earl Douglass designated the "Blacktail Deer beds" and from which he collected fossils.

Fifty-five to sixty miles southeast of Dillon, near the confluence of the east and west forks of the Blacktail Creek, basalt capping a small butte appears to dip eastward into the Bozeman "lake beds" and to be underlain by quartzite gravel. A short distance south of this butte, light-greenish clay also is exposed. From the top of the butte there is an extensive view north and northeast over a remarkable smooth but somewhat dissected piedmont terrace. This terrace rises northeastward, to an altitude of 7,000 ft or more above sea level high on the west flank of the rugged Snowcrest Range. Two or more terrace levels are seen near the Blacktail Creek, of which the highest is probably of late Tertiary (Pliocene) or early Pleistocene age. The terraces appear to bevel the edges of the gently tilted Bozeman "lake beds."

About 8 miles southwest of Dillon, at Barratts, the Beaverhead Valley narrows abruptly at the Buffalo Rocks. Thence southwestward to Armstead, at the mouth of Horse Prairie Creek, the north-flowing river has cut a steep-sided valley a mile or less in width through a hilly upland whose tops have the generally worn-down aspect of an old erosion surface. In several places where upturned beds of volcanic or other hard rock are transected, the valley is constricted to narrow inner gateways cut below benched spurs whose tops appear to present cross profiles of an older and broader valley, possibly of late Tertiary or early Pleistocene age. Between these gateways the river meanders over flat bottom land, and the lateral benched slopes are graded down to the tops of bluffs lower than those at the gates.

These benched slopes are partly strewn with cobblestones, largely of quartzite, and some of the gulches transecting the benches and the lower bluff expose reddish sandstone with interbedded conglomerate consisting of waterworn pebbles and 1- to 2-ft boulders of quartzite. In places, besides volcanic rocks, there are exposures of limestone and travertine. These deposits may be mostly older than the Bozeman "lake beds", but the writer, because of insufficient study was unable to determine satisfactorily their stratigraphic relations and geologic ages. Many fragments of white agate and some of fossil wood were found here and there in adjacent parts of secs. 5, 6, 7, and 8, T. 9 S., R. 9 W. In places quartzite gravel appears to underlie cappings of basalt which form benchlike shoulders on the slope as though they were remnants of flows poured out on old valley bottoms. Near Dalys the Grasshopper Creek comes from the northwest through a gorge which is so constricted most of the way below Bannack, as not to be traversed by a road. The upland north and south of this gorge is very largely underlain by folded and faulted Paleozoic rocks (limestone, sandstone, and shale), part of which are unconformably covered by tilted and beveled volcanic rocks of early Tertiary (?) age.

BASINS OF RED ROCK RIVER AND SAGE CREEK

About 1 mile north of Armstead, Horse Prairie Creek from the west joins Red Rock River from the southeast to form the Beaverhead River. Red Rock River flows through a valley 3 to 5 miles wide on a broad alluvial flat bordered on one or both sides by piedmont terraces composed of coalescent alluvial fans of Pleistocene and Recent age, some of considerable extent. The lower edges of these terraces are in places truncated by bluffs 50 to 100 ft in height. Underneath the terrace gravel there are probably Tertiary deposits like the Bozeman "lake beds". On the west an abrupt and much higher line of bluffs and steep slopes rises from the terraces. Above it a dissected plateau, in part a hilly to mountainous upland, is underlain by folded and faulted Paleozoic rocks, largely limestone of the Quadrant and Madison formations of Carboniferous age. East of Red Rock River the upper slopes are less rugged; more than half of the country between Red Rock River and Blacktail Creek is a belt of smoothly rounded grassy hills apparently carved out of Tertiary deposits. These deposits include the "Sage Creek beds" near Lima, so-called by Douglass, who regarded them as doubtfully of Eocene age. The deposits extend eastward, overlapping pre-Cambrian rocks and the upturned Paleozoic and Cretaceous strata—the southwest extension of those forming Sawtooth Mountain and Snowcrest Range.

Red Rock River flows westward from Centennial Valley through this belt of hills. The inner valley is constricted where it cuts across limestone at the Lima Reservoir dam. Below, the valley widens and has a broad, flat, alluvial bottom. The bordering slopes show remnants of well-defined benches up to heights of 1,000 ft or more. They are capped with cobblestone gravel and boulders 1 to 4 ft in diameter, consisting very largely of reddish quartzites. The stones are smoothly waterworn, show percussion marks, and have probably been derived locally from an older conglomerate, such as that exposed in Clark Canyon north and east of Armstead. The benches, however, probably represent late Tertiary and early Pleistocene stages of development of the outlet of the broad Centennial Valley.

Near Lima, Red Rock River turns to the right and flows northwestward in the broad valley leading to the Beaverhead River at Armstead. In the angle of convergence between Sage Creek and Red Rock River, near Dell, is a hill known as the Red Butte. This butte is composed of conglomerate with thin interbedded layers of reddish sandstone dipping southeast at an angle of 20 to 25 degrees. A large part of the pebbles are 1 to 3 in. in diameter but occur with larger cobblestones and with 1- to 2-ft boulders, partly angular, partly well rounded. The stones exposed in the bluff face are very largely of gray limestone, with a smaller percentage of red and light-colored quartzites and still fewer of lava and sandstone. The loose stones scattered over the top of the butte, however, are mostly of quartzite. Similar conglomerate is exposed also north of Sage Creek and 3 miles southwest of Dell in the mouth of Sheep Canyon. Possibly this conglomerate is of Triassic age.

Deposits that closely resemble the Bozeman "lake beds" are well exposed on lower Sage Creek, about 7 or 8 miles east of Dell, near Cook's sheep ranch (sec. 34, T. 12 S., R. 8 W.). Here a bare bluff beside the road (fig. 2) exposes southwest-dipping beds of light-greenish, buff, and brown clay, sandstone, and concretions. At the top of the bluff is conglomerate or gravel consisting of rounded quartzite pebbles and cobblestones. Semi-indurated gray rhyolitic tuff is exposed one or two miles to the west. No quartzite pebbles or boulders are included in the tuff, but the slope and terrace above are paved with them. Similar deposits are exposed farther north near the head of Sage Creek, where there are thin beds of lava in places on the upland slopes. Lava is also present on slopes and crests in places north and northeast of Lima. An unpublished geologic map of western Montana shows a hilly area of 150 sq mi between Red Rock River and the State line near Monida as underlain by Tertiary "lake beds". What proportion of these deposits is Oligocene or Miocene age is not definitely known to the writer. Here and there upturned strata are exposed that appear to be older.

FIGURE 2.—Tertiary "lake beds" (Oligocene?) east of Dell near Cook's ranch on Sage Creek, Beaverhead Valley. Clay interbedded with sandstone layers tilted, beveled, and overlain by coarse quartzite gravel (early Pleistocene).

Seven or eight miles southeast of Lima, quartzite gravel was found strewn over hillslopes and upland tracts 1,000 ft or more above the valley bottom near Snowline and also capping remnants of well-defined benches. In this vicinity and nearer Lima, quartzite gravel in places lies on the upturned and eroded edges of a folded conglomerate in which the pebbles are almost wholly of limestone. The limestone-pebble conglomerate belongs to one of the older rock formations here comprising an anticline which extends northwest along the valley of Junction Creek between Lima and Monida.

BASINS OF SHEEP CREEK AND MUDDY CREEK

In the most southwesterly part of Montana, Sheep Creek and its headwater branches drain a broad basin 12 to 25 miles southwest of Lima. Three to four miles southwest of the junction of Nicholia and Sheep Creeks, in the northeastern part of T. 15 S., R. 11 W., there are low ridges between Nicholia, Meadow, and Alkali Creeks, rising 50 ft or more above the smooth gravelly terrace. Bare scarps on the slopes of these ridges expose gray to dark-colored shale (possibly Cretaceous) containing crystals of gypsum. Overlying the shale are interbedded clay and buff to brownish sandstone with some small-pebble conglomerate layers. In the sandstone are many fragments of fossil coniferous wood, the species of which have not been determined but may be of Tertiary age. The tops of these inter-stream ridges appear to be remnants of a higher stream terrace (early Pleistocene?), as they are strewn with pebbles and 1- to 2-ft boulders of white, gray, and reddish quartzite, some of limestone, basalt, and granite, all of which probably came from the Beaverhead Range. Most of them are smoothly waterworn and show percussion marks.

Three or four miles farther north on the northeast side of Cabin Creek are exposures of greenish-yellow and white to gray sandy clay and friable sandstone resembling the Bozeman "lake beds". They contain fragments of fossil wood and casts of small gastropods. These exposures are near the foot of the great wall of upturned limestones on the northeast. In some places these deposits are overlain by beds of travertine that are broken into a series of steps with treads tilted toward the nearby mountain wall. It looks as though these Tertiary(?) beds had either slid or been faulted down from a higher level. In places a belt of reddish to orange-colored gritty clay lies between the beds. That part of the travertine was formed at a much higher level is suggested by the presence of a deposit of travertine near the pass 10 to 12 miles to the southeast at an altitude nearly 2,000 ft higher up at the edge of the smooth upland (see p. 40).

On the crest of the terminal moraine of the Cottonwood glacier below Eighteen Mile Peak on the Beaverhead Range, a level-sight was taken to the upland above the limestone-walled gorge of Sheep Creek. From this viewpoint it seems that a stream heading at this altitude (8,300 ft) on the piedmont below Eighteen Mile Peak and flowing northeastward on an average gradient of about 100 ft per mile across Tertiary beds filling the basin would cross the lower part of the smooth upland of beveled, upturned limestone beds and may have initiated the erosion of the conspicuous box canyon of Sheep Creek at levels 500 ft or more above the present channel of the stream. It is rather remarkable that there are three narrow portals through the mountain wall at the head of this canyon traversed, respectively, by Alkali, Nicholia, and Deadman Creeks.

A few miles southwest of the mouth of its canyon, Sheep Creek is joined by Muddy Creek which flows somewhat east of southward to the junction through a smaller intermontane basin in which there are Tertiary deposits. Only the road in the southern part of this basin has been traversed by the writer. Here thinly laminated, soft, friable shale contains fragments of fossil coniferous and dicotyledonous wood; they may be Tertiary although the age was not determinable from the specimens collected. The deposits have a low dip toward the mountain ridge on the east.

It is stated by Condit (1920, p. 26) that "a well drilled for oil near the center [of Muddy Creek basin] is said to have reached a depth of 1,000 feet without encountering hard rocks, and it seems probable that the bottom of the lake beds was not reached." Some brownish lignitic layers were tested by him for the presence of oil.

From the pass at the northwest end of the basin of Sheep Creek (sec. 31, T. 13 S., R. 11 W.), Medicine Lodge Creek flows northward through a narrow belt of Tertiary deposits bordering the east foot of Beaverhead Range. The spur of that range that extends northward past Medicine Lodge Peak and Jeff Davis Peak to a point south of Grant. Both north and south of the pass, the crest of the Beaverhead Range (in Tps. 13 and 14 S., Mont.) appears not to be marked by rugged peaks, but to be worn off smooth, probably as the result of erosion in early or middle Tertiary time. The Tertiary deposits at the pass (about 7,625 ft above sea level) lie far below the level of this worn-off top.

BASIN OF HORSE PRAIRIE CREEK

Another basin, similar to the basin of Sheep Creek but larger, is drained by numerous headwater branches of Horse Prairie Creek. This basin is encircled on the south, southwest, and west by the Beaverhead Range and on the northwest by the Big Hole Divide. The basin is mapped as very largely underlain by Tertiary "lake beds" with Tertiary volcanic rocks flanking the east and west borders and exposed in places near the railroad. The "lake beds" observed by the writer, consist mostly of soft gray clay. A railroad cut one mile west of Grant exposes thinly laminated beds of brittle limestone with some interbedded sandy layers dipping southeast at a low angle. In 1938, R. W. Brown collected from this sandstone plant remains and fragments of a fossil fish which may be of Oligocene age.

Upstream from this locality and west of the railroad, extensive terrace remnants of a Pleistocene(?) gravel plain 30 to 50 ft above bottom lands border Horse Prairie, Trail, and other creeks, but no remnants of higher terraces or benched spurs were seen from the highway north of Jeff Davis Creek. South of Donovan Ranch the creeks are bordered by well-defined terraces above low bluffs where the Tertiary deposits are capped with Pleistocene(?) gravel.

The ridge forming the Continental Divide between the headwater branches of Horse Prairie Creek on the north and Canyon Creek, Idaho, on the south, is capped with, possibly entirely composed of, deposits resembling the Bozeman "lake beds". These deposits also underlie the rounded grassy hills for about 4 miles south of the divide. The highway at the pass is in a shallow sag 7,672 ft above sea level; a short distance east, the narrow crest is pierced by the railroad tunnel. Cuts near the tunnel expose light-colored friable sandstone overlain by stratified sand and gravel. The crest between the tunnel and the highway, although narrow, is smooth and flat like a remnant of an old erosion surface. This crest is capped with bouldery gravel. An excavation just above the highway at the pass exposes light-colored sandy clay below the thin deposit of gravel. The subangular pebbles and the 2-ft boulders in the gravel and on the surface consist mostly of quartzite with some granite and some black chert. Whitish friable sandstone exposed in cuts farther down the south slope contains fine branching stems of fossil plants and volcanic ash. C. L. Gazin reports (personal communication) that he considers fragments of fossil bone found in these deposits somewhere near the Bannock Pass to be probably of lower Miocene age. Gray to greenish friable sandstone and clay exposed in a steep hillslope above the railroad near Whiskey Spring Creek contains abundant small fossil gastropods. Exposed in the slope above are ledges of limestone-pebble conglomerate. South of its junction with Cruikshank Creek, Canyon Creek enters a steep-walled, narrow gorge cut in upturned Paleozoic limestone.

It has been suggested (Atwood, 1917) that the stream or body of water in which these Tertiary sediments were deposited was originally tributary southward to the Snake River basin. The present writer found no evidence that would clearly support this suggestion. There are some indications that the Continental Divide in the vicinity of the Bannock Pass may have been 4 or 5 miles farther south in late Tertiary or early Pleistocene time than it now is and that it may have been shifted to its present position by the headward erosion of Canyon Creek.

There is a road that extends for several miles on the Idaho side near the Divide and the State line southwest of the pass. It leads to smooth, grassed, undulating upland tracts within the limits of the Salmon National Forest between the heads of several sharp, branching gulches which deeply gash the flanks of the Beaverhead Range. Near this road are outcrops of gray fossiliferous Paleozoic limestones and some of hard siliceous rock or quartzite. These tracts appear to be remnants of an ancient erosion surface perhaps as old as, or older than, the Oligocene and Miocene deposits which have been uplifted and deeply dissected. These tracts are shown on a topographic map of the Little Eight Mile mining district, Idaho (advance sheet).

BASIN OF GRASSHOPPER CREEK

From the smooth, broad bottom land in the vicinity of Grant a broad low hilly belt, 10 to 12 miles wide and underlain by Tertiary clay, extends northward to the basin of Grasshopper Creek. At the head of the gorge of this creek is the old mining village of Bannack, the first capital of Montana. Near the low divide, about 5 miles south of Bannack, there is a small butte capped with columnar basalt, possibly of Pliocene or Pleistocene age. West and northwest of Bannack the soft Tertiary sand and clay underlie extensive interstream benchlands above the broad flat bottom lands used for hay fields. In places, the Tertiary strata dip eastward toward the hills, and the gravel lies on the beveled edges of the strata. These benches, capped with coarse quartzite gravel, are parts of an extensive gravelly plain or piedmont terrace which formerly headed at the east front of the short smooth-topped range. The range, composed of pre-Cambrian rock (9,000 to 9,300 ft above sea level), is known as the Big Hole Divide. The smooth, gently sloping plain, which is probably of early Pleistocene age, is transected by the valleys of Swamp, Buffalo, and Reservoir Creeks, 50 to 300 ft or more in depth. It must have been when Grasshopper Creek was flowing at levels relatively much higher than these broad benchlands that the present course was established and the stream cut the narrow gorge through the hills of Paleozoic sedimentary and Tertiary volcanic rocks southeast of Bannack. It may have been at about the same time (Pliocene?) that the streams were flowing out onto the high bench, which is now 7,400 to 7,500 ft above sea level, at the foot of the abrupt mountain front west of the basin.

North of Swamp Creek interstream remnants of the broad gravelly benchlands are not well preserved. There are remnants of a well-defined gravelly piedmont terrace 100 to 300 ft above the flat south of Polaris. The gravel capping the Tertiary beds shows a mixture of quartzite cobblestones and granitic pebbles and boulders derived from the region of Baldy Mountain to the northeast. The divide between the heads of Grasshopper Creek and Wise River to the north is a smooth worn-down upland. Contour maps of the U. S. Forest Service show it about 7,500 to 8,000 ft above sea level.

Where the highway north of Bannack extends eastward to Rattlesnake Creek west of Dillon it crosses a broad smooth-topped grassy ridge about 6,700 ft above sea level, with higher wooded mountains to the south and north. Tertiary clay and scattered gravel lap part way up on the west slope but not over the top. The highway extends eastward down a long sparsely grassed slope on Tertiary(?) clay strewn with quartzite gravel and dissected by numerous gulches. An old wagon road and telephone line to Argenta extends downward onto and across a high, smooth, sloping gravel-strewn bench, which is probably a remnant of a Pliocene or early Pleistocene terrace 200 to 500 ft above the Rattlesnake Creek at the village in the inner gorge. This gorge is cut in quartzite and granite. This high-bench remnant is one of the best preserved found by the writer in the Beaverhead River basin. The larger boulders on its top may be glacial erratics of early Pleistocene age. No granitic boulders from the region of Baldy Mountain were found here, however, although they are abundant on the moraines down in the inner gorge.

BASIN OF BIG HOLE RIVER

From the Rattlesnake Creek near Argenta, the rugged Pioneer Mountains extend northward to the gorge of Big Hole River west of the village of Divide. West of Dillon are low hills of Tertiary lava and from these hills northward, to and along the Big Hole River, the Tertiary "lake beds" underlie the smooth terraces and rougher foothills bordering the east front of the range. They are interrupted by the rocky gorge north of Melrose, beyond which they continue northward across the Continental Divide to the Deer Lodge Valley near Silverbow. Exposures in places along the highway (U S 91) show grayish to brownish sandy clay and friable sandstone (Miocene?) with cross-bedded sand and gravel. In places south of the village of Divide there is semi-indurated arkosic material, possibly pre-Tertiary, mixed with other sand and pebbles underlying the bench gravel. The Tertiary beds are generally overlain by coarse bench gravel (Pliocene or Pleistocene) composed of quartzite and granite cobblestones. The eroded slopes below the benchlands are largely grassed and obscured.

Pardee (1926, p. 14) states:

About 3 miles north of Divide, east of the Oregon Short Line Railroad, thick beds of buff clay with interbedded thin layers of gravel or conglomerate are exposed that aggregate 200 feet in thickness. The beds strike N. 15° W. and dip 12° E. In the same neighborhood along a ridge extending eastward are several exposures of the gravel beds, which owing to their comparative hardness project somewhat above the adjoining clay beds. These gravel layers are from 3 to 6 feet thick and consist of subangular cobbles and pebbles in an abundant matrix of sand and clay. In places they contain boulders as large as 3 feet in diameter.

An apparent thickness of at least 500 feet of Tertiary beds is indicated by these exposures. However, the beds may be repeated by faults that are concealed by the superficial cover. This idea is suggested by the fact that the eight or more outcrops of the gravel beds are very much alike. In Townsend Valley, near Toston, Mont., Tertiary beds similar to these in occurrence are observed to be repeated by faulting.

Deer Lodge Pass, crossed by the Oregon Short Line Railroad at 5,814 ft above sea level, is a broad, smooth gap with grassy slopes between mountains on the east and west. The main stream, Big Hole River, instead of following the belt of soft rocks all of the way from the village of Divide to Melrose, has shifted to the west side of this trough and for several miles north and south of Moose Creek has cut a deep narrow gorge through folded and upturned limestone and quartzite.

The presence of deposits of light-buff to gray friable sandstone in the Wise River basin (Tps. 2 and 3 S., R. 12 W.) between 6 and 12 miles south of the village of Wise River suggests that the late Tertiary history of this basin is similar to that of the basin of Grasshopper Creek directly to the south and to the other intermontane basins. The smooth old Harrison Park upland to the south and the similar Vipond Park upland to the east are described on pages 42–43.

The crescent-shaped valley drained by Big Hole River in southern Deer Lodge County and Beaverhead County is one of the most southwesterly of the intermontane basins whose drainage is tributary to the Missouri River. Its late Tertiary history apparently corresponds to that of the other basins described above. This basin is about 50 miles from north to south, with broad bottom lands and extensive, grassy terraces in marked contrast to the high and rugged mountain ranges that encircle it. Many of the surrounding peaks are scalloped by glacial cirques and rise high above the timber that covers their flanks. At the east the concave side of the crescent, is the highland known as the Pioneer Mountains, which is bifurcated by the valley of Wise River, a north-flowing tributary of the Big Hole River, and by the upper valley of Grasshopper Creek at the south. On the northwest along the Continental Divide, the serrate peaks of the Anaconda Range are largely composed of intrusive granitic rocks and of pre-Cambrain sedimentary rocks of the Belt series; on the southwest is the Beaverhead Range, mostly composed of Belt rocks, separating the Big Hole Basin, as this hollow is called, from the valley of Salmon River in Idaho. The larger part of the basin below the flanks and spurs of the surrounding mountains appears to be underlain by Tertiary "lake beds". These beds are generally overlain by bench gravels of Pleistocene age and by glaciofluvial alluvium on the broad bottom lands.

In places, especially near Fishtrap, Mont., the Tertiary deposits are thin and overlie badly decomposed granitic rock. In many parts they probably reach thicknesses of hundreds of feet, although exposures in section are small. Perry (1932, p. 9) says,

The total thickness of the valley filling is not known. The Wilson well at Jackson did not pass through the fill at a depth of 118 feet, and a well on the Highland ranch 2 miles west of Briston school was in soft sediments at a depth of more than 160 feet. In the center of the basin the hard rock floor may be 500 feet or more below the present land surface.

Where the beds are not smoothly beveled by the extensive gravel-capped benchlands they have been carved into low hills and gently undulating uplands. In the bluff below the cemetery, 2 to 3 miles north of the village of Wisdom, whitish to ashen-gray, semi-indurated clay and arkose, probably with intermixed volcanic ash, are exposed below about 20 ft of coarse bench gravel. These Tertiary beds are tilted and beveled off below the terrace gravel. No fossils were seen by the writer at this or any other of the exposures of the Tertiary beds in this basin. Similar, semi-indurated, whitish deposits are exposed in places farther north and farther south. One of the exposures is in the 30- to 40-ft bluff at the edge of the terrace west of the highway, 6 to 7 miles north of Wisdom on the south side of the valley of North Fork of Big Hole River. Four to five miles southwest of Fishtrap, buff friable sandstone exposed in a bluff north of the bridge has a westerly dip.

From the lithologic character and stratigraphic relations of the late Tertiary deposits in the Big Hole Basin it is inferred that they correspond in age to the so-called "lake beds" in the other intermontane basins and are of Miocene, or Oligocene and Miocene age. The tilted positions of the beds indicate dislocation of the deposits and possible downfaulting prior to the beveling of the strata and deposition of the overlying bench gravels by broadly shifting streams. The relations of the gravel benches and terraces are described on pages 76 to 79. It seems to the writer that these benches and terraces are of late Tertiary and Pleistocene age and are the correlatives of like features in the other basins east of the Continental Divide. It has been suggested by other writers that these several intermontane basins once formed parts of a system draining to the Pacific. The present writer has no definite data bearing on such an ancient history. It seems fairly clear, however, that at least as far back as Pliocene time, when the deposition of the Tertiary beds had been completed, and until well along in early Pleistocene time the upper Missouri River was discharging the runoff from all of these basins east of the present divide to Hudson Bay.

BITTERROOT VALLEY

From the vicinity of the famous Big Hole Battlefield, 10 to 12 miles west of Wisdom (where the Seventh U. S. Infantry under General Gibbons was defeated in August 1876 by Nez Perce Indians under Chief Joseph) a highway extends westward on an easy grade up Trail Creek over badly decomposed granite to a pass near the south end of the Anaconda Range. The pass, 6,902 ft above sea level, is on a narrow but smooth, flat, wooded tract, apparently a small remnant of an old high-level erosion surface on Tertiary volcanic rock. This flat is in striking contrast to the steep dissected slope down to Camp Creek on the west.

At Sula, Mont., which is in a broad basin surrounded by steep mountain slopes, the waters of the East Fork of the Bitterroot River and several tributaries unite. It is not know that there are any Oligocene or Miocene sedimentary deposits in this broad basin. Most of the rock exposed near the roads is granitic; some pre-Cambrian sedimentary and Tertiary volcanic rocks are exposed in places. The bottom lands are alluvium. To what extent faulting may have had a part in the formation of this basin is not evident. Below Sula the East Fork flows northwestward for about 12 miles through a deep gorge cut in the granitic rocks. Warm Springs Creek, a tributary from the south, has also cut a deep gorge in the same rocks. A gravel-capped, rock terrace remnant near and 250 ft above the junction of these streams marks a late stage in the cutting of the gorges. Near Conner, about 3,950 ft above sea level, the East Fork joins the main stream of the Bitterroot from the south and flows thence northward through the great Bitterroot Valley.

The headwater branches of the Bitterroot head on the encircling slopes of that part of the Beaverhead Range which extends in a broad irregular curve southwestward from Gibbons Pass on the east to the Blue Nose, a peak 8,660 ft above sea level, and a neighboring pass and thence northwestward to the Nez Perce Pass (about 6,500 ft above sea level). There are at present no detailed topographic maps of the upper Bitterroot region, but the configuration of much of it is shown in aerial photographs taken for the Forest Service. In the vicinity of these three passes, the crest of the range is very narrow and uneven and shows little if any evidence of any actual remnants of a high-level (Tertiary?) peneplain. On the Idaho side the flanks of the range are deeply dissected by gorges tributary to the Salmon and Selway Rivers; on the Montana side the steep, wooded slopes are greatly dissected by sharp and deep gulches tributary to the upper Bitterroot River. From the Nez Perce Pass the Bitterroot Range extends nearly due north for about 70 miles. Many of the gorges cut in its east flank by streams north of Nez Perce Fork were considerably scoured out by Pleistocene glaciers.

From the junction of the East Fork and Bitterroot Rivers near Conner to points somewhat south of the latitude of the Nez Perce Pass and Gibbons Pass the basin is entirely in granitic rocks of the great Idaho batholith. Farther south, as shown on geologic maps, the rocks are mostly of the Belt series, with some Miocene(?) rhyolite at both high and low levels. Near the village of Conner the flat valley floor broadens. It is bordered most of the way thence northward for about 65 miles, to the valley of the Clark Fork near Missoula, in part by extensive gravel-capped terraces and in part by low foothills underlain largely by Tertiary (Miocene?) "lake beds" and in places by rhyolite. Above them, on the west, rises the remarkably straight, steep front of the Bitterroot Range, a noteworthy example of a fault-line scarp. This part of the Bitterroot Range is composed mostly of granitic rock, a part of the Idaho batholith.

The following is part of a brief outline of the geological history of the region including the Bitterroot Valley, by Waldemar Lingren (1904, pp. 26–28):

We may conceive a post-Triassic uplift of great importance, followed or accompanied by vast intrusions of granite, the granite of the Bitterroot, Clearwater, Salmon, and Coeur d'Alene mountains.

We may further, with great probability, assume a long-continued erosion, which planed down this uplift to the moderate relief of the Clearwater, Salmon, and Coeur d'Alene plateaus, and which exposed the intrusive granite by the removal of great masses of covering sediments.

Going one step further, it is necessary to assume a second great and evenly-distributed uplift which raised this eroded surface several thousand feet above the sea, an uplift of post-Triassic and pre-Miocene age. This was probably accompanied by breaks along what is now the western margin of the plateau, and was necessarily followed by the establishment of the systems of the Bitterroot, Clearwater, and the Salmon rivers. These streams trenched the plateau broadly and deeply, with the result that their canyons during the Miocene epoch were cut to a depth equal to that of the present day. The relations of the Columbia River lava to the old topography prove this on the western side, and similar evidence is adduced for the South Fork of the Bitterroot, by the fact that the rhyolites there filled a valley coinciding in depth and configuration with that of today.

Going back a little further from the Miocene datum plane, perhaps to a time when the Bitterroot River first flowed over the uplifted plateau, which probably reached far into Montana, a dislocation of great importance occurred along what is now the Bitterroot Range. This dislocation, the beginning of which perhaps scarcely antedated the close of the Cretaceous period, extended for 60 miles north and south, only bending westward close to its southern end. This fault plane was inclined eastward at angles up to 26° from the horizontal, and the rocks along it bear evidence both of molecular and molar movement; the former expressed in schistosity, the latter in striated slipping planes. The direction of the movement was that of a normal fault, and seemed to have been of a stretching and shearing character. The foot wall seems to have moved up as expressed by the raising of the Bitterroot Range above the general level of the Clearwater Plateau. The hanging wall seems to have moved down as expressed by the apparently structural trough of the Bitterroot Valley. The minimum amount of the dislocation along the plane of fault is 2 or 3 miles; the minimum horizontal component would be but little less, while the corresponding vertical component is about 5,000 feet. The evidence finally shows that movement along this dislocation has proceeded for a very long time, and probably still continues along certain parts of the fault. The flat dip of the fault plane has naturally aided the preservation of the record. * * *

On the eastern slope the happenings of late Tertiary time are less easily traceable, but it is probable that the damming by basalt of the Clark Fork of the Columbia and the subsidence of Bitterroot Valley along the great fault made a lake basin of this valley for a limited time.

Lindgren (1904, p. 112) also reports the occurrence of lignite interbedded with clays and sands in the upper part of the rhyolitic flows along Coal Creek in the valley of West Fork Bitterroot River and a few miles south of Alta.

From the valley of Nez Perce Fork northward to the vicinity of Conner and Darby there is a dissected belt of wooded foothills between the inner valley of the Bitterroot River and the higher mountain flank, or fault-line scarp, on the west. This belt, overlying the granite, is transected by numerous gulches and gorges, some of which have been severely glaciated. As seen from above the configuration of the interstream ridge crests in this belt suggest the presence of a piedmont bench or a down faulted, broad valley bottom of late Tertiary or early Pleistocene age, which has since been very much eroded (pl. 5, p. 50).

West of the West Fork ranger station, on the north side of Nez Perce Fork, much-weathered granite is exposed in a bluff topped by smooth-sloping tracts. These smooth tracts are gravel-strewn and may be remnants of a piedmont terrace. At one place weathered limestone is exposed on the slope north of the ranger station. Quartzite is exposed in a few places near Chaffin Creek but most of the rock is granite, badly weathered where not glaciated.

The relations of the glaciated spurs near and north of Tin Cup Creek are described on pages 99 to 100. Near and between Conner and Darby later and lower gravel-capped benches lie on the beveled surface of this granite and gneiss, which, in places, is badly disintegrated.

From the vicinity of Darby northward the Bitterroot River is generally bordered by flat bottom lands 1 to 3 miles in width between lines of low bluffs. South of Sleeping Child Creek, steep dissected slopes rise directly from the east bank of the river. These slopes are mostly on granite, but for several miles south and north of Como the hills consist of rhyolite as high as 1,500 to 2,600 ft above the river. Farther north there are gentler slopes and broad benchlands underlain by Tertiary sediments east of the flat bottom lands. On the west side, from Darby northward and between the low river bluffs and the great mountain scarp, there are broad Pleistocene terraces, alluvial fans, and in many places glacial moraines and outwash deposits. South of Darby the low bluffs expose deeply weathered granite and gneiss. For 7 miles north of Darby, Tertiary rhyolite is exposed in places in these bluffs. Farther north there appear to be Tertiary sands and gravels below the Pleistocene deposits.

In general, the exposed Tertiary beds other than the rhyolite in this valley appear to be oxidized, buff to brown, friable sandstone and loose sand with some intermixed gravel. One of the best exposures is about 2 miles northeast of Florence where the river washes the foot of the east bluff (fig. 3). At this place the following section was observed:

FIGURE 3.—Tertiary "lake beds" in river bluff northeast of Florence, in the Bitterroot Valley. The deposits contain silicified wood (Miocene?) and are overlain by glacial Lake Missoula sediments (Pleistocene).

Deposits northeast of Florence

	Feet
Sediments of glacial Lake Missoula (?):	
Sand and gravel	6
Clay, greenish-gray	3
Sand and fine gravel, cross-bedded	30–35
	40±
Miocene "lake beds":	
Clay "soil", local, dark, humic-stained	1
Clay, greenish-yellow, jointed	5
Sand and fine gravel, stratified; Sand, coarse, and friable sandstone, orange brown and stained red, especially around pockets of white sand	95
	100±

All the above Tertiary sand is granitic and is accompanied by only a little gravel.

The only fossils noted were fragments of silicified, dicotyledonous wood, cream colored and embedded in sand about 15 ft below the old buried "soil". Pardee (1913, p. 234) states that Douglass found a few Miocene vertebrate remains north of Stevensville in light-colored sand and tuff. About a mile south of Fort Missoula Military Reservation in a gravel pit south of the river bend there was exposed in 1931 a considerable deposit of stratified, northwest-dipping gravel and sand. The pebbles are mostly of quartzite and argillite from the Belt rocks and are mostly fine, but some are as much as 4 in. in diameter. The degree of oxidation suggests Tertiary age, but the material may perhaps be Pleistocene washed from the mountains to the southeast into glacial Lake Missoula. At many places, especially on the west side of the valley, there is much arkosic sand either from decomposition of granite in situ or washed out from the nearby mountains or hills. To what depth this valley was filled by Tertiary deposits and how much these deposits have been dislocated by downfaulting is not known to the writer.

The highest altitude at which the Tertiary "lake beds" have been mapped between Conner and Missoula is about 4,500 ft above sea level or 1,300 ft above the river. There seems to be no reason for thinking that this valley was entirely filled. Some of the coarse gravel deposits are undoubtedly old alluvial fans.

MISSOULA VALLEY

In the broad valley of the Clark Fork near Missoula and for 20 miles northwest, Tertiary beds are probably buried beneath the Pleistocene alluvial terrace gravel and the laminated silts deposited in glacial Lake Missoula. As along the east side of the Bitterroot Valley to the south, so also along the north side of this part of the Clark Fork valley there is a belt of foothills 500 to 1,000 ft or more high composed of Tertiary "lake beds", which border the higher hills of Belt rock. In these foothills the following section, described by Pardee (1913, pp. 234–235) is exposed:

Tertiary strata exposed north of Missoula, Mont.

	Feet
Clay, gray to cream-colored, and volcanic ash containing one or more coal beds	200+
Sandstone, light gray, micaceous	40±
Coal	7±
Clay, greasy gray	50±
Clay, brown to red	-----
Total	297±

The beds at one of the coal mines are reported to dip away from the center of the basin and toward the mountains, and elsewhere rather complex folds are found as the result of dislocation of the strata. The ash beds near Missoula containing fossil leaves have been described by Rowe (1903, pp. 21–23, pls. 6, 7, and 8). The coal beds that have been developed are said to be in the lower part of the Oligocene deposits. These foothills were mostly submerged during the higher stages of glacial Lake Missoula, and the erratic cobblestones and boulders scattered in many places over their tops and slopes may have dropped from icebergs floating in this lake.

J. P. Rowe (1903, pp. 21–23), not specifying the exact location, gives the following section:

Section of well near Missoula

	Feet
Volcanic ash	35
Sandstone	45
Lignite and fire clay	6
Sandstone	14

Coarse rusty gravel exposed lower down in the slopes, near the coal mine on Ravalli Creek, is probably a part of the Tertiary deposits. In places there is so much rusty gravel on top of the hills as to suggest that the hills are, in part at least, erosion remnants of high benchlands capped with post-Miocene gravel.

Five miles west of Missoula, in the upper east slope of Council Hill (in the NE¼ sec. 22, T. 13 N., R. 20 W.), a ledge of loosely compacted conglomerate is exposed. It is 15 ft thick and is composed of rounded pebbles and cobblestones, mostly of quartzite. None of the stones, so far as noted, shows glacial striae. Scattered on the hill slope are 3- to 5-ft angular blocks of quartzite that may have been dropped from icebergs floating on glacial Lake Missoula. The lower north slope of the hill is overlapped by laminated glacial-lake silt. It is possible that the conglomerate exposed in the east slope may be a remnant of a preglacial alluvial fan formed by O'Brien Creek which at this point flowed out from the hills to the south during Tertiary time. The hill may have been cut off by erosion of the river channel after glacial Lake Missoula had been drained away late in the Pleistocene.

The geologic age and stratigraphic relations of the deposits exposed at the west salient of the upper terrace about 10 miles northwest of Missoula are not very clear and they suggest possible faulting on a northerly extension of the postulated fault that cuts across the hills at Sherman Gulch south of the river. In the ditch below the Northern Pacific Railroad, dense, hard, gray limestone (of either pre-Cambrian or Paleozoic age) is exposed. The ledges here are overlain by laminated silt of glacial Lake Missoula. Just to the west there are upturned beds of red clay and decomposed limestone and of quartzite fanglomerate. In a railroad cut higher up, the lake silt of Pleistocene age overlaps 1 to 5 ft of cobblestone gravel above a deposit resembling a "fanglomerate" of angular fragments of quartzite embedded in buff to red clay. At the bend west of this cut, lake silt overlaps coarse gray quartzite gravel 1- to 3-ft boulders above red and gray clay.

About 2 miles northwest of De Smet a 50-ft cut on the highway (U S 10) grade (seen in 1937) exposed fine stratified gravel overlain by north-dipping whitish to buff semi-indurated clay (Tertiary?) and capped with coarse quartzite gravel.

About 2 miles farther north a 50-ft cut at the railroad trestle over O'Keefe Creek exposes southeast-dipping (Tertiary) beds of buff clay, sandstone, and 1 to 3 ft of lignite overlying 8 to 10 ft of interbedded, semi-indurated, 1- to 4-in. layers alternating with thin layers, of dark-brown putty-like clay. The whole resembles "varves" between the upper and lower beds of lignite. No fossils other than fragments of plant remains were noted. The beds composing the foothills north of the Pleistocene terraces in the Missoula Valley are certainly erosion remnants of a great valley fill deposited during Oligocene and Miocene time. There has been a good deal of landsliding on the hills of Tertiary clay 2 to 4 miles northeast of De Smet. The numerous boulders of Belt rocks, 1 to 5 ft in diameter, sprinkled over these slopes at and below the 4,000-ft level may have been dropped from icebergs floating on glacial Lake Missoula.

A northwestward continuation of this belt of foothills is a similar dissected plateau between the mountains that border the broad basin, in the western part of which is the inner valley of Ninemile Creek northwest of Huson.

On Kennedy Creek, in T. 16 N., R. 23 W., lignite interbedded with gray shale and soft sandstone dips toward the mountains on the northeast at angles of 10° to 35° in a small exposure. The coal also is said to have been encountered in drilling on the plateau. The tops of the interstream tracts on this plateau north and northwest of Huson appear to have been definitely benched (probably in the Pliocene) between the time the Tertiary beds were displaced and the time of their dissection by the sharp gorges a few hundred feet deep.

The location of the outlet for the waters of Oligocene and Miocene time, in which the Tertiary "lake beds" now found in the Ninemile, Missoula, and Bitterroot Valleys were deposited, is unknown. There is no definite evidence that the outflow was northwestward where the Clark Fork now flows, although it may have been. It has been supposed by some that outflow was southward from the Big Hole and other basins—an outlet now blocked by the Beaverhead Range—to the Pacific by way of Snake River. If the outflow from the Bitterroot Valley was not previously by way of the Clark Fork, this stream must have taken its course through the mountains between Missoula and Paradise while the "lake beds" still filled the basins from side to side. No Tertiary "lake beds" are known to be present in the Hell Gate Canyon of the Clark Fork for nearly 30 miles above Missoula, between the Sapphire Mountains on the south and the Garnet Range on the north. This, of course, does not necessarily mean that Hell Gate Canyon has been wholly cut since Miocene time, but it is in harmony with the idea that the final cutting and deepening of this gorge occurred later, in Pliocene and Pleistocene time. There is, however, lava of supposed middle Tertiary age unconformably overlying older rocks on the sides of the valley several hundred feet above its bottom between Baird and Nimrod, 30 to 35 miles upstream from Missoula. Farther east, near Bearmouth, lava extends down to the bottom land, the valley broadens, and Tertiary "lake beds" are found in tributary basins under smooth grassy slopes and benches.

UPPER BASIN OF THE CLARK FORK AND DEER LODGE VALLEY

The Tertiary "lake beds" are generally present in the broad Deer Lodge Valley from Drummond on the Clark Fork to the Deer Lodge Pass south of Silverbow. They are continuous through the pass southward to the Big Hole River below Divide. Possibly as some geologists think, the drainage in Miocene time was southward through the Beaverhead basin past Dillon and Monida to the Snake River in Idaho. It seems probable, however, that by Pliocene time the Clark Fork was established in its present course above Missoula.

Over large areas south of Anaconda and north of Butte the weathered and deeply eroded surface of the Boulder batholith (Cretaceous or early Tertiary) is overlain by rhyolitic lava. The lava extends from the hills across the Silver Bow Valley west of Butte, and through it the creek has cut a narrow gorge 200 to 400 ft deep. The stream probably established this course when flowing upon the top of the "lake beds" in Pliocene or early Pleistocene time, fully 600 ft above its present channel. In places nearby, the eroded "lake beds" still lap up onto either the lava or the granite to an altitude of approximately 5,800 ft above sea level.

Weed (1912, p. 29) describing the relations of the granitic batholith and other rocks of the Butte district, states:

That the granite is younger than the andesitic rocks is proved by the presence in it of blocks of andesite near Pipestone Springs and north of Whitehall, and by the pronounced baking of the andesite at the contacts. The facts observed elsewhere indicate an Eocene age for the andesite, which would make the granite Miocene in age.

A large part of the granite tract is now covered by volcanic rocks which have been cut through by the canyons of the region. Between the time of the granite intrusion and the later rhyolitic volcanic outbursts a prolonged period of erosion must have intervened, during which the rocks above the granite were largely removed and the mountain masses and intervening valleys of the present day carved out by the streams, the Butte district being thus developed into a roughly hilly surface before the succeeding periods of volcanic activity began.

The Jefferson and Missouri valleys on the east and the Deer Lodge Valley on the west were at that time deeper than and as broad as they are today. A long period of undisturbed equilibrium was succeeded by a tilting of the region which reversed the drainage of the greater valleys, whose water accumulated in lakes, a phenomenon general throughout the region. The lake beds formed at this time may be seen about the borders of the granite tract, and in the Silverbow Valley they are deposited upon the granite itself.

Of the "lake beds", he wrote earlier (Weed, 1897, p. 3)

Deposits of sediment which accumulated on lake bottoms are found only in the extreme western part of the district. They consist of compact but generally unconsolidated sands, gravels, tuffs, and stony clays. The beds are horizontal, but show local cross-bedding, and vary from place to place both in general character and in the nature of the material composing them. The gravel is composed of granite and aplite. The tuff beds are formed of fine rhyolitic ash, which also enters into the composition of some of the beds of sand. The stony clays show no bedding, or only such as is too rude to be recognizable in prospect shafts. The true nature of the material forming the tuff beds is discernible only under the microscope. It is a volcanic dust, the product of an ash shower from an explosion of a volcanic vent. It is composed of minute angular particles and threads of glass which chemical analysis shows to be rhyolitic in nature.

These deposits represent the material washed into a lake which covered the Silver Bow Valley west of Rocker, extending south across what is now the continental divide. Only the extreme eastern margin and shore of this lake were within the district described, but the deposits were continuous westward and southward to places where vertebrate bones have been found. These fossils were of upper Miocene types. The evidence is of importance, as the lake beds were contemporaneous with the rhyolite eruptions, and these latter took place after the period of ore deposition, so that the age of the ores must be pre-Miocene.

South of Silverbow, the "lake beds" consist of interbedded buff to brownish gritty clay and fine sand and gravel with bedding, in places, dipping east to southeast. The deposits are cut by gulches, and in places the tops and slopes of the ridges between are strewn abundantly with granite boulders ranging in diameter from 1 to 10 ft or more. Where crossed by the Butte, Mont. water pipeline near the foot of a north-south granite cliff, there are boulders as large as 15 ft in diameter; they may rest as residual boulders on the thinly covered surface of deeply weathered granite. Such boulders are plentiful up to and on top of the rock cliff at the one place examined by the writer. The distribution of the boulders, if they were originally scattered on top of stratified finer material, is such as might perhaps have resulted from either a glacial deposit or a torrential boulder fan transported from the highlands to the south-southeast.

So far as noted by the present writer, however, the boulders in the area of the "lake beds" south of Silverbow appear to lie wholly on the surface and not to be embedded in the finer stratified material. The ridges appear to be erosional in character, and certainly not moraines. The present topography of the highlands and the Red Mountain mass to the southeast is such that glacier ice heading thereon (unless very early in Pleistocene time) would hardly be expected to extend thence out over this boulder belt. North of the Silverbow Canyon arkosic sand and gravel are exposed in places underlying coarser bench gravel in some cuts of the Chicago, Milwaukee, St. Paul & Pacific Railroad along the east side of the valley. A gulch north of Dry Cottonwood Creek exposed 50 ft of flat-lying beds of loose, pebbly, sandy clay below the gravel cap of the great dissected piedmont terrace. The "lake beds" doubtless underlie the alluvial gravel on the bottom lands both south and north of Deer Lodge, but to what depth is not known to the writer.

A few miles west of Anaconda, both north and south of Warm Springs Creek, there are tilted and eroded beds of "earlier gravel"—that is, Tertiary, partly overlain by Pleistocene terrace gravel. Inasmuch as these gravels contain abundant pebbles of unmetamorphosed rocks, such as are not exposed in the Warm Springs Creek basin, it is clear that at one time the area around Georgetown Lake drained eastward.

The character, distribution, and dislocation of these "earlier gravels" indicate that a very considerable amount of erosion of the uplands had already taken place when they were laid down by the several streams prior to Pliocene time. The deposits, however, are not known to be as old as Eocene.

North of Anaconda, on the west side of the valley, there are extensive remnants of the sloping, gravel-capped upper terrace heading at the east front of the Flint Creek Range. Tertiary sand and clay deposits underlying both the upper and lower terraces are exposed in places below the cappings of later (Pleistocene) gravel. Exposures near the road on the sloping bench 3 to 7 miles northwest of Deer Lodge show at the top deeply weathered coarse gravel and boulders (early Pleistocene?) in which the granitic pebbles and boulders crumble readily under a hammer. Beneath this is finer and more waterworn (Tertiary?) gravel interstratified with layers of sand and clay with some bright reddish streaks.

At Kohrs, 5 miles north of Deer Lodge, Tertiary deposits are exposed in the bluff at the eastern edge of the benchland. At the top of the bluff, about 300 ft above marshy bottom land, coarse, angular to subangular cobblestone gravel consists mostly of quartzite and lava pebbles with some disintegrating granites. This may be Pliocene or Pleistocene bench gravel. Underlying it is buff to reddish sandy clay, with some interbedded thin layers of gravel consisting of pebbles of lava. A few fragments of fossil bones (Tertiary?) were found in the sandy beds. Northwest of this locality there are hills of Cretaceous or Tertiary lava that project above the surrounding and overlapping Tertiary "lake beds" in adjacent parts of the dissected benchland. The lava is cut through by the narrow gorges of Mill and Rock Creeks.

A short distance southwest of Goldcreek a gravel-capped butte (5,000 ft above sea level) rises about 800 ft or more above the river. The capping gravel consists very largely of subangular pebbles and cobbles of quartzite, lava, and flint. This bench gravel is a remnant of an old stream deposit washed from the mountains to the southwest, probably in Pliocene or early Pleistocene time. Underlying the gravel is Tertiary sandy clay containing white marly layers in which are fresh-water shells.

Some of the placer diggings in this vicinity cut through the glacial deposits and expose the underlying Tertiary gravel and sandy clay "lake beds." One of the largest pits seen by the writer was excavated in the slope below the smooth gravelly top of a narrow remnant of a bench, locally known as Gold Hill, 400 to 600 ft higher than the village of Pioneer, and just north of Pikes Peak Creek. The material exposed here consists of very stony clay, in which the stones are mostly angular with abraded edges and but little waterworn. They are composed mostly of quartz and quartzite with some of granite. No striated stones or other evidence of glaciation were noted in this exposure, which is not far outside a well-defined late Pleistocene lateral moraine of Pikes Peak glacier. The stony clay appears to be an ancient torrential deposit or fanglomerate of Pikes Peak Creek, possibly of Miocene to Pliocene age. There was probably much erosion of the Tertiary "lake beds" in the Deer Lodge Valley and in the region of Pioneer and Garrison prior to the earliest Pleistocene glaciation, which deposited the Pioneer drift found on what are now very small remnants of the Pliocene gravelly benches, such as Ballard Hill near Pioneer.

South of the Garnet Range, from Gold Creek westward past the north end of the Flint Creek Range to the vicinity of Drummond and the Flint Creek Valley there is a broad basin in which the Tertiary "lake beds" underlie dissected remnants of extensive gravel-capped benchlands. The highest are probably of Pliocene or early Pleistocene age. In this basin are the villages of Drummond, New Chicago, and Hall, and through it the Clark Fork flows in a northwesterly direction. A large part of the runoff from the uplands on the south and west reaches the Clark Fork at Drummond by way of Flint Creek and its tributaries. Douglass (Pardee, 1925, pp. 18, 19) obtained fossils of Miocene age from what he has named the Flint Creek beds near New Chicago.

Pardee (1913, pp. 233–235) reports the following:

Section of Tertiary and Quaternary formations in the Flint Creek Basin

System	Series	Character	Thickness in feet
Quaternary.	Recent.	Alluvium (gravel, sand, and silt).	
		Unconformity	
	Pleistocene.	Coarse- to medium-textured terrace gravel, locally gold-bearing.	0–50
		Unconformity	
Tertiary.	Miocene.	Mostly massive, slightly indurated tuff, composed in part of clay; prevailing colors light-yellow to brown. Contains some beds of fairly pure volcanic ash, impure limestone, sand, and fine, light-gray gravel; fossiliferous, yielding bones of oreodonts and other vertebrates.[a]	1,000+
		Unconformity(?)	
	Oligocene(?).	Mostly massive, slightly indurated tuff, composed in part of clay; prevailing colors light shades of gray and cream. Contains some thin beds of fairly pure volcanic ash, shale, and impure limestone, the latter yielding remains of fresh-water mollusks.	200
		Mostly massive, slightly indurated tuff, composed in part of clay, prevailing colors very light shades of gray and cream; dome beds of brownish and greenish tints, the whole divided by many thin layers of fairly pure volcanic ash, impure limestone, thinly laminated or "papery" shale containing fragments of plants, and a few layers of sand and fine gravel.	1,300
		Impure limestone or marl ("cement").	10
		Massive tuff composed in part of clay; prevailing colors light-gray to brown.	490
		Coal.	4±
		Massive, greasy gray to red clay.	96
		Unconformity	
		Basalt.	
		Andesite.	
		Rhyolite.	
		Unconformity	
Pre-Tertiary.			

[a] Douglass, Earl, New vertebrates from the Montana Tertiary: Carnegie Mus. Annals, vol. 2, 1903, pp. 153, 171–180.

Tertiary rocks

That the Tertiary period was one of almost continual volcanic activity in this general region is shown not only by the remnants of extensive lava flows but by the large proportion and vertical distribution of volcanic ash in the formations. Although these ash beds form much the greater volume of the bench lands, they are in most places concealed beneath a superficial cover of gravel. Perhaps the best exposures are those afforded by ravines that dissect the benches east and west of Flint Creek, near Drummond. As indicated by their history, they are apt to be lenticular, and no stratigraphic section is representative over a large area.

In the massive tuff of the upper portion of the Flint Creek section Douglass found Miocene vertebrate remains. The lower beds, which contain the coal, are here doubtfully referred to the Oligocene, no distinctive fossils having as yet been found in this locality. Douglass referred these beds to the White River.

The section given above appears to be fairly typical of the Tertiary formations in all the valleys enumerated. In the northern half of Avon Valley yellow to brown, somber-hued tuffaceous clays prevail, whereas in the southern half light-colored tuff, thought by Douglass to be White River, is exposed. In the Philipsburg area massive cream-colored to brown tuff, that is thought to be of Miocene age, occurs.

* * * * *

Steeply inclined normal faults of small throw are numerous in the marginal portions of Flint Creek Valley and are to be expected in the more severely deformed beds elsewhere. Slightly tilted beds, however, exhibit few if any faults.

FLINT CREEK AND ROCK CREEK

Tertiary deposits exposed in gulches below the smooth grassy benches east of Flint Creek consist mostly of stratified and semi-indurated pinkish to brownish sand or sandy clay. Overlying this is a capping of coarse, unsorted, or poorly sorted, bouldery gravel 20 to 30 ft thick, with finer material intermingled. This bench gravel appears to be a torrential stream deposit of fanglomerate, probably of Pliocene or early Pleistocene age. Old placer diggings at the edge of the high bench 2 miles south of the village of Hall and 200 to 300 ft above Flint Creek afford good exposures of it. The stones are mostly less than 6 in. in diameter but range in size from small pebbles to boulders 4 ft in maximum length. They are somewhat waterworn and show percussion marks, but are subangular rather than well rounded. Unlike the glacial deposits along Flint and Boulder Creeks, this material appears to contain few granite pebbles or boulders.

Certain "earlier gravels" (Tertiary) interbedded with and overlain by volcanic breccia, tuff, and ash are described in the Philipsburg folio (Calkins and Emmons, 1915, p. 10) as remnants of a gravel deposit that once deeply filled an old stream channel west of the Continental Divide and is now exposed near the western boundary of the Philipsburg quadrangle, bordering the valley of Rock Creek. This gravel is partly cemented into conglomerate. It is said to be overlain in places by small remnants of a lava flow, and "its relation to this lava, and its intimate association with pyroclastic rocks suggest its correlation with the older gravels found near Anaconda". (Calkins and Emmons, 1915, p. 10.)

AVON VALLEY

At Garrison the Clark Fork is joined by the Little Blackfoot River, which comes from the northeast through a narrow gorge after leaving the broader Avon Valley, another of the intermontane basins. This basin, including some low hills of Tertiary lava, is 6 to 10 miles wide and is bordered on the east by the slopes rising to the Continental Divide. Its northern part is drained northwestward to the Blackfoot River, through a more constricted valley, by Nevada Creek. A large part of it is occupied by gravel-capped benchlands. These benchlands and parts of the adjacent slopes are underlain by Tertiary "lake beds". Light-yellow to brown tuffs and clays with beds of sand and volcanic ash are exposed in old placer mines along Carpenter Gulch and Ophir Creek, on Six Mile Creek north of Ophir, and elsewhere. They are similar to the Oligocene beds in Townsend Valley, and near Ophir and south of Avon they contained thin beds of coal (Pardee and Schrader, 1933, p. 14). It is reported (Pardee, 1913, p. 243) that placer miners found 1 ft or more of coal a short distance above the mouth of Jefferson Gulch in T. 12 N., R. 9 W. Tertiary beds are also exposed in places in the eroded bluffs below the capping bench gravels, which are in places 100 to 175 ft or more above the bottom lands.

NEVADA VALLEY

Near Helmville, the valley of Nevada Creek opens out into another intermontane basin 8 to 10 miles wide, known as Nevada Valley. Blackfoot River enters this valley from a narrow gorge to the east and flows in a meandering course through it, first southwestward then northwestward, to the vicinity of Ovando. Tertiary deposits probably extend throughout the basin under cover of glacial drift and alluvial gravel. At several places below the bridge, which is about 6 miles northwest of Helmville, light-buff to reddish clayey sandstone, dipping eastward, is exposed in the river bluff below 10 to 15 ft of reddish glacial till. A picturesque bluff at the confluence of the North Fork Blackfoot River with the main stream, a few miles south of Ovando, exposes thinly laminated and jointed semi-indurated buff sandy clay dipping gently to the northeast. In the northwestward continuation of this basin, near Ovando, glacial and glaciofluvial deposits cover most of such Tertiary beds as may be present. This is true of the smaller Lincoln basin, which is drained by the Blackfoot River northeast of Helmville. In a smaller basin known as Camas Prairie, which is drained to the Blackfoot River by Union Creek east of Bonner, there are also Tertiary deposits. Where exposed near the road, about 2 miles west of the village of Potomac, they consist of semi-indurated, ashen-gray to cream-colored sandy clay, probably containing volcanic ash.

Gray, semi-indurated tuff breccia is exposed near the road 7 to 8 miles east of the village of Potomac. About 1½ miles upslope to the southwest a cut on an old logging railroad grade (about 4,100 ft altitude) exposes buff, semi-indurated sandy clay containing small shells and concretions.

TERTIARY DEPOSITS ALONG FLATHEAD RIVER

Tertiary deposits occur in some of the intermontane valleys farther north than the Blackfoot River. The best exposure of Tertiary (Miocene?) strata is in the great gorge of the South Fork Flathead River at Coalbanks (SE¼ sec. 3, T. 27 N., R. 16 W.). In the lower part of the 15-ft bluff 1 to 3 ft of coal is exposed, at the water's edge. It is friable and soft to lustrous, dips northward at a low angle, and is overlain by gray sandy clay containing some fragments of fossil plants. The bank here and a little farther north at the mouth of Paint Creek was examined in 1913 by R. W. Stone (unpublished notes) who found yellow, red, maroon, and salmon-colored clays.

Dark reddish material, composed largely of angular rock fragments resembling talus with some streaks of red jointed clay, was exposed (1931) in the lower part of the bluff east of the bridge over Riverside Creek (sec. 13, T. 29 N., R. 18 W.). It is possibly a fanglomerate of Tertiary age. Similar reddish material is exposed in a road cut a little farther south. Such material gives a reddish color to the glacial till in places. The valley of the South Fork is about 4 miles wide in this vicinity and the tops of the foothills are 500 to 1,000 ft above the river, like the tops of the interstream spurs in the Tertiary rocks on the upper reaches of the Flathead River. As shown by Clapp (1932, pl. 1) this and most of the other longitudinal valleys north of the transverse valley of the Blackfoot River appear to be along lines or belts of faulting.

About 8 miles south of the head of Swan Lake (T. 24 N.), Swan River is cutting at the foot of a bare bluff about 50 ft in height. The lower part of the bluff, where not obscured by talus, shows rusty, clayey sand and buff sandy clay with some gravel in which some of the pebbles are badly decomposed. These sediments may be either of Tertiary or early Pleistocene age. They are overlain by lighter colored, grayish glacial drift containing striated pebbles.

VALLEYS OF THE MIDDLE FORK AND FLATHEAD RIVER

The longitudinal valley east of the South Fork valley is that of the Middle Fork. Southeast of Coal Creek the Middle Fork has incised a meandering inner gorge, 100 to 200 ft or more in depth, below terrace remnants of the broader bottom of the valley. The gorge is now known as John F. Stevens Canyon. The broader and older valley bottom is underlain in places by northeastward-tilted and beveled beds of buff to gray friable sandstone to Tertiary (Miocene?) beds exposed on the main stream of the Flathead River above the forks.

At Halfmoon Lake, north of the ranger station and about 2 miles north of Red Eagle railroad station in Glacier National Park, a landslide scarp several hundred feet high exposes soft, friable thin-bedded, nearly horizontal, sandstone. These beds may possibly be of Miocene age. K. E. Lohman found no diatoms in a specimen of this sandstone which he examined. Gastropod and pelecypod shells were collected from this rock by the writer in July 1936, and F. S. MacNeill, who examined these specimens, reports as follows:

Determination of fossils from north of Halfmoon Lake, 2 miles north of Nyack ranger station, Glacier National Park, Mont.

Gastropods:
- *Helisoma* sp.
- *Amnicola* sp.
- *Lymnea* sp. High-spired type
- *Lymnea* sp. Low-spired type

Pelecypods:
- *Pisidium* sp.
- *Elliptic* sp.

None of the gastropods is well enough preserved to be determined specifically. One, the *Lymnea* with a high spire, is of a type that is not believed to be older than middle Tertiary. The earliest known species of this group is from beds of White River age. The species in the collection from Halfmoon Lake are of even more recent aspect.

The pelecypod *Elliptic* appears to be well enough represented for specific determination, but does not conform to any described species, most of which are Eocene or older.

Eugene Stebinger, in 1914, found a bed of "near" coal, 3½ ft thick, about 110 ft below the top of this scarp. He states, in his unpublished notes, that these rocks are very much like Eagle sandstone or Horsethief sandstone and beds above it, and are almost certainly of Cretaceous or Tertiary age.

Thinly laminated gray fissile shale grading downward into friable sandstone is exposed in railroad cuts near the mouth of Tunnel Creek, 7 or 8 miles northwest of Essex. The deposits dip northeastward at an angle of 40° and are unconformably overlain by terrace gravel and glacial till. Carbonized plant remains and one fragment of a fossil fish were found in the shale by C. L. Gazin and the writer. The fossil fish was examined by J. W. Gidley, who reported (written communication) that while this specimen was too incomplete to permit even generic identification, it was a well-developed teleost fish. Gidley had no doubt of its Tertiary age, saying it may be either Eocene or Miocene. T. W. Stanton (written communication) also collected from the same vicinity near tunnel 3 a few fossil plants that F. H. Knowlton recognized as "*Liquidambar* (sweet gum) close to and probably identical with *L. europaeum* Al. Br. [Alexander Braun]" and an unidentified *Ficus* (fig). Knowlton thought that the meager material was "most probably Miocene." At tunnel 2 in the same neighborhood, Stanton collected "fragments of *Sequoia* and possibly *Pinus* and a few fresh-water gastropods belonging to *Limnaea* and *Planorbis*." A few miles farther southeast, tilted gray shale, probably Tertiary, is exposed below 25 to 30 ft of buff-gray gravel.

The dip and strike of these beds are about the same as those of the Belt series in the mountains bordering this part of the valley of Middle Fork on the east and west, as though the beds were involved in whatever post-Miocene faulting took place along the southeastward continuation of the supposed "Roosevelt Fault" (Clapp, 1932, pl. 1) which parallels the main Flathead River, passing beneath the upper part of Lake McDonald.

It has not yet been determined whether Tertiary deposits continue northwestward to Lake McDonald through the broad gap between the Belton Hills and the mountains on the northeast. It is possible if not probable, however, that such deposits comprise a large part of the bulk of the transverse Snyder Ridge and Howe Ridge, which border the Lake McDonald trough. From Howe Ridge northwestward to the international boundary there is a broad trough between the much-dissected flank of the rugged Livingston Range on the northeast in Glacier National Park and the similar mountains composed of upturned Belt rocks of the McDonald Range on the southwest. For about 30 miles southeastward from the Canadian boundary, as measured on an air line, the Flathead River follows this trough.[4] Nine miles northwest of the foot of Lake McDonald it turns sharply first to the west, out of this broad intermontane valley, and then south and follows a deep narrow gorge west of the Apgar Mountains. Structurally and topographically the broad intermontane trough is continuous from Lake McDonald to the Canadian boundary.

Daly (1912, p. 117), in his report on the 49th parallel in commenting on the structure of the "Galton-MacDonald" mountains west of the Flathead Valley, writes as follows:

> The Carboniferous limestone on the west side of the Flathead is on the same level with strata on the east side, belonging to the lower Appekunny [of the Belt series]. One may fairly estimate that a net displacement of at least 15,000 feet or possibly 20,000 feet is here indicated. The western part of the Clarke [Livingston] range has been lifted nearly or quite three miles higher than the most easterly block of the MacDonald range. The latter block is downthrown by an even greater amount with respect to the block next on the west. The Carboniferous limestone at the Flathead valley is, in fact, the visible upper portion

[4] Rather generally, in common parlance in this region, that part of the Flathead River between 49th parallel and the confluence with the Middle Fork southwest of Belton is referred to as the north fork of Flathead River.

of a broad block or series of parallel blocks which have been dropped a minimum of about three miles below the adjacent blocks of the Clarke and MacDonald ranges. The Flathead trough is thus structurally a typical fault-trough or 'graben'. It is also highly probable that the depression has always been a graben in a topographic sense. It has been partially filled with [Tertiary] lake beds and has been deformed by the folding of those beds but there is no evidence that the initial trough form was ever quite destroyed.

There are numerous scattered exposures of deposits in this trough, some of which are known to be Tertiary deposits (Miocene or older), and others are probably so. That part of the trough east of the inner valley of the Flathead River in northern Montana is transected by numerous streams heading in the Livingston Range, and between them are interstream ridges several hundred to 1,500 ft or more in height, which extend southwestward from the mountain flank to the borders of the inner valley. In cross-country views from relatively high points the tops of these interstream ridges, including Howe Ridge and Snyder Ridge on either side of Lake McDonald, appear to merge in the hazy distance into a plain or piedmont bench which corresponds approximately to the plain or bottom of the Flathead valley as developed in late Tertiary and early Pleistocene time by the truncation of faulted and upturned Tertiary beds and by the deposition of torrential wash, bench gravel, and pre-Wisconsin glacial drift. These interstream ridges are wooded and there are but few exposures to show their composition. Among those examined are two scarps due to landsliding in a gulch high up on the southeast side of Howe Ridge, 1,200 ft or more above the lake at a point N. 67° W. of the mouth of Sprague Creek. They are visible from the east side of Lake McDonald. The upper big scarp whose top is 100 to 200 ft or so below the top of the ridge, shows about 100 ft of glacial till. Poorly exposed below the till is reddish jointed clay. Similar clay is also exposed 200 to 300 ft lower down the slope beneath cemented till. This clay resembles some of the Tertiary(?) clay exposed near Pinnacle in the valley of the Middle Fork of the Flathead River. There is a slight indication that the clay dips S. 67° E. but this dip is not certain. Below the red clay is gray sandy clay, sand, and gravel.

Another of the scarps examined is at the top of Camas Ridge, about 5 miles northwest of the head of Lake McDonald and 2 miles northwest of, and 1,400 ft above, Rogers Lake and Camas Creek. The upper 100 to 150 ft of the material exposed appears to be glacial till, buff in color with indefinite alternating bands of material of deeper buff tint. Below is a mixture (talus or torrential wash) of angular fragments of green argillite and clay, whose top is marked by a rusty, yellowish, gravelly band of material due to the oxidation of fragments of greenish argillite apparently as the result of long exposure before the deposition of the overlying glacial drift. This lower deposit may perhaps be of Tertiary age.

Traverses of parts of the crests of the ridges immediately southeast and northwest of the Lower Quartz Lake did not reveal any Tertiary deposits beneath the cover of later material, glacial drift. Bowman Creek, however, in eroding its inner valley 2 to 3 miles downstream from Bowman Lake, has cut into Tertiary deposits below the ridges.

About half a mile northeast of international boundary post 261 the Canadian Custom House stands on a gravel-capped terrace a short distance southeast of the bridge over the Flathead River. In the bluff below this terrace the Tertiary beds, which Daly (1912, pp. 87–88) described as the "Kishenehn formation," are exposed. Of these deposits, Daly wrote as follows:

The exposures are here fairly good but are not extensive enough to show the full thickness or relations of the formation.

The rocks consist chiefly of light to rather dark bluish-gray, often sandy, clays. In these there are numerous interbeds of hardened, light-gray sandstone, varying from two inches to a foot in thickness. The sandstone is very often characteristically nodular, with many concretions. A few seamlets of lignite up to 2 mm. in thickness and a few small, woody stems were observed in the clays. The latter are usually very homogeneous and have the look of lake deposits.

At the river not more than 250 feet of different beds were actually seen, but it is probable that the total thickness represented in this section exceeds 500 feet. Ten miles down the Flathead valley, near the mouth of Kintla Creek, the Kintla Lake Oil Company has drilled through 700 feet of soft "shales" and sandstones bearing at intervals thin seams of coal. It is likely that these rocks form the southern continuation of the sediments at the Boundary line. Otherwise there is at present no hint as to the full extension of the lake beds.

Both clays and sandstone are at several horizons moderately fossiliferous. The fossils consist of small and extremely fragile shells. These have been examined by Dr. T. W. Stanton, who reported the collection to "consist entirely of fresh-water shells belonging to the genera *Sphaerium*, *Valvata* (?), *Physa*, *Planorbis*, and *Limnaea*. Similar forms occur as early as the Fort Union, now regarded as earliest Eocene, but there is nothing in the fossils themselves to prevent their reference to a much later horizon in the Tertiary, because they all belong to modern types that have persisted to the present day, though it should be stated that their nearest relatives among the western fossil species are in the Eocene."

Dr. Stanton lists the species as follows:—

"*Sphaerium* sp. Related to *Sphaerium subellipticum*, M. and H.

Valvata (?) sp. Resembles *Valvata subumbilicata* M. and H.

Physa sp.

Planorbis sp. Related to *Planorbis convolutus* M. and H.

Linnaea sp.

For convenience this group of Tertiary beds may be called the Kishenehn formation, the name being taken from that of the neighboring creek. * * *

At the Boundary line the dip is 18° to the eastward. Farther north the attitude is fairly constant in all the exposures, with strike north and south and dip, 40–45° east. The formation has evidently been disturbed by a strong orogenic force. The date of this particular phase of mountain-building cannot yet be fixed with certainty. It is pre-Glacial and post-Laramie. With some probability it may be referred to a mid-Tertiary stage, during which, according to Willis and Peale, crustal deformation took place in Montana.

It would be a matter of considerable interest to know the nature of the terrain underlying the lake beds. The fact that the drill at the Kintla Creek oil-prospect struck continuous limestone at the depth of 1,290 feet suggests either that the lake beds lie directly on the Carboniferous or pre-Cambrian, or else, that only a very small thickness of Mesozoic strata (presumably Cretaceous) intervene between the lake beds and the pre-Mesozoic formations beneath the floor of the valley.

These beds were also described by Dawson (1886, p. 52) in 1885 and by Willis (1902) in 1901. Willis states that "they may be of Miocene or Pliocene age, as are beds near Missoula, which they resemble."

Near the mouth of Kintla Creek, the creek bank and cuts on the road to Kintla Lake expose northeast-dipping deposits of probable Tertiary age consisting of ashen-gray to greenish-gray, sandy clay streaked with dark red and stratified gravel cemented to conglomerate.

The bluff at the river bend encircling Round Prairie (NW¼ sec. 30, T. 36 N., R. 21 W.) exposes Tertiary beds dipping N. 50° E., at 19°. These stratified deposits consist of gray sandy clay and gray sandstone with interbedded thin layers of lignite. There are other exposures in the east bluff about 2 miles farther downstream. Tertiary sandstone and sandy clay are also exposed in the cut about 1½ miles west of Polebridge, where the road extends downward to the broad lower terrace. South of Polebridge ranger station near the mouth of Bowman Creek the road cut in the east bluff of the river exposes similar northeast-dipping beds under 15 ft of coarse gravel and boulders. About a mile farther south the following section is exposed:

Section, 1 mile south of Polebridge

	Feet
Till, gray, stony clay	50–65
Gravel, coarse, waterworn, stratified	20–25
Clay, Tertiary in age, buff-gray and semi-indurated, having a northerly dip	12–15
Total, about	100

Bluish-gray Tertiary sandstone and shale are also exposed on Bowman Creek, about a mile above its mouth. The beds here have a dip of about 25° northeastward and are overlain by a deposit of boulders. About a mile farther east a landslide scarp, 300 to 400 ft above the creek has exposed the same friable grayish sandy clay shale (Tertiary?), with a northeasterly dip of 20° to 25°, thinly overlain by glacial drift. Another scarp about half a mile farther northeast on the same slope exposed 100 ft of the same shaly beds with a dip of 10° to the northeast. In the upper part of the scarp is a 1-ft bed of impure lignite.

About half a mile southeast of Quartz Creek, Tertiary beds are exposed at the bottom of the 60- to 70-ft east bluff of the river (NW½ sec. 18, T. 34 N., R. 20 W.). The following is the section exposed:

Bluff section near Quartz Creek

	Feet
Till, gray, pebbly clay	15–20
Gravel, coarse	10±
Gravel, fine, with interbedded sand layers, partly cemented near bottom	50
Unconformity.	
Clay, fine, gray, sandy, or friable sandstone. Tertiary (Miocene?) with dip of 15° to 30° toward the northeast	15–20

One thin layer of lignite is interbedded, and in one layer fossil leaves were found. Some of these fossil leaves were identified by E. W. Berry as probably *Betula* cf. *heterimorpha*, Knowlton, of Miocene age.

Two to three miles farther south there is a large remnant of a piedmont terrace at the mouth of the gap in the mountains traversed by Coal Creek. This terrace is bisected by a narrow gorge which Coal Creek has cut through the capping drift and gravel into underlying southeast-dipping Tertiary deposits known as the Coal Banks.

The following section was exposed in 1913:

Section on Coal Creek

	Feet
Pleistocene:	
Clay, gray, partly cemented	45 ±
Drift, coarse, bouldery, with slight appearance of bedding, partly cemented	45 ±
Tertiary sediments, tilted, (Miocene?):	
Sand, gray, and semi-indurated, gray, sandy clay	45 ±
Clay, brownish-gray, hard semi-indurated	1–2
Sandstone, gray, friable.	

The coal was not exposed at the time of the writer's visits.

Poorly preserved fragments of *Sequoia equisetum* and other plants found by J. D. Northrop in 1932 in deposits beside the river south of the Coal Banks (sec. 33, T. 34 N., R. 20 W.) were regarded by Roland W. Brown (written communication) as possibly of early Tertiary age. Fresh-water shells found by Northrop at the same place were regarded by W. C. Mansfield (written communication) as "more closely related to an Eocene species than to any known species in the Cretaceous."

E. M. Parks (unpublished notes) found 50 ft of grayish-green friable sandstone exposed in the south bank of Quartz Creek less than a quarter of a mile below the east-side road. The sandstone dips 18° NE. One bed was sufficiently indurated to make a 3-ft waterfall. Above the beveled edges of the sandstone was about 50 ft of reddish-gray till.

About 2½ miles above the point where the road crosses Dutch Creek, M. R. Campbell and the writer examined a 50- to 60-ft bank which exposed semi-indurated and jointed, massive, chocolate-red clay with two interbedded layers of gravel 2 to 3 ft thick dipping 25° toward the northeast; the whole was overlain by gravelly material. Half a mile farther up the creek the bank exposes laminated whitish-gray clay and opposite this and below 5 ft of coarse bouldery gravel is dense, compact, pebbly, gray clay, the upper inch or two of which is oxidized and brownish in color. The clay contains fragments of lignite.

About half a mile above the mouth of Dutch Creek, 5 ft of stream gravel unconformably overlies the beveled edges of Tertiary beds that dip about 35° NE. The Tertiary beds consist of alternating beds, 5 to 10 ft thick, of conglomerate and of semi-indurated, red, yellow, greenish, and gray clays. The uppermost exposed bed of clay is about 40 ft thick. The clays are rather sandy and the colors are in blotches and streaks. Dutch and Camas Creeks here flow in narrow valleys cut about 100 ft below a nearly flat, drift-covered bench or terrace, northeast of Huckleberry Mountain.

About a quarter of a mile east of the bridge on Anaconda Creek and 150 ft above the stream there was, in 1936, a small exposure of buff clay overlying brownish semi-indurated clay which may be of Tertiary age. About 2 miles above the bridge the bank of Anaconda Creek exposed the following:

Section on Anaconda Creek

F. Till, grayish
E. Sand and sandy clay, pebbleless
D. Gravel, reddish
C. Clay, pebbly, reddish
B. Clay, massive, chocolate-red, greenish, and purplish streaked
A. Gravel, coarse

The upper till (*F*) is of Wisconsin age, and the lower pebbly clay (*C*) is possibly pre-Wisconsin till, although no striated pebbles were observed in it. The lower beds (*A* and *B*) are probably Tertiary. They have a dip of 24° toward the northeast. In 1913 E. M. Parks and C. S. Corbett examined exposures lower on Anaconda Creek. About a third of a mile south of the road, they observed partly consolidated Tertiary beds composed of yellowish fine sand, greenish-gray clay and sandy clay, and fine gray sand beneath 5 ft of sandy till, in a 60-ft bluff. These beds appear to dip N. 5° W., at about 27°.

At places north of Coram in the sides of the narrow 100-ft inner gorge of the Flathead River below the railroad grade, reddish to salmon-colored clay with some conglomerate is exposed. It seems probable that these deposits below the drift are of Tertiary age, especially inasmuch as the presence of "coal" at the bend of the river in sec. 19, T. 31 N., R. 19 W., has been reported (written communication by R. E. Dumblazer, 1937). With these deposits is perhaps to be correlated some dense, light-colored clay exposed in the river bed less than a mile northeast of the junction of the Middle Fork and the Flathead River below the silt-covered gravelly terrace on which is the North Fork ranger station. In the bare 200-ft bluff on the south side of the Middle Fork at this place about 100 ft or so of gray pebbly till is exposed. There is a similar exposure of till overlying gravel in a river bluff half a mile to the south. Downstream from this bluff, are the highly colored deposits supposed to be of Tertiary age. These deposits are similar to some of the Tertiary deposits exposed much farther upstream on the upper Flathead River, on the Middle Fork, and on the South Fork.

FLATHEAD LAKE BASIN AND THE ROCKY MOUNTAIN TRENCH

One of the most conspicuous of the intermontane valleys, called the Rocky Mountain Trench by R. A. Daly (1912, p. 26), extends southward from Canada into Montana between the Whitefish Range and Salish Mountains (figs. 1, 14). Continuous southward with this trench is the Flathead Lake basin ranging from 5 to 20 miles in width. At the east side of this basin are the steep western flanks of the Mission Range and the north end of the Swan Range; on the west is the less rugged southern part of the Salish Mountains. For these mountains Clapp (1932, p. 14, pl. 1) used the name "Selish Range" because of the use of the name Flathead Range for the mountains between the South and Middle Forks of the Flathead River. East of Columbia Falls the Flathead River enters this basin through the constricted Bad Rock Canyon at the north end of the Swan Range below Coram and then flows south past Kalispell. For 27 miles Flathead Lake, one of the largest freshwater lakes in the United States, occupies almost the full width of the middle part of this broad basin west of the Swan and Mission Ranges. From the outlet at Polson, at the southwestern extremity of the lake, the river continues in a general southerly course through the western part of the valley, leaving it by a gap in the hills north of Dixon. Thence the river flows westward to join the Clark Fork near Paradise. For 40 miles north of Kalispell the Rocky Mountain Trench is traversed by the southeastward-flowing Stillwater River. From a width of 3 miles at the low divide near Dickey Lake this trench, here drained northwestward by Tobacco River, broadens to a width of about 10 miles where it merges with the valley of the Kootenai River between Eureka and the international boundary. For 80 miles north of the boundary the Kootenay River flows southeastward in the great Rocky Mountain Trench, here bordered on the west by the Purcell Mountains, and farther north the Trench is followed by the headwaters of the Columbia River, there flowing northward. The abrupt eastern wall of this trench in Montana is probably, in most places, a fault-line scarp.

There are several small low rocky islands and peninsulas rising above the surface of Flathead Lake and, south of the lake, several similar low buttes and ridges of east-dipping Belt rocks rise above the gently undulating surface of the surrounding glacial and glaciolacustrine deposits.

From the rocky hills south and west of Whitefish Lake northwestward to the vicinity of Eureka, the floor of the great trench is more uneven, being marked by many low smoothly glaciated hills and ridges of northeast-dipping rocks of the Belt series, largely maroon-colored argillite and quartzite, and some limestone.

The relation of the fossiliferous Devonian limestone, 5 to 6 miles east of the Kootenai River at Gateway, to the Belt rocks near the international boundary, as Daly (1912, p. 118 and map sheet no. 3) indicates, "shows that the net relative displacement * * * has been at least 10,000 feet and may be several thousand feet greater. We are therefore prepared to find that the Rocky Mountain Trench at the Forty-ninth Parallel has been located on a zone of strong faulting."

It seems probable that much of that part of the Rocky Mountain Trench south of the Canadian boundary and including the Flathead basin may contain Tertiary fluvial or lacustrine deposits, but very few exposures of such beds beneath the Pleistocene glacial and associated deposits have been seen by the writer.

In cuts of the Great Northern Railway south of Olney siding, thinly laminated gray to buff silt with a northerly dip is exposed below the glacial drift. Just south of the viaduct this silt contains fossil leaves and coniferous needles, possibly of Tertiary age. Other railroad cuts 4 to 5 miles southeast of Olney expose rusty oxidized gravel and semi-indurated silt and sand, possibly of Tertiary or early Pleistocene age, below fresher looking, light-buff, glacial till. In places the semiconsolidated older material withstands rain wash so well that it projects as buttresses below the fresher overlying glacial drift. These cuts, 100 ft or more above the river, are at the west edge of what appears to be an undulating forested bench 3 or 4 miles in width north and northwest of the head of Whitefish Lake. No Tertiary rocks are known to be exposed thence southward to the foot of Flathead Lake. Numerous soundings in the main body of the lake, as reported by Clapp (1929, p. 5, map), show depths ranging from less than 100 ft to 329 ft. A well drilled on the ridge 4 or 5 miles southwest of Polson at a point about 400 ft above the lake is reported not to have penetrated hard rock of the Belt(?) series until a depth of more than 1,200 ft was reached, although such rock is exposed at nearby points in the hills and in the river gorge. Much, perhaps half, of the overlying 1,200 ft of material is probably glacial drift and associated Pleistocene deposits. Between these deposits and the hard Belt(?) rock are 600 ft or more of clay, sand, gravel, and sandstone beds, which resemble those exposed on the Flathead River in the Glacier Park region and may be of Tertiary age. These deposits may lie between blocks of the Belt series which are faulted and tilted, like those at the nearby exposures.

Three to four miles below the Polson dam site the river has cut its narrow gorge into upturned rock dipping N. 35° E., in and near sec. 15, T. 22 N., R. 21 W. The lower part of the exposed rock is gray and rather thick-bedded; above is thinner bedded, friable sandstone grading upward into a fragmental deposit weathered buff to orange, suggesting that this fragmental deposit may perhaps be of Tertiary age. Slumping and overgrowth obscure the unconsolidated beds, which are stratified in part. The upper cliff and pinnacles are composed of about 125 ft of glacial till.

Beds that are probably Tertiary in age are exposed about 20 miles farther south, in the cut on a branch of the Northern Pacific Railway half a mile southwest of Moiese station. Somewhat similar material is exposed in the creek bank just north of this railroad cut.

Section near Moiese, Mont.

Pleistocene: Clay of Lake Missoula, laminated; unconformably overlying eroded edges of the following northeast-dipping beds.

Tertiary(?):
5. Gravel, rusty.
4. Sand, rusty.
3. Clay, or volcanic ash, whitish.
2. Lignite, 3 to 6 inches.
1. Clay, grayish to white.

Meager as is the evidence cited above, the presence of these probable Tertiary beds is in itself some indication of the similarity of conditions of pre-Pleistocene sedimentation, faulting, and erosion in the Rocky Mountain Trench, the valleys of the Flathead River and its Middle Fork and South Fork, the Bitterroot, and other valleys now drained by the Clark Fork and its tributaries.

South of Mission Creek, which joins the Flathead River near Moiese, a transverse range composed of the hills of the National Bison Range and the Ravalli Hills separates the Flathead basin from the much smaller basin through which the Jocko River flows northwestward past Arlee to join the Flathead. Midway between Arlee and Ravalli, 20 to 30 ft of semi-indurated buff clay is exposed in a low bluff beside the highway (U S 93) and the Northern Pacific Railway. This material is different from the overlying Pleistocene silt of glacial Lake Missoula and is probably of Tertiary age. Near the Shoemaker ranch, on the opposite side of the river about a mile farther west, the following Tertiary(?) deposits are exposed underlying glacial drift: gravel, rusty and cemented, and interbedded clay and gravel, 5 to 20 ft; sandstone, gray, friable, and compact sand with thin seams and pockets of lignite, a few feet; clay, rusty, massive, and jointed, only slightly exposed at base of the bluff.

These deposits are bent or thrust up in a sharp fold in the northwestern part of the exposure, possibly as the result of push by the glacier which deposited the overlying glacial drift. Buff to reddish, partly cemented gravel (Tertiary?) is also exposed below silt of glacial Lake Missoula in places a mile or so south of the Shoemaker ranch buildings.

TERTIARY(?) DEPOSITS NEAR SAINT REGIS, MONTANA

Railroad and highway cuts in the faces of the river bluffs 1 to 3 miles southeast of the Clark Fork bridge at Saint Regis expose a peculiar deposit, whose age and mode of origin are not well understood by the writer. The deposit, in part at least, may be of Pleistocene age, or it may be of Tertiary age or older. At the southeast ends of the cuts below the highway (U S 10) a reddish mass of unsorted and unstratified material consists of boulders and fragments of rock embedded indiscriminately in finer material. This material has a general till-like aspect, but no striated stones were observed. It may be a torrential deposit. At one place, about 15 ft above the track of the Chicago, Milwaukee, St. Paul & Pacific Railroad, there is an included bed of dark-red sandstone, with a low downstream dip, and a little lower is a thin bed of hard red clay. At one point the red material is overlapped by gray terrace gravel. Farther northwest the red, bouldery material overlies fractured Belt rocks. Many of the reddish and greenish boulders here are so smoothly waterworn and polished that they glisten in sunlight, with metallic luster. At one place an included 6-in. bed of hard, indurated clay is either carbonaceous or manganiferous. Just north of the mouth of Cold Creek the material is colored orange-red, with more clay and fewer included boulders, but many rock fragments. At one point this orange-red material is underlain by loose, fine, cross-bedded sand, and the terrace top above is mantled with fine, sandy silt. There are exposures of similar reddish deposits containing highly polished boulders in cuts on the Northern Pacific Railway on the opposite side of the river near the mouth of Cold Creek.

Railroad cuts 1 to 2 miles west of Saint Regis, near the mouth of Little Joe Creek, also expose certain deposits which may possibly be of Tertiary age. The first cut west of the wagon bridge shows, beneath an upper clay (or silt of glacial Lake Missoula), east-dipping layers of thin, shaly, friable sandstone overlying a mass of smooth, well-rounded cobbles and boulders, many of which are polished and show a metallic luster like those in the cuts southeast of Saint Regis. A railroad cut east of Little Joe Creek shows nearly 100 ft of similar cobbles and boulders, poorly sorted but distinctly bedded and dipping eastward at an angle of 25°. Many of these cobbles and 1- to 3-ft boulders have polished surfaces with high metallic luster. Parts of the deposit are cemented to conglomerate. Some of the stones are sliced as though fractured under pressure and, at the west end of the cut, there is a mass of breccia. As stated above, it is possible that these deposits are of Tertiary age. The cuts are at the ends of benched spurs of the mountain slope which are like remnants of an old valley fill.

LITTLE BITTERROOT VALLEY AND CAMAS PRAIRIE BASIN

On Irving Creek in the broad basin of White Clay Creek, about 15 miles west of Polson (NE¼ sec. 32, T. 23 N., R. 22 W.), there are exposures of yellow, orange, and brownish pebbly clay, and of badly weathered gravel which may perhaps be of Tertiary age.

It is reported (oral communication by a well driller) that some wells south of Niarada in the Little Bitterroot Valley did not reach hard bedrock in depths of 285 to 485 ft. To what depths the Pleistocene deposits extend or whether or not they are underlain by Tertiary deposits is not certainly known. John C. McCoy, Principal of Schools at Lonepine, Mont., stated (oral communication) that a well drilled in search of oil in the SW¼ sec. 24, T. 23 N., R. 24 W., near his place northeast of Lonepine, reached the first hard rock at a depth of about 1,200 ft and ended in "hard limestone" at 1,485 ft. It is possible that some of the 1,200 ft of unconsolidated or poorly consolidated deposits penetrated by this deep well above the "hard rock", like those penetrated by the deep well southwest of Polson, may be Tertiary "lake beds". Mr. McCoy also stated that a nearby well in the SE¼ sec. 25 was drilled into "soft sandstone" between depths of 87 and 123 ft.

Near Niarada and extending thence northward along the hills between the Little Bitterroot River and the valley of Sullivan Creek, there are deposits of intrusive and extrusive volcanic rocks—latite, andesite, and trachyte with some interbedded conglomerate composed largely of quartzite pebbles. In their description of this district, in which the Flathead mine is located, Shenon and Taylor (1936, pp. 6, 8, and 15) make the following statements:

> Light-colored volcanic rocks were extruded in some parts of the Flathead Mountains probably during and after the deposition of the Tertiary lake beds and must have interfered with the local drainage, as they completely fill some of the valleys. Conglomerates interbedded with the volcanic tuffs have been noted in several places. They are exposed along the road just north of the old Flathead Indian Reservation boundary in T. 25 N., R. 23 W., and Alden has recorded an occurrence of interbedded conglomerate in T. 24 N., R. 24 W., just south of the old reservation [line].
>
> * * * * *
>
> The finer-grained porphyritic andesites show marked flow structure; the coarser-grained porphyritic andesite does not exhibit more than a suggestion of flow banding, but pieces of carbonized wood found in it prove it to be an extrusive rock.
>
> * * * * *
>
> The age of the deposits [at the two mines] is not definitely known, but because the enclosing rocks are believed to be correlative with similar rocks in other parts of northwestern Montana, the deposits are tentatively assigned to the later Tertiary.

Both deposits are believed to have been formed at a shallow depth.

Farther up the valley at a point about 4 miles south of Little Bitterroot Lake yellowish, friable sandstone, possibly of Tertiary age, was seen in a small exposure under laminated gray silt of glacial Lake Missoula.

In the broad basin of Camas Creek (called Camas Prairie Basin), north of Perma, Tertiary sediments are not known to be present beneath the Pleistocene deposits. Considerable thicknesses of soft friable Tertiary sediments, such as the so-called "lake beds", however, may have been removed by preglacial stream erosion from this basin and also from the valleys of the Little Bitterroot River and White Clay Creek and from the Rocky Mountain Trench.

TERTIARY(?) DEPOSITS NEAR PLAINS, MONTANA

From a narrow steep-sided gorge between Saint Regis and the vicinity of Paradise, the valley of the Clark Fork broadens near Plains to a basin several miles wide, which is drained in part by Lynch Creek. Through this basin the river meanders between broad alluvial and glaciolacustrine terraces. At the river bend, 4 to 5 miles northwest of Plains, excavation (in 1937–38) for the new grade of State Route No. 3, exposes deposits which at one time were thought possibly to be correlated with the Tertiary "lake beds" and the Latah formation (Miocene) of northern Idaho and eastern Washington. At the southeast end of the cut were beds of closely-jointed, fine, gray, micaceous sandstone, in places greenish-gray with brown-stained joint faces. The beds change from nearly horizontal to a northerly dip increasing in a short distance to 67°. This rock disintegrates, or grades westward into ashen-gray to white siliceous, sandy clay, which is so slippery where wet by seeping water as to have caused serious landsliding. This material extends westward beyond the ranch house where the old road descends the bluff. In places the color is mottled reddish and gray and above the old road this clay is overlain by coarse gravel capping a broad, farmed bench which extends northward and westward to higher mountain slopes. It may be noted that this gravel-capped bench is higher than the broad sandy terrace south of the river and is not as high as the Boyer Creek bench north of Plains. The contact between the tilted Belt rocks to the west and the soft, gray, sandy clay was not well exposed. The ashen-white color of the sandy clay has suggested the presence of volcanic ash; however, C. S. Ross,[5] who examined a sample of the white material reports it to be composed of "quartz and sericite with no indication of ash". Pardee is of the opinion that the whitish sandy clay exposed in the above cut between Plains and Weeksville is not of Tertiary age but is a product of hydrothermal alteration of Belt rocks in place here. It is, therefore, not certain that Tertiary "lake beds" were deposited in this rather broad intermontane basin between Plains and Weeksville. It is possible that the width of the basin between Plains and Weeksville is due, in part at least, to the presence of easily erosible deposits in the Belt rocks rather than to the presence of Tertiary "lake beds" in a fault basin. It is also quite possible that, before Pliocene or early Pleistocene time, the bottom of the Clark Fork valley in the narrow gorge above the mouth of the Thompson River was not cut down much if at all below horizons that now have altitudes of 3,000 or 3,500 ft.

[5] Personal communication. Ross also made a similar analysis of a sample from the Tertiary "lake beds" near Salmon, Idaho, and a sample of similar whitish material from the Tertiary "lake beds" northwest of Missoula, near De Smet, Mont. Both contained "quartz, feldspar, micas, and augite with very fine-grained interstitial sericite" but no volcanic ash.

LOWER VALLEY OF THE CLARK FORK

It is not known to what depth the valley of the Clark Fork in western Montana had been eroded prior to the outpouring of the Columbia River basalt in eastern Washington and Idaho. As the lava blocked the westward flow of the rivers, sedimentation in the ponded waters laid down the fossiliferous beds of the Latah formation that are as much as 1,500 ft thick and partly well-exposed in the region of Spokane, Wash., and near Coeur d'Alene Lake, Idaho. These deposits are regarded by Berry (1929, pp. 234–235) as not older than middle Miocene and as probably of upper Miocene age. The present altitude of the rim of the basalt overlying the Latah formation is approximately 2,500 ft above the sea. If the relative altitudes in eastern Washington and western Montana were about the same as at present, slack water would have extended up the valley of Clark Fork to the vicinity of Thompson Falls, or even Plains, Mont. Alluvial deposits might be built up to considerably higher levels by incoming tributary streams and later dislocated by faulting. The northeasternmost remnants of this basalt rim are 8 to 10 miles southwest of, and 500 to 600 ft higher than, the southern end of Pend Oreille Lake, Idaho, and at altitudes of 2,500 to about 2,600 ft above sea level.

Although there are no data at hand showing definitely the presence of Tertiary deposits farther west than Dixon, Mont., beneath the Pleistocene deposits in the lower valley of Clark Fork, it seems not improbable that such deposits did accumulate there, at least while the valley of the Columbia River and its tributaries were blocked by basalt in northern Idaho and eastern Washington. The great depth of Pend Orielle Lake basin possibly may be due, in part to the presence of a great thickness of loose, easily erosible Tertiary deposits at that place.

Sampson (1928, p. 12) states that:

> The position and size of this valley may be related to the profound faulting believed to have taken place along it, but the

author believes that its present form is largely the result of glaciation. Soundings by the author indicate that the floor of the lake is nearly flat and about 1,100 feet below present water level at the deepest place found, between Granite Point and Talache. These soundings and the visible topography show that the valley has the U-shape typical of those carved by glaciers.

In the vicinity of Cabinet, Idaho, near the Montana-Idaho State line the Clark Fork now flows in a small inner gorge cut into the Belt rocks below the glacial drift, but there may be a deeper and wider preglacial gorge buried beneath the glacial drift a short distance farther south. There are numerous small rock hills projecting above the Pleistocene valley fill at different places on the Clark Fork, both below and above Plains. These hills, suggest that this part of the valley has developed along a zone of faulting and may have been occupied by a stream in Miocene time. If so, whatever Miocene sediments were deposited therein have since been very largely, if not wholly, removed by erosion. The same may be true of parts of the valley of the Kootenai River in northwestern Montana and northern Idaho. So far as is known to the writer, no definite evidence of the presence of either Oligocene or Miocene deposits in these northern troughs has been found. South of lattitude 47°, Oligocene fossils were found by Douglass and others in beds that are definitely stated to underlie those containing Miocene fossil remains.

PLIOCENE(?) AND EARLY PLEISTOCENE EPOCHS

UPPER MISSOURI RIVER BASIN

FEATURES NORTH AND SOUTH OF THREE FORKS

As has been described in Professional Paper 174, the highest of the gravel-capped benches near the Rocky Mountain front in the Great Falls region appear to be correlatives of the gravelly "Flaxville plain" of northeastern Montana, the development of which is regarded as having been completed in Pliocene time. Although well represented by erosion remnants, those remnants in Cascade and Lewis and Clark Counties are of relatively small extent and are separated by wide stretches of country that were cut down to lower levels in Pleistocene time.

There is one such remnant in one of the intermontane basins in the southern part of Lewis and Clark County in the angle between Canyon Creek and Little Prickly Pear Creek, about 25 miles northwest of Helena (pl. 3 *A*). The flat top of this remnant or butte, which is locally known as the Gravelly Range (T. 12 N., R. 6 W.), slopes eastward from an altitude of about 5,500 ft above sea level at the west end to 4,900 ft at the eroded east margin, and is 500 to 1,000 ft above the nearby creeks. This butte is capped with about 100 ft of coarse gravel in which many fairly well rounded boulders 3 to 6 ft in diameter are imbedded. The smooth top is 1,400 to 2,000 ft higher than the Missouri River at the Gates of the Mountains, 12 to 16 miles to the east. It appears to be older than any of the well-preserved gravelly bench remnants described by Pardee as bordering the Missouri and its tributaries in the Townsend Valley, in Broadwater County, southeast of Helena, Mont.

About 20 miles southeast of Helena, Beaver Creek emerges from the Elkhorn Mountains at about 4,750 ft above sea level and flows northeast across a great smooth alluvial fan composed of coarse gravel. Near the canyon mouth, 2 to 3 miles southwest of Winston, Beaver Creek is bordered on the south by benched rocky spurs of the mountain slope and on the north by a steep bluff that rises to a corresponding height (about 400 ft) to a foothill tract, which appears to be a dissected remnant of an old, high-level bench about 5,300 ft above sea level. In the face of the bluff there are exposures of andesite; the hilltops above are strewn with cobbles and boulders. The relations suggest that these bouldery hilltops are remnants of an old, high-level alluvial fan or piedmont bench (Pliocene or early Pleistocene) that extended from the canyon mouth northeastward down to the benched top of the hill east of Winston, which also is strewn with 1- to 3-ft boulders. Such a bench here would correspond to the high bouldery bench remnant at about the same altitude on Little Prickly Pear Creek 25 miles northwest of Helena, which also may be of late Tertiary or early Pleistocene age. The stones seen on the bench above Beaver Creek range from cobbles to boulders 5 to 8 ft in diameter and are mostly of andesite though some are of basalt and a few are of argillite. They are not residual but have been transported, and many are waterworn. There may have been small glaciers at the heads of the valley in the Elkhorn Mountains, but none of the boulders, so far as noted, show glacial striae. In Pliocene or early Pleistocene time, Beaver Creek may have flowed northeastward across this hilltop bench and the bench east of Winston before the present lower valley of the creek was formed. At a later stage, as Beaver Creek cut down, it may have swung from east to southeast and spread part of the fan gravels. Later the creek was diverted northeastward across the big gravel fan and was joined by the waters of Staubach and Antelope Creeks in its present lower valley.

It was probably when flowing on the Pliocene or Pleistocene valley bottom at a level that is now about 5,000 ft above the sea, or 1,000 to 1,200 ft above its present channel, that the Missouri River established its winding course across the faulted and upturned Mesozoic, Paleozoic, and pre-Cambrian rocks north of Lombard (T. 4 N., Rs. 2 and 3 E.), instead of locating itself on the softer Tertiary deposits, whose surface was then higher to the east or west.

Among the most significant and best preserved remnants of what is regarded as a Pliocene or Pleistocene terrace in the upper Missouri River basin are those which border the sides of the lower Madison Valley north of the mouths of Elk Creek and Cherry Creek in adjacent parts of Gallatin and Madison Counties (in Tps. 1 and 2 S., Rs. 1 and 2 E.), 8 to 18 miles south of Three Forks and Logan. The head of this terrace remnant, which is about 8 miles northeast of Norris, is now about 1,100 ft above the river 2 miles away (pl. 3, *B*).

Above the east-facing upper cliff of Tertiary sandstone is about 100 ft of coarse gravel capping the flat terrace. This gravel consists of smoothly waterworn, varicolored, discoidal cobblestones 1 to 12 in. in maximum diameter. They are mostly composed of quartzite and many show percussion marks. The smooth, flat terrace top slopes northward at an average rate of about 50 ft per mile. Four or five hundred feet below its eroded eastern edge is a younger set of terrace remnants, and still lower and only 15 to 20 ft above the river is the lowest, or late Pleistocene terrace. It seems probable that the quartzite gravel was deposited on the eroded surface of the underlying Tertiary (Bozeman) "lake beds" by the Madison River in late Pliocene or early Pleistocene time. The stream may then have flowed between the small buttes of rhyolite and basalt that rise above the head of the terrace to the south and southwest, or it may have flowed just east of the rhyolite butte along or near the line of the "lower" Madison Canyon Ten miles farther north this terrace is 800 ft or more above the river. Farther west the high terrace has been cut away by tributaries of Willow Creek. The smooth plateau north of Elk Creek on the east side of the river (where examined by the writer west of the Anceney branch of the Northern Pacific Railway) is a remnant of the same high terrace, here 700 to 800 ft above the river, and it is similarly capped with coarse, quartzite, cobblestone gravel overlying light-colored sandstone (Bozeman "lake beds"). From the western edge of this gravel cap there is an unobstructed view southwestward across the head of the high terrace west of the river to the top of the Table Mountain bench near Ward Peak west of McAllister.

Projection of the eastern terrace remnant southward at a gradually increasing gradient leads to the smoothly worn upper slopes of the north foothills of the Madison Range east and west of Cherry Creek basin, about 6,000 ft above sea level. So, also, projection of a nearly smooth, similar gradient southward and southwestward from the head of the western terrace remnant clears all but the highest parts of the hilltops north and south of Hot Springs Creek, above and below Norris, and connects with a conspicuous high, benched top of a spur of the Tobacco Root Mountains, near Ward Peak on the headwaters of North Meadow Creek west of McAllister. Thus a Pliocene or Pleistocene piedmont terrace, or an alluvial gravel fan formed by North Meadow Creek, may have been continuous northeastward from the high boulder-strewn bench locally known as Table Mountain, near Ward Peak, to the high terrace near the mouth of Cherry Creek. Such a terrace would also slope smoothly eastward across the beveled edges of the tilted Bozeman "lake beds" to the Pliocene bottom land along the Madison River, and on this bottom land the river would flow freely across the then buried ridge of rock of Archean type that now separates the upper and lower broad sections of the Madison River valley (pl. 3 *B*). A similar but steep gradient projected southwestward along the line of the valley of Willow Creek would head at a smooth high, boulder-strewn bench about 8,000 ft above sea level on the granite, 3 to 4 miles south of the village of Pony and 2,000 ft or more above the present nearby channels of North and South Willow Creeks. It requires no stretch of the imagination to picture a Pliocene or early Pleistocene landscape, with Madison River flowing near the line of its present gorge north of McAllister but on an alluvial plain 1,100 to over 1,600 ft higher than its present channel. The physiographic and topographic relations of the gravel that floors these high terrace remnants leave little reason for doubt in the mind of the writer that it corresponds to the high-terrace gravel east of the mountains, which has been correlated with the Flaxville gravel of northeastern Montana. The gravel here on Madison River overlies the beveled edges of the gently tilted Bozeman "lake beds" of Oligocene and Miocene age.

For 12 miles north of Ennis Lake the river flows in a narrow gorge that it has cut to a maximum depth of 1,600 ft or more in gneiss and schist of Archean type. This rock composes a broad transverse ridge, which separates the lower river valley from the main broad valley of the river in Madison County. The ridge is a northwestward, but lower, continuation of the Gallatin Range. So narrow is the gorge that State Route 1 bypasses it and crosses the hills between Norris and McAllister. For 4 or 5 miles north of the mouth of Cherry Creek the uneven surface of the gneiss and schist slopes northward from the north foothills of the Madison Range until it passes below the present river level; overlying this sloping surface and exposed in the high bluff west of the river are the Bozeman "lake beds" of Oligocene and Miocene age noted above.

For 20 miles or more south of Ennis Lake, all remnants of a Pliocene(?) piedmont and correlated river terraces appear to have been cut away by erosion. There may perhaps be some remnants on the west side of the valley.

Bordering the South Fork of Indian Creek for a mile or more below its canyon mouth, southeast of Cameron, there is a narrow-crested spur whose top joins the higher mountain front about 7,400 ft or more above sea level and slopes thence northward to an abrupt end 600 to 800 ft above Indian Creek (T. 8 S., R. 1 E).

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The spur is partly mantled with glacial drift, but its size and position suggest that it may be primarily an erosion remnant of a high-level, piedmont terrace of Pliocene or early Pleistocene age (pl. 3*C*). Below this spur, on the east side of the river is the remarkably well preserved second terrace. It extends 8 to 10 miles farther south to Wolf Creek, beyond which (in T. 10 S., R. 1 E.) a long, smooth slope rises southward somewhat more steeply to a gently rolling upland or bench between the lower gorges of Moose and Squaw Creeks. The bench is underlain by Tertiary lava. Barometric readings show the bench to be 800 to 1,000 ft above the river. The gently undulating surface extends southward nearly 6 miles farther, cut only by the lower gorges of Squaw and Papoose Creeks. These streams and their tributaries have cut down the piedmont to the east, so that there is now somewhat lower ground between the high bench and the foot of the mountains. It seems probable that this undulating bench is an erosional surface of late Pliocene or early Pleistocene age. Scattered over its surface, east of the river, are boulders of granite and gneiss as much as 6 ft in diameter; a few boulders 10 to 15 ft in diameter were seen. Some of the boulders have been carried down the steep bluff to the river side by slumping on underlying friable Tertiary sedimentary beds. Smoothly rounded cobblestones of quartzite showing percussion marks are abundant on the bluff face and landslides below the lava rim. There are but few on the higher part of the upland, suggesting that they may be from a bed of Tertiary conglomerate below the lava. One to two miles directly east of the boulder-strewn upland are the great terminal moraines at the canyon mouths of Moose, Squaw, and Papoose Creeks. The nearness of the moraines suggests that the boulders may be remnants of a deposit of drift carried out by glaciers that occupied canyons in the Madison Range in early Pleistocene time before the present inner valley, which here is 800 to 1,000 ft deep, was eroded. Similar boulders of gneiss, some 10 to 15 ft in diameter, together with big blocks of rhyolite which now lie on one of the lower terraces on the southwest side of the river about 3 miles south of Hutchins bridge, may have been let down from higher levels by erosion or sliding.

From the south side of the canyon mouth of Papoose Creek (T. 11 S., R. 2 E.) a high narrow ridge or spur projects diagonally across the direct line of the canyon (pl. 3*C* and fig. 4). The top of this ridge is 7,400 to about 7,500 ft above sea level, and it is about 500 to 600 ft above the depression in the piedmont bench immediately to the west. Evidently the last glacier to extend out of the canyon mouth was diverted north of west by this spur instead of advancing directly out to the south of west. It is possible that this high spur also, like that at Indian Creek, is a remnant of the Pliocene or early Pleistocene piedmont terrace and is to be correlated with the boulder-strewn bench underlain by lava that forms the east river bluff. The high spur near Papoose Creek is transected by the Recent fault that borders the Madison Range. Farther south the lower and later (early Pleistocene?) smooth-sloping piedmont terrace is developed on the bluff, 500 to 600 ft above the river.

FIGURE 4.—Drift-covered, benched spur on Papoose Creek. An erosion remnant of an old piedmont terrace (Pliocene? or early Pleistocene) as seen from the broad terrace of early to middle pleistocene age. In the gap between the spur and the mountain front at right are moraines of Papoose Creek glacier (Wisconsin stage) crossed by the scarp of a Recent fault. The benched top of the spur is more than 1,000 ft above the Madison River, about 2 miles away.

It will be noted that the several features, which are regarded as erosion remnants of the Pliocene or early Pleistocene piedmont and river terraces, are high above the present stream channels, of relatively small extent, and of widely scattered distribution along the valleys of the Missouri and Madison Rivers. They are, therefore, of considerable age; yet, they are 1,000 to 2,000 ft or more below the nearest mountain tops, one of which, Sphinx Mountain, is capped with a thick deposit of conglomerate of supposed Eocene age. These terraces in place lie on the beveled edges of the faulted and tilted Bozeman "lake beds" of Oligocene and Miocene age. On some of them are what may be very early Pleistocene glacial deposits. It therefore seems reasonable to regard them tentatively as of Pliocene and early Pleistocene age.

It is possible that some of the basalt that caps the ridge east of Virginia City for 13 miles from north to south, flowed out on part of the Pliocene or early Pleistocene erosion surface. Some of this basalt, however, extends so far down the side slopes of the ridge of older rock as to indicate that the valley of the Madison River had already been cut much below its supposed Pliocene or early Pleistocene bottom before the deposition of basalt was completed. It is quite possible, however, that the low-level part of the basalt is either of later Pleistocene age or that it is older and has been faulted down. This erosion surface of Pliocene or early Pleistocene age may perhaps be correlated with the smooth slopes leading up to the Reynolds Pass, south of the Madison Valley, and the smooth-sloping upland on the lava adjacent to the gorges which contain Wade, Cliff, and Hidden Lakes, and to the gorges of Elk River and its tributaries west of these lakes, on the flanks of the smooth-topped Gravelly Range. (pl. 3 *C*.)

No features in the Gallatin River valley have been definitely identified as correlatives of the highest terrace northeast of Norris on Madison River. One possible correlative is the high, boulder-strewn part of the piedmont at the west front of the Bridger Range on North Cottonwood Creek, 18 to 19 miles north of Bozeman. Others are benched spurs east and west of the canyon mouth of South Cottonwood Creek, 10 miles southwest of Bozeman at the north end of the Gallatin Range.

It appears that northward from the vicinity of Cliff Lake, Reynolds Pass, and the mouth of Madison Canyon, there is some basis for regarding, at least tentatively, the high bench and terrace remnants, 800 to 1,000 ft or more above the river, to be of Pliocene or early Pleistocene age. As stated above, these features seem to indicate that not much later than the close of Tertiary time the Missouri River, south of the Gates of the Mountains, was traversing a broad valley which was 1,000 ft or more below the tops of the adjacent mountain ranges.

FEATURES NEAR LIVINGSTON, MONTANA

In harmony with the high gravel-capped terraces bordering the Madison Valley west and southwest of Bozeman are certain features in the Yellowstone River basin in the region around Livingston, about 50 miles east of the Madison River, as described in Professional Paper 174 (Alden, 1932, p. 25). Among these features are high-level remnants of the bench 1 heading at the south flank of the Crazy Mountains, which must have been developed when the Yellowstone was flowing at levels nearly 1,000 ft above the present channel. Another possible correlative feature is a conspicuous spur about 10 miles south of Livingston. This spur, hundreds of feet in height, borders the South Fork of Deep Creek for about a mile (sec. 32, T. 3 S., R. 10 E.). The boulder-strewn crest of the spur is narrow and the sides are very abrupt. It appears to have a somewhat oblique trend across that of the glaciated canyon of the South Fork, and a terminal-moraine loop curving around its lower north end extends farther down the slope nearly to the forest ranger station. The narrow spur joins the steep mountain slope at the west side of the canyon portal at a height of about 6,800 ft above sea level and nearly 2,000 ft above the Yellowstone River near the highway (U S 89). Like similar features near Indian Creek in the valley of the Madison River, this spur, although partly covered with morainal drift, may not be wholly of glacial origin but may be primarily an erosion remnant of an ancient piedmont terrace.

A similar foothill spur at the north side of the mouth of Pine Creek canyon 1 to 2 miles farther south, which was not closely examined by the writer, may be composed of rock, although there is a great deposit of morainal drift tailing off from its distal or northwest end, and it also is capped with glacial drift. The southeast end is separated from the abrupt mountain slope by a broad gap due perhaps to a fault and to later erosion. It seems possible that this ridge and the spur to the north are primarily erosion remnants of an ancient piedmont terrace of Pliocene or early Pleistocene age, which was formed about the time when the Yellowstone River had notched the wall of upturned limestone south of Livingston to 5,500 ft above sea level at the place where it now flows at an altitude of about 4,550 ft in the lower gorge. Horberg (1940, fig. 7, p. 291 and p. 298) describes both of these spurs as lateral moraines composed of glacial drift, which he correlates with Blackwelder's "Bull Lake" moraines of the Wind River Range, Wyo., and which he regards as of early Wisconsin age. (See p. 187.) These spurs are in the northern part of the foothill belt which Horberg refers to as the "Short Hills".

CENTENNIAL VALLEY AND RED ROCK RIVER

Centennial Valley, an eastward trending basin, lies between the abrupt north front of the Centennial Range and the south end of the less rugged Gravelly Range to the north. It seems probable that this broad, flat-bottomed basin is not wholly due to erosion but that there has been downfaulting here since Miocene time.

No remnants of a late Tertiary terrace or bench are distinguishable as such on either side of Centennial Valley above the broad bottom land between Red Rock Pass at the east and the foot of the Lima Reservoir. In places at the north side there is much coarse gravel composed mainly of smoothly rounded, varicolored quartzite cobblestones and boulders (as large as 2 ft in diameter), with some of granite but few of rhyolite or basalt. This gravel caps hills and covers slopes in the southeastern part of T. 13 S., R. 4 W., and the southeastern part of T. 13 S., R. 3 W., as high as 1,800 ft above Red Rock River. It may be derived from conglomerate of either Cretaceous or Tertiary age, but no ledge of conglomerate was observed here in situ.

At the dam (about 6,500 ft above sea level) about 15 miles east of Lima, the inner valley is very narrow. About two miles west of the dam there are well-defined bench remnants on the north side of the valley, the highest one examined being about 1,000 ft above the bottom land (7,400 to 7,500 ft above sea level). These benches and the slopes below are covered with smoothly rounded cobblestones and some 1- to 5-ft boulders of quartzite, many of which show percussion marks. These stones may be derived from a reddish conglomerate (Tertiary?) exposed in a nearby landslide scarp.

Another gravelly bench remnant about 200 ft lower tops a dissected alluvial gravel fan whose abrupt lower margin stands as a bluff above the flat. There is a similar old dissected fan about 4 miles farther east. The gravel here contains some pebbles of crystalline rock and some of limestone. These and similar features farther west probably represent Pliocene and Pleistocene terraces, marking stages in the downcutting of the valley of Red Rock River below the outlet of the Centennial Valley.

UPPER TERRACE ON RUBY RIVER

An observer looking northward down the upper valley of Ruby River from a point near its head, or from high points farther north, gets the impression that the tops of the higher interstream ridges on the east and the west were graded to slope down to a relatively high terrace, or bench, below which the inner valley has been cut.

The slope on the west, before its dissection, rose to the abrupt east face of Snowcrest Range as an extensive piedmont terrace beveled across warped Cretaceous deposits and probably capped with gravel of coalescent alluvial fans. One of the most southerly remnants of this high (late Tertiary or early Pleistocene) terrace appears to be between Divide and Corral Creeks. This and other similar remnants farther north were seen by the writer only from a distance. The terminal moraine on Divide Creek (sec. 11, T. 12 S., R. 4 W.) lies in a valley cut several hundred(?) feet below the grade of this postulated high terrace. The remnants of this terrace are much smaller than those of the next lower (Pleistocene) terrace, which border the intervening gulches and extend to the tops of the bluffs along the west side of the river and also on the east side in places.

Two and a half miles below the mouth of Warm Springs Creek the river has cut a narrow portal through the upturned limestones, shales, and quartzites of Paleozoic age that compose the Snowcrest Range. Between this gap of Ruby River (sec. 18, T. 9 S., R. 3 W.) and Blacktail Creek, about 20 miles southwest, remnants of a high piedmont terrace (as seen from a distance) appear to head at the west flank of this range. The heads of these remnants are probably about 7,000 to 7,200 ft above sea level.

There are also small remnants of this terrace found above the main early Pleistocene terrace on the north side of Ruby River, near Greenhorn and Willow Creeks (in the southeastern part of T. 8 S., R. 4 W.). One slopes from an altitude of 6,450 ft (about 800 ft above the river) to 6,200 ft, where the eroded edge drops steeply to the back of the second terrace about 5,900 ft above sea level. The smooth, palmately dissected top of the higher terrace is capped with coarse gravel composed of pebbles of quartzite and various igneous and metamorphic rocks.

For 17 miles northward down the Ruby River the upper terrace has been almost entirely cut away by erosion. Five or six miles south of Alder, the river (5,300 ft above sea level) flows through another narrow gap 600 to 800 ft deep; this gap is cut through garnetiferous crystalline rock. The dissected bench above the walls of the gap is probably at the horizon of the Pliocene(?) terrace, though no actual remnant seems to be preserved. For about 20 miles northwestward down the valley below this narrow gap, to the vicinity of Sheridan, both the upper and the second terraces have been almost entirely destroyed by erosion. Below Sheridan the Ruby River flows northwestward to join the Jefferson River, through a broad bottom land several hundred feet below the great piedmont terraces that border the western foot of the Ruby Range and Tobacco Root Mountains to the south and north, respectively. The altitude where the piedmont terrace joins the steep western front of the Ruby Range south of Sheridan is about 6,000 ft above sea level, fully 1,000 ft above Ruby River.

UPPER TERRACE ON BOULDER RIVER

A considerable part of the hilly to mountainous tract between Butte and Helena (Knopf, 1913, pl. 7 and also topographic maps of Helena and Fort Logan quadrangles) is drained to Jefferson River, 10 miles east of Whitehall, by Boulder River. There are some indications of several stages in the development of this river valley. An observer standing on top of the benched spur above the bluff south of the town of Boulder, and looking northwest to west, sees a worn-down and deeply dissected upland surface. Below this surface are steep slopes to the bluffs of the inner gorge. Farther west above Bernice, some slopes are flattened markedly so as to form a sloping bench (now dissected) above the lower bluffs. These slopes may be seen particularly well if viewed from the west toward Pole Mountain, near Bernice. The benches are developed on dacite, which Weed (in Knopf, 1913, p. 39) regards as of upper Miocene age. The benches represent the long side slopes of a valley much broader and older than the inner gorge. This old valley is probably of Pliocene or early Pleistocene age. The bottom of the old valley is probably to be correlated with the broad, flat bottom of Elk Park, a high-level, through valley northeast of Butte. North of Elk Park, Bison Creek has cut a narrow inner gorge several hundred feet deep below the old valley bottom. The lower part of this gorge also is cut in the upper Miocene(?) dacite.

The several old-valley remnants noted above afford some basis of tentative correlation southward on the west side of the Missouri River from the high gravelly bench, 20 miles northwest of Helena, to the features of supposed Pliocene or Pleistocene age in the valleys of Jefferson and Beaverhead Rivers and their tributaries.

GRAVELLY RANGE, CENTENNIAL MOUNTAINS, AND BEAVERHEAD RANGE

The stratigraphic relations of the rhyolitic lava (Miocene or early Pliocene?) capping the flanks of the southern part of the Gravelly Range suggest that there has been considerable deformation since this lava was deposited. There are remnants of the rhyolite overlying the pre-Cambrian gneiss and schist and also on the eroded surface of the gently folded Paleozoic and Mesozoic sedimentary rocks in interstream tracts on the crest and upper east flank of the range northward to the vicinity of Black Butte. The side slopes of the Gravelly Range have been deeply dissected by tributaries of both the Madison and Ruby Rivers. The crest, where traversed from north to south for 15 or 20 miles by a Forest Service road, is narrow and rocky in places and is surmounted by Black Butte, an abrupt basaltic neck hundreds of feet in height. It has smooth, gently undulating tracts, apparently remnants of an old erosion surface between 8,000 and 9,000 ft. above sea level. This surface may be of Pliocene age or older.

Between Elk Creek and the West Fork of the Madison River the rhyolite is nearly continuous and slopes east to northeast to the gorge in which Wade, Cliff, and Hidden Lakes (in Tps. 12 and 13 S., R. 1 E.) are located. From the vicinity of Wade Lake northward the lava on the lower cliffs forms a bench 1 to 4 miles in width which slopes northward on the west side of the river, decreasing in altitude until it disappears beneath the terrace gravels in the southern part of the Three Forks quadrangle. In this lower part there are Pleistocene river-cut terraces on the lava. It seems probable that in late Pliocene(?) time, following uplift, this northward-trending lava-capped bench was faulted down before its top was terraced by the river. In places there has been a good deal of slumping, and near the mouth of the West Fork and also farther north, coarse stratified gravel (largely of quartzite) and interbedded sand and clay of Miocene(?) age are exposed below the rhyolite. South of the West Fork gorge the lava caps much of the south end slope of the Gravelly Range, in places down to or near the east-west road north of Centennial Valley. In contrast with this moderately steep but considerably dissected south slope is the abrupt and high north front of the Centennial Mountains east and west of Lakeview. West of Lakeview, where there appears to be a considerable thickness of poorly consolidated sediments of Cretaceous or Tertiary age underlying the north flank of the range, there has been much landsliding.

The Centennial Mountains are part of the north rim of the broad Snake River basin. The south flank of the range in Clark County, Idaho, where not too much dissected, is capped with tilted rhyolite, or "late acidic" lava (Kirkham, 1927, pl. 4), of Miocene(?) age, which slopes southward to, and seems to disappear under Pleistocene basalt flows of the Snake River Plain.

In the vicinity of Monida and the pass traversed by the Butte branch of the Oregon Short Line Railroad, the Beaver Creek valley in Idaho separates the western end of the Centennial Mountains from the eastern end of the Beaverhead Range, which is part of the north rim of the Snake River basin depression and has its south flank capped with rhyolite of Miocene(?) age. This rhyolite also is tilted southward and spreads out forming a broad piedmont sloping down to the northwest border of the overlapping basalt of the Snake River Plain. The piedmont lava plain extends for miles to the west and southwest of Spencer, Idaho, beyond the transecting gorges of Indian, Middle, and Medicine Lodge Creeks. For about 15 miles west of Beaver Creek this part of the Beaverhead Range appears to be very largely composed of a thick deposit (Kirkham, 1927, p. 22), 1,000 ft or more, of coarse gravel. Where examined by the writer this deposit consists mostly of quartzite pebbles and boulders with interbedded finer gravel and sandy layers. This gravel probably is mostly of early Tertiary age (possibly Eocene or older). In places it is cemented into conglomerate and has been tilted and folded. During its deformation most of the smoothly rounded quartzite pebbles and cobbles were fractured under pressure. The gravel is overlapped at the south by the rhyolite. As the late Tertiary streams flowed southward across the tilted rhyolite much of the coarse gravel derived by headwater dissection of the higher mountain slopes was swept southward and redeposited over the rhyolite. Later, because of continued uplift, the streams cut transecting gorges one hundred to several hundred feet in depth, leaving extensive smooth interstream lava remnants of the rhyolite covered with the coarse gravel. Edie, Irving, and Webber Creeks, and other tributaries of Medicine Lodge Creek (Idaho) cut deeply into Mesozoic and Paleozoic strata beneath the rhyolite and also beyond its northwest limits.

Whether or not the rhyolite extended northward over the crest of this eastern part of the Beaverhead Range is not known. For quite a distance east of Monida and for 1 to 3 miles southwest of it the Continental Divide is now capped with rhyolite which is underlain in places by quartzite gravel. In those parts traversed by the writer at altitudes of 7,000 to 7,800 ft, the crest, which resembles other erosion surfaces of Pliocene(?) age, is less than a mile wide.

Possibly to be correlated with the upland surface of Pliocene(?) age at the western end of the Centennial Mountains, are the higher of the smooth upland surfaces on the hills between the valley northwest of Monida and the valley of Red Rock River east of Lima. The erosion surfaces, which are strewn with smoothly rounded quartzite cobblestones north of Snowline, have altitudes of 7,000 to 7,600 ft (barometric) or about 1,000 ft above the streams on the north and south. There are also high benched spurs radiating from Garfield Mountain and other high peaks 3 to 6 miles south of Lima. Some are strewn with quartzite cobblestones, perhaps derived from reddish quartzite-pebble conglomerate, such as is exposed near the head of Willow Creek south of Lima.

Six to eight miles northeast of Lima, between the valleys of Red Rock River on the south and Sage Creek on the north, there is an upland tract (Pliocene?) so smooth that it can be traversed readily by an automobile between altitudes of 7,000 and 7,600 ft (barometric). This smooth top is paved with rounded quartzite pebbles, cobblestones, and 1- to 2-ft boulders. In sec. 18, T. 13 S., R. 7 W. this coarse gravel is overlain by lava 5 to 10 ft thick. Similar gravel with 1- to 5-ft boulders caps several benched spurs or terrace remnants (several hundred to 1,000 ft above the stream) on the north side of Red Rock River west of the Lima Reservoir. Quartzite gravel also caps the eroded surface of the tilted beds of friable sandstone and clay of Miocene(?) age exposed in a bare scarp at Cooks ranch near Sage Creek (sec. 34, T. 12 S., R. 8 W.). This bouldery quartzite gravel may have been derived by erosion from a reddish conglomerate, such as that exposed not far from the head of Sage Creek about 5 miles east of Armstead. Whether or not this quartzite gravel extends all the way along the range of hills between the valleys of Sage Creek and lower Red Rock River and thence to the Beaverhead Range southwest of Monida is not known; neither has its age been determined. Such quartzite gravel is remarkably widespread throughout this belt, however, so far as can be judged from the traverses made. Whatever its source, much of the gravel scattered on the terraces and uplands was probably redeposited on these erosion surfaces, being shifted from higher to lower levels by sliding and wash as the valleys were deepened. The quartzite gravel deposits are quite different from and appear to be younger than a limestone-pebble conglomerate exposed in some of the same localities near Lima.

DEPOSITS ALONG SHEEP CREEK AND OTHER STREAMS

Fifteen to sixteen miles southwest of Lima is the Medicine Lodge Pass, a broad sag in the crest of the Continental Divide at the east side of the headwater basin of Sheep Creek which flows northward through a narrow gorge to join Red Rock River at Dell, Mont. Between 2 and 4 miles east of the Medicine Lodge Pass (T. 13 N., R. 32 E.) there is a 100-ft cliff of white, porous, bedded travertine (fig. 5). The top of this cliff is a smooth, nearly flat, upland tract, 8,400 to 8,500 ft above sea level, upon which the Montana-Idaho State line is located. From the cliff great masses have slid down on the slope below. Back of and somewhat higher than the crest of the travertine cliff, a thin deposit of purplish-red rhyolite underlies the smooth surface of the upland. Apparently the travertine was deposited on an old erosion surface by springs issuing from the nearby Paleozoic limestone before the adjacent valleys had been excavated to anything like their present depths. The smooth top is part of a gently rolling upland surface of Pliocene age which bevels the upturned Paleozoic limestone strata for some distance to the north and the northwest; below it are the deeply incised gorges of Sheep Creek and Little Sheep Creek and the broader basin of Muddy Creek. Immediately west of the travertine cliff the head of Pine Creek has cut into dense gray clay, which probably extends eastward under the smooth, grassy slopes and underlies the travertine. These slopes near the State line are strewn with smoothly rounded cobblestones showing percussion marks. They consist very largely of white, red, and purplish quartzites and some dark-gray limestone, roughly etched. Such coarse gravel may also lie on the clay underneath the travertine; none was seen on the top of either the rhyolite or the travertine. From the top of the white cliff there is a very extensive view southeastward down the Medicine Lodge Creek and across the bordering benchlands in Idaho to the lava plain of the Snake River.

FIGURE 5.—Travertine cliff southwest of Lima, Mont., at the edge of the Tertiary (?) upland between the heads of Sheep Creek in Montana and Lodgepole Creek in Idaho.

Thirty to thirty-five miles northwest of the Medicine Lodge Pass another sag in the Continental Divide is known as the Bannock Pass. This pass is crossed by a highway and, nearby, the Gilmore and Pittsburg Railroad tunnels through friable sandstone of Tertiary (Miocene?) age which underlies the Divide. An excavation above the highway at the pass shows a thin deposit of gravel overlying light-colored sandy clay of Miocene age. The subangular pebbles and 1- to 2-ft boulders consist mostly of quartzite, some granitic rock, and some black chert. The gravel-capped crest of the Divide between the highway and the notch at the railroad tunnel is smooth and flat, although narrow. For 5 or 6 miles southeast of the railroad tunnel, the top of the Divide is mostly smooth, flat, and gravel-strewn and rises gradually toward the higher and more rugged part of the Beaverhead Range like the remnant of an old, high-level, alluvial fan that it is. In places, the top has been so narrowed by erosion that the gravel has been removed and the crest has been notched and lowered. The pebbles and boulders are mostly of white to yellowish quartzite with some of deeply weathered gneiss. Between the Continental Divide near Deadman Pass and Jeff Davis Peak there appear to be other similar high-level remnants of this old sloping piedmont terrace beveling the Miocene(?) deposits that border the west front of the mountains. Horse Prairie Creek heads about 3 miles farther south than the railroad tunnel and flows northwestward; the gravelly top of the Divide on the south, which is the State boundary, also slopes in the same direction. So also, Divide Creek, which flows northeastward to join Horse Prairie Creek, heads about 2 miles farther south than the pass. The junction of these two creeks near the siding for Donovan Ranch is now about 1,000 ft lower than the pass. These relations suggest that in Pliocene time, when the high bench was probably formed, the Divide was farther south and perhaps on the higher upland tract on the Paleozoic limestone south of Cruikshank Creek. If so, post-Pliocene erosion by Canyon Creek, a tributary of the Lemhi River, has pushed the Divide northward across the Tertiary deposits now exposed in its headwater basin and has robbed Montana of an area of about 25 sq mi. Perhaps this shifting may be one reason why the Miocene(?) deposits extend from the head of the Horse Prairie Creek nearly 5 miles south of the Continental Divide but appear not to be continuous thence southward to the Lemhi Valley. As seen in a distant view across this valley, the inner gorge of Canyon Creek in Idaho appears to be cut about 1,000 ft below the bottom of a broad old high-level valley.

In the western part of the basin of Horse Prairie Creek between Bannock Pass and the Lemhi Pass, 10 miles farther north, a belt of Tertiary volcanic rocks has been carved into hills by erosion. To the east the interstream ridges on both sides of the bottom lands along Horse Prairie Creek appear to be composed mostly of the softer Miocene or Oligocene clays and sands, although some volcanic rock and quartzite are exposed. Where the Tertiary beds have been sufficiently eroded the streams are bordered by well-defined Pleistocene gravel terraces.

With the exception of the environs of Bannock Pass and Medicine Lodge Pass, the crest of the Continental Divide on the Beaverhead Range northwest to the Lemhi Pass has not been traversed by the writer. Lemhi Pass (about 7,200 ft, barometric) is at the head of Trail Creek (sec. 15, T. 10 S., R. 15 W.), about 20 miles west of the village of Grant, Mont. The Lewis and Clark Expedition first crossed this pass to the Pacific slope in 1805. The crest of the Divide north and south of the pass is narrow and smoothly undulating and looks like an old erosion surface. Below it, on both the east and the west, the flanks of the range are deeply gashed by stream gorges. The pass is about 1,200 ft above the bottom lands west of Grant and about 2,500 ft above the Lemhi River in Idaho. Farther north the crest of the range is higher and appears more rugged as seen from the lowlands on either side; the northeast slope at the head of Bloody Dick Creek and the flanks of the high peaks west of the Big Hole Basin are scalloped with cirques in which many Pleistocene glaciers headed.

North of the broad, flat-bottomed valley of lower Horse Prairie Creek an extensive upland in and near the southwestern part of the Dillon quadrangle, although considerably dissected, still retains parts of a fairly smooth old erosion surface. From the top of the west bluff of the Beaverhead Valley, 3 to 4 miles north of Armstead, an observer may look far out to the northwest over this upland of beveled upturned limestone beds of Paleozoic age. The upland ranges in altitude from 6,500 to 7,000 ft or more and is probably a late Tertiary (Pliocene ?) erosion surface. Farther north it is transected, for 12 or 13 miles southeast of Bannack, by the deep, narrow gorge of Grasshopper Creek. Parts of the upland, both south and north of the Grasshopper Creek gorge, are underlain by Tertiary volcanic rocks. Northward from the narrow top of the north part of the upland, at an altitude of 7,000 ft, is a well-defined remnant of a smooth sloping piedmont bench which borders the gorge south of Argenta and heads against a higher slope. Since Rattlesnake Creek, which heads in the Pioneer Mountains near Baldy Mountain, flowed over this bench it has cut the gorge 300 to 500 ft in quartzite and granite in which it now flows above Argenta. The cutting of this gorge was practically all accomplished prior to the Pleistocene glaciation of the upper part of the canyon. The bench is one of the best preserved remnants of a late Tertiary or early Pleistocene piedmont found by the writer in the Jefferson River basin. It is possible that the larger boulders scattered over this bench are glacial erratics of early Pleistocene age. The gravel and boulders, however, may be a torrential stream deposit of Pliocene age.

In the southern part of the intermontane basin of Grasshopper Creek above the head of the gorge at Bannack there are extensive, well-preserved remnants of Pleistocene gravel-capped terraces formed by streams issuing from the range of hills on the west. Bordering the east front of these hills from Swamp Creek north to the pass in T. 6 S., R. 13 W., is a narrow piedmont bench strewn with quartzite cobblestones. On this bench are the terminal moraines of glaciers of Ames Creek and Harrison Creek, more than 7,000 ft above sea level. This bench probably represents the piedmont slope onto which the streams issued in Pliocene or early Pleistocene time, when Grasshopper Creek was just beginning to cut its lower gorge across the upland southeast of Bannack. The bench and the terraces below appear to be underlain by poorly consolidated Tertiary deposits.

It is quite probable that parts of Pliocene fan terraces are preserved in the extensive piedmonts bordering the Tobacco Root Mountains and Ruby Range. The larger parts of these piedmont terraces are undoubtedly of (early?) Pleistocene age. There is little doubt that more detailed study of the valley slopes and bordering uplands would add considerably to the known physiographic history of the Jefferson River basin.

VIPOND PARK AND HARRISON PARK UPLANDS

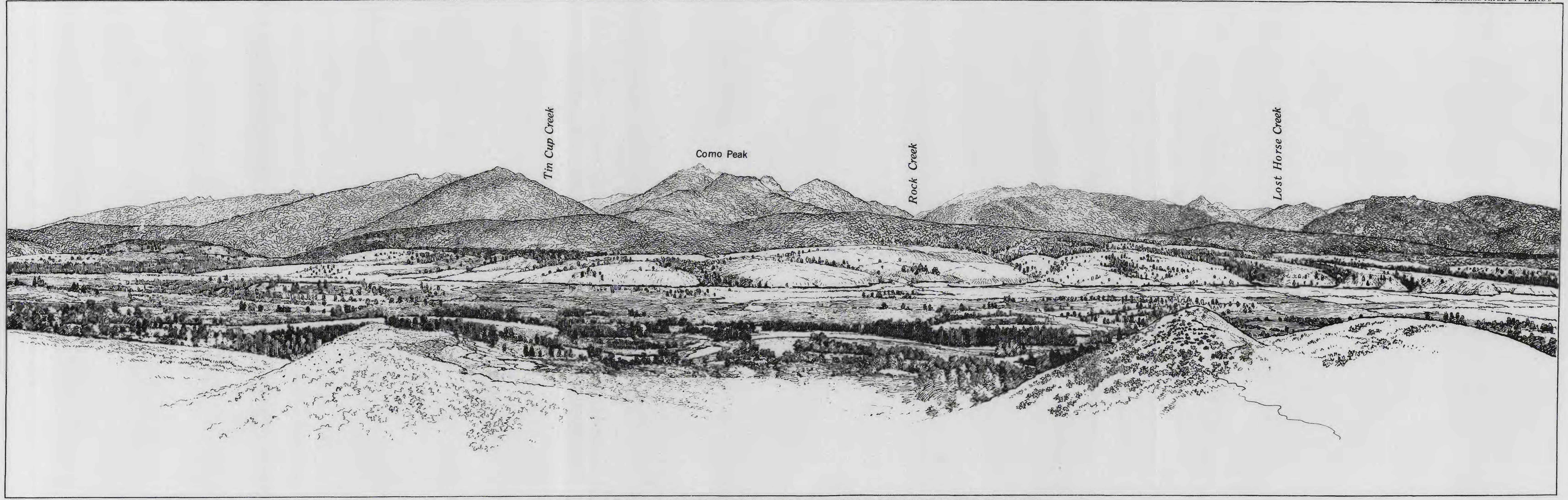
One of the most notable remnants of an upland that may be of Pliocene age is that known as Vipond Park in the Pioneer Mountains, 10 to 15 miles northwest of Melrose on the north side of Canyon Creek. From an altitude of about 5,500 ft on the low terrace at Dewey, the narrow gulch between steep wooded slopes is marked by rocky crags and pinnacles. About 2,500 ft above the river, the woods give way to a smooth, grassy, rolling prairie nearly surrounded by higher hills and mountain peaks. According to a topographic map of this part of the Beaverhead National Forest this rolling upland ranges from about 7,600 to 8,300 ft above sea level. The smoothly undulating, old erosion surface is strewn with angular blocks and subangular to rounded boulders of gray and yellowish quartzite 1 to 3 ft in diameter. This upland extends southward to the lateral moraine lying along the smooth crested north wall of the narrow glaciated trough in which Canyon Creek flows 1,000 ft. below. This old erosion surface not only is of preglacial age but clearly antedates the canyon-cutting cycle in the Pioneer Mountains.

Another smooth, upland remnant similar to Vipond Park and probably of the same age (Pliocene?) is about 15 to 18 miles farther southwest between the heads of Wise River and Grasshopper Creek. This upland, which is shown on the reconnaissance topographic map of the Beaverhead National Forest (T. 4 S., R. 12 W.) as 7,700 to 7,900 ft above sea level, lies like a broad shallow valley between higher hills, behind which to the southeast is a line of rugged cirque-scalloped peaks—Saddleback and Torrey Mountains, Tweedy Peak, and others—rising to altitudes of 9,000 to 11,000 ft or more, at the heads of the glaciated valleys of Elkhorn and David Creeks. These smooth meadows are strewn with many granite boulders 1 to 5 ft in diameter. They may be either boulders of disintegration of underlying granite or boulders transported here by early Pleistocene glaciers heading in the mountains to the east. Were it not for the long climbs to reach this smooth upland from either Wise River on the north or Grasshopper Creek on the south, an observer looking across the smooth meadows toward the higher mountains might think he was standing on a lowland tract. Before the late Pleistocene glaciation the valleys were deepened 500 to 1,000 ft or more. Judging from the topographic map, there are other remnants of this old erosion surface farther west and northwest.

Five to six miles east of the Big Hole River at Melrose on the crest of the ridge west of Rochester Creek, is a narrow remnant of a smooth, old upland surface about 6,500 to 6,700 ft above sea level, or 1,200 to 1,500 ft above the river. This surface and the eroded slopes below it are strewn with smoothly rounded pebbles, cobbles, and 1- to 4-ft boulders of quartzite and crystalline rock. The bouldery gravel extends southward along the smooth crest east of a belt of west-dipping limestone strata for 6 or 7 miles. The narrow, gravel-capped upland also extends northward for an unknown distance toward the ridge top south of Camp Creek. No evidence was noted by the writer indicating that this belt of bouldery gravel marks the outcrop of an older bed of conglomerate. In places there are ledges of basalt that was possibly poured out on this old erosion surface, which may be of Pliocene age. The gravel may have been deposited by a stream heading to the northeast in the highlands near Red Mountain, about 15 miles northeast of Melrose. Possibly, but not probably, this bouldery gravel may have been derived by erosion from conglomerate beds at the base of the Kootenai formation (lower Cretaceous), such as is exposed farther south in Tps. 4 and 5 S., R. 8 W.

One thousand feet or more below the gravel-strewn upland remnant is the broad, remarkably smooth piedmont fan terrace, formed in early Pleistocene time; it is at the top of the line of low bluffs that border the flat bottom land on the east side of the Big Hole River valley. This terrace is 12 to 14 miles wide and is transected by several dry gulches and creek valleys 50 to 75 ft in depth. Its lower edge has been eroded by the river. Also on this terrace and covering the bluffs are well-rounded pebbles, cobblestones, and boulders 1 to 3 ft in diameter like those on the old upland crest to the east, together with much limestone material. This great gravelly fan terrace (early Pleistocene) is probably partly underlain by Tertiary (Miocene?) deposits similar to those exposed in road cuts to the north near Moose Creek.

Near the Continental Divide, 5 to 10 miles east to southeast of the Deer Lodge Pass, some smooth old upland tracts are traversed (about 7,000 ft above sea level) by a road leading to the Highland mine south of Butte. Some of these tracts are underlain by deeply weathered granite and in places there are remarkable towers and pinnacles of granite and jumbles of great granite boulders of disintegration like those near the railroad and



PANORAMIC VIEW OF THE BITTERROOT RANGE FROM THE TERRACE NORTHEAST OF DARBY

Sketched from photographs showing the bottom lands and terraces along the river, the moraine-covered spurs (?) in front of the canyons, and the even slope of the gneiss zone along the southern end of the range at the left. Reproduced from W. Lindgren, U. S. Geological Survey Professional Paper 27, plate X.

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FIGURE 6.—Granite boulders of disintegration in the Bitterroot Range at Lolo Hot Springs southwest of Missoula on the Lewis and Clark trail.

U. S. Highway 10 S on the pass southeast of Butte and at Lolo Hot Springs southwest of Missoula.

DEPOSITS IN BIG HOLE BASIN

One of the most interesting of the intermontane basins is the valley drained by the Big Hole River southwest of Anaconda. This basin has an extent of about 50 miles from north to south. The broad hay fields on the bottom lands and the long, smoothly sloping, piedmont terraces are in marked contrast with the high and rugged mountain ranges by which it is shut in on all sides. It is in such a headwater pocket, or basin, as this that one might expect to find preserved some Pliocene and early Pleistocene features, like those noted farther down the Missouri River drainage basin. Pleistocene features are well preserved and easily recognized, but there is some question as to which ones, if any, can be classed as of Pliocene age.

Above the village of Wise River the Big Hole Basin curves crescent-wise to the southwest. Beginning with French Gulch, numerous streams come down to the river from the Continental Divide on the rugged Anaconda Range to the northwest, and from the Beaverhead Range on the southwest side of the Big Hole. The upper courses of many of these streams occupy mountain gorges that were glaciated in Pleistocene time; some of them are bordered by long benched spurs which appear to be erosion remnants of extensive high-level piedmont terraces, which may be of Pliocene age. The glaciated trough of La Marche Creek above the forest boundary is bordered on the east and west by long, wooded, drift-covered spur ridges which rise abruptly 500 ft or more above the bottom of the intervening glaciated trough. The smooth crests of these spurs, in places, are beveled across Tertiary (Miocene?) and older rocks. The partly wooded surface, for some distance outside of the bouldery west lateral moraine, is evidently part of an extensive piedmont bench which is underlain, in part at least, by rhyolite and has been considerably dissected by tributaries of Fishtrap Creek. Unlike the nearby lateral moraine, which carries many large granite boulders 1 to 10 ft in diameter, the surface of the bench is paved with subrounded cobbles and 1- to 2-ft boulders of whitish, greenish, and reddish quartzite. Ten to sixteen miles farther southwest similar drift-covered benched spurs were examined by the writer. These spurs border the glaciated troughs of Pintlar and Howell Creeks (pl. 3*D*).

There are several similar long benched spur ridges bordering the glaciated troughs heading at the northeast flank of the Beaverhead Range between 15 and 25 miles southwest of Wisdom. These wooded spurs, like those described above, as seen from a distance, appear to merge like interstream erosion remnants of a distinct, relatively high, piedmont bench. The most readily accessible are those bordering the north and south sides of the glaciated trough of Miner Creek 5 to 12 miles west of Jackson. The height of the drift-covered north ridge, where traversed, is 400 to 700 ft above Miner Lake, and where they join the higher mountain slope on either side of the canyon portal the north and south ridges appear to be fully 1,000 ft high. It is probable that there are rock cores, very thinly covered, in both of these ridges. These benched spurs are 4 or 5 miles long and well-defined lateral moraines tail out from their eastern ends.

It seems probable that in Pliocene or early Pleistocene time, before its dissection by preglacial and interglacial stream erosion, this piedmont was continuous and sloped gradually eastward to the river which was then flowing on a smooth flat bottom of the basin, 500 to 1,000 ft above its present channel. The faulted and tilted beds of Tertiary (Miocene?) age are beveled along this valley bottom and piedmont slope, which was the near correlative in the Big Hole Basin of smoothly worn-down upland tracts, such as the Harrison and Vipond Parks on the Pioneer Mountains to the east, the high bench at Argenta, and the smooth upland tracts north and south of the lower gorge of Grasshopper Creek, southeast of Bannack.

At only two places—the Big Hole Pass west of Wisdom and the Lemhi Pass west of Horse Prairie Creek—has the crest of that part of the Beaverhead Range from the vicinity of the Bannock Pass on the south to the vicinity of Gibbons Pass on the north been examined by the writer. Judged by conditions at these passes and by long-distance views from both the east and the west, there is little or no indication that any remnants of an old high-level peneplain of Tertiary(?) age are preserved on this part of the Continental Divide. The crest appears mostly to be narrow and rugged, with numerous high peaks like those of the Anaconda Range shown on the topographic map of the Philipsburg quadrangle. With the exception of a few fairly smooth upland remnants, such as those described on the Pioneer Mountains, there seems to be no regional physiographic datum plane above the zone of the uppermost benched spur remnants of the dissected piedmont slopes or terraces in the upper Missouri drainage basin.

Before the transecting lower valleys were developed in Pleistocene time, these piedmont slopes may have been remarkably smooth and quite extensive, like the broad piedmont terraces now bordering the west foot of the Ruby Range and the Tobacco Root Mountains in the Dillon quadrangle. They resemble, in surface contours, the so-called pediments of the arid regions of the Southwest. Whether or not they were really pediments, it would seem that there must have been some local controls that permitted such extensive destructive and constructive planation in the several intermontane basins. Such control may have been afforded by the retarding effect of the hard rocks through which the constricted parts of the gorges connecting the several broad basins were cut between the Gates of the Mountains below Helena and the headwaters of the tributaries of the Missouri River. Among the controlling gorges with walls of hard rock are the Big Hole River gorges above and below the mouth of Wise River, the gorge about 15 miles north of Dillon, the Jefferson River gorge about 20 miles above Three Forks, the lower Madison Canyon 20 to 30 miles south of Three Forks, the Missouri River gorges in the vicinity of Lombard, and those north of Helena. The obstructions through which these several gorges were cut in Pliocene and Pleistocene time must have been quite effective in controlling stream erosion and deposition on the piedmonts and terraces.

WEST OF THE CONTINENTAL DIVIDE

INTRODUCTION

Before proceeding with the description of features west of the Continental Divide that are treated in this paper as possibly of late Tertiary age, it may be well to have in mind certain conclusions reached by Daly, with which the writer is in general agreement, regarding the geomorphology of the Cordillera as a result of his studies along the 49th parallel from the front ranges in Glacier Park westward to and beyond the Idaho-Washington State line.

In discussing the question of a Tertiary peneplain in the Rocky Mountain System, Daly (1912, pp. 610–643, 642) states his belief:

* * * that the Front ranges, as well as the Galton-MacDonald group, were uplifted in the one episode of the Laramide orogenic revolution and have undergone steady erosion ever since, this erosion reaching maturity and no later stage. It is possible that a horizontal thrust has deformed the unconsolidated Miocene clays of the Flathead trough, but there is no clear evidence that this movement affected the great blocks to east and west in any essential way.

In discussing the question of possible Tertiary peneplanation of the Purcell Mountains, which lie between the Rocky Mountain Trench and the Purcell Trench, and are crossed by the 49th parallel, Daly (1912, p. 642), makes the following statement:

Each of the three constituent ranges shows the accordance of summit levels in a very notable way. In no case, however, is there any known remnant plateau of an old, uplifted peneplain. The problem of explaining the accordance of summit levels is the same as in the Galton range and, in fact, throughout the majority of the ranges crossed by the Forty-ninth Parallel, we have the same phenomenon.

So also, in discussing erosion of the Nelson Range of the Selkirk Mountains west of the Purcell Trench, he writes as follows:

In general, therefore, the physiographic development of the Nelson range is, to all appearance, parallel to that in the Purcell and Front range systems. The evidence for more than one important erosion cycle since the post-Laramie upturning is practically nil. Considering the enormous amount of erosive work represented in the actual dissection of the monoclinal mass, it would seem that all Tertiary time has been no more than sufficient for the one erosion-cycle carried to the present stage of "maturity."

Later in his paper Daly (1912, pp. 631–641) discusses "Development of accordance of summit levels in Alpine Mountains" in other ways than by peneplanation and states his conclusion in part as follows:

The work of reducing the original chain of early-Eocene mountains to the present more subdued relief is of the same order as that accomplished by the erosion which was active through the entire Tertiary period in the equally resistant terraces of the Appalachians and of other mountain-chains. The opening of Waterton lake valley, the Rocky Mountain and Purcell trenches, the Selkirk Valley, and the Okanagan valley forms a series of tasks comparable to those of opening the Great Valley, or the Hudson, Connecticut, or Berkshire valleys of the east. The many narrower valleys of the Cordillera are analogues of the young to mature Tertiary valleys cut in the Cretaceous peneplain of the Appalachians.

Some individual canyons of the Cordillera are due to rearrangements of drainage through glacial action or through river-capture, or through other exceptional causes; but there is little doubt that there has been a general uplift of the Cordillera in this latitude during the late Tertiary. The relief has consequently been increased—perhaps by as much as that claimed by Dawson, 2,000 feet, for the Belt of Interior Plateaus. Such uplift is an important incident complicating but not radically changing the erosion conditions which already existed before the elevation. Before it took place, we may believe that the mountains all the way from the Gulf of Georgia to the Great Plains, ranged in height from 3,000 to 8,000 feet or more. This late Tertiary uplift invigorated the rivers; it did not begin a new erosion cycle at the close of a completed former cycle.

At numerous places in the valleys of the Clark Fork and its tributaries, there are what appear to be small remnants of well-defined terraces cut across the edges of upturned pre-Cambrian, Paleozoic, and Mesozoic beds. These terraces are at various heights, 100 to several hundred feet above the present streams. They suggest that the progress of deepening of these valleys was interrupted from time to time by stages of terracing or valley broadening, either when the valleys were originally eroded in pre-Miocene time or at later dates when the streams were cutting away Tertiary deposits with which they may have been partly filled, as in the valley of the upper Missouri River and its tributaries. Such terracing west of the Continental Divide may have been controlled in part by the progress of the Columbia River in cutting its post-Miocene gorge in and around the basalt and other rocks underlying the plateau west of Spokane, Wash. Such terracing, if of post-Miocene age, would truncate not only Miocene deposits in the valleys but any rocks encountered by the meandering streams at the various places, regardless of geologic age and, rather generally, also regardless of lithologic composition. Later stream work may very largely have consisted of clearing out friable Tertiary deposits from between the down-faulted and truncated blocks of older and harder rocks. The general situation in most of the valleys west of the Continental Divide is such that the interpretations here presented cannot be so well supported by evidence as is desired; they must, to a large extent, be conceded as hypothetical. Nevertheless, it seems worth while to present them in outline for consideration in further and more detailed studies of the region.

GLACIER NATIONAL PARK AND THE FLATHEAD RIVER BASIN

Among the noteworthy features in the interior of Glacier National Park are a broad, high-level, sloping bench above the so-called Glacier Wall between Heavens Peak on the west and the big bend in McDonald Creek valley, a similar high-level bench known as Granite Park between this valley and the rugged mountain crest north and south of the Swiftcurrent Pass (fig. 7), and

FIGURE 7.—Granite Park in Glacier National Park. View north from Logan Pass to Granite Park (middle), an erosion remnant of a Pliocene(?) or early Pleistocene benchland. Haystack Butte and The Garden Wall (Continental Divide) at the right.

Flattop Mountain between upper McDonald Creek and Mineral Creek. Separated from Flattop Mountain by the gorge of Continental Creek is a similar bench known as West Flattop Mountain. As shown by the topographic map, the altitude of these smooth, high-level benchlands is between 6,500 and 7,000 ft. They are dissevered remnants of the floor of an interior synclinal basin now transected by glaciated gorges, ranging in depth from 1,500 to 2,500 ft or more, which drain to the Flathead River. Undoubtedly these several high interior benches are very largely due to the relatively low dips of the underlying strata in the syncline. It seems clear, however, that the general plateau surface, in terms of physiographic development, is the correlative of the high-level, gravel-covered bench remnants at the eastern front of the Lewis Range. (See pl. 4 *A*, *B*.)

It also seems probable that the interstream and interlake ridges in the western part of Glacier National Park near and northwest of Lake McDonald, in the broad trough drained by the Flathead River, are the near correlatives of the interior Flattop plateau remnants and of the highest of the gravel-capped ridges east of the front ranges in, and south of Glacier National Park (pl. 4 *B*). These latter, as described in Professional Paper 174 (Alden, 1932, pp. 12–17 and 32–34), are erosion remnants of extensive piedmont terraces that were developed by planating and gravel-depositing streams issuing from the Rocky Mountains, largely in Miocene time but probably not completed in undissected form until late Pliocene or early Pleistocene time. On some of these remnants east of the mountains there are also beds of glacial drift that were deposited in early Pleistocene time by mountain glaciers before much dissection of the piedmont terrace had been accomplished. If the interpretation is correct, the several ridges in question at the west side of Glacier National Park are composed of faulted and tilted Miocene (or Oligocene and Miocene) strata whose edges were beveled and terraced by mountain streams in Pliocene time. At least some of these ridges are also capped with glacial drift, but they are probably not “winged-out moraines” nor wholly nor mostly composed of glacial drift, as was inferred by Daly (1912, p. 583). That these ridges are as well preserved as they are is probably due to their having been somewhat protected from stream and glacial erosion by their positions behind (east of) the north ends of the Swan, and Flathead Ranges, the Belton Hills, Apgar Mountains, and the other mountain ridges composed of rocks of the Belt series west of the Flathead Valley. The depths of erosion below the general plane of the ridge tops, that represent the Pliocene bench, as thus interpreted, range from 1,000 to 2,000 ft; most of the erosion was probably accomplished in early Pleistocene time, as was that east of the front ranges. Farther south and west in the Flathead Valley and other valleys west of the Continental Divide the amount of Pleistocene erosion was still greater, so much so that in places the only remnants of high-level piedmont terraces, or what appear to be such, are very small and are preserved in particularly specialized situations, such as beneath morainal cappings flanking the mouths of numerous glaciated canyons. These terraces merit somewhat detailed description.

For nearly 50 miles south of Bad Rock Canyon, through which the Flathead River flows east of Columbia Falls, there is little or no indication of a piedmont terrace higher than the present plain ever having bordered the abrupt west fronts of either the northern part of the Swan Range (fig. 8) or the Mission Range. Perhaps this is a result, in part at least, of tremendous scour along the eastern margin of the great Flathead glacial lobe that was being deflected here from a southeasterly to a southerly course. East of the south end of Flathead Lake at an offset or reentrant in the mountain front, there appears to be a broad, slightly uneven, wooded rock bench 500 ft or more above the lake shore. From here southward to the canyon of Mission Creek east of Saint Ignatius several of the canyon mouths are flanked by narrow spurs hundreds of feet in height; upon them and tailing out from the ends are great lateral moraines formed by the Pleistocene mountain glaciers. Between Mission Creek and Dry Creek, in the alcove between the southern end of the Mission Range and the Ravalli Hills, are other foothills, not so much covered by morainal debris, that may be remnants of a piedmont bench 600 to 700 ft high. (See pl. 4 *C*.)

FIGURE 8.—Abrupt west face and glacially scoured, fault-lined scarp at base of the Swan Range south of Bad Rock Canyon.

The moraine-covered spurs east of Pablo are interstream ridges between which the branches of Mud Creek flow out from the mountain gulches. These spurs trend northwestward athwart the eastward trend of the glaciated mountain gorge. The crest of one traversed by the writer joins the mountain front about 4,800 ft above sea level, or 1,600 ft above the level of the irrigation canal to the west. This trend is in marked contrast to the southwesterly trend of the similar spurs farther south and evidently was not affected by the southward advances of the great Flathead glacier. There are slight transverse sags or short steplike drops in the narrow crest line of the northernmost of the spurs traversed, at altitudes of about 3,800, 4,200, and 4,800 ft, such as might possibly be results of faulting during Recent time. These steps may, however, be due to erosion.

Farther south, in Lake County, there is in general a rather marked tendency for the combined moraines and rock spurs and the intervening gulches to be deflected southward. Crow Creek emerges from its glaciated canyon 300 ft below the tops of the bordering spurs. At this place nothing was noted suggestive of faulting during Recent time, unless it be truncation at the outer end of the spurs. Similar moraine-covered spurs, which border tributaries of Crow Creek directly east of Ronan, join the steep mountain front at an altitude of about 4,800 ft. The crest of one is marked by small transverse sags, possibly due to faulting, at altitudes of about 4,200 and 4,400 ft. Views north and south over these and adjacent spurs show general uniformity in height, supporting the suggestion that they may be erosion remnants of a piedmont terrace. Similar high spurs between 3,900 and 4,500 ft border South Crow Creek at the mouth of the glaciated canyon, and to the north of them there seem to be stubs of other such spurs where there are no glaciated gorges. Short unglaciated stubs of spurs south of the high glaciated spurs seem to border Mohlman Creek, in the southeastern part of T. 20 N., R. 19 W. A noteworthy spur on the north side of this creek joins the higher steep mountain slope at about 4,600 ft. Midway of its length, at an altitude of 4,450 ft, there is a short, sharp drop of about 25 ft in the crest, suggesting that the western part of the spur has been faulted down in Recent time. From this spur there is a fine view up the glaciated mountain gorge.

East of Ninepipe Reservoir, in the northern part of T. 19 N., R. 19 W., is McDonald Lake, a reservoir maintained by an artificial dam at the mouth of the glaciated gorge of Post Creek. Flanking the north side of the glaciated trough below the dam is another of these spurs, whose moraine-covered core is probably composed of Belt rocks and may be an erosion remnant of a piedmont terrace. A short distance from the foot of the steep rocky mountain slope, a small gulch heads in a notch that transects the crest of the spur near the dam. The appearance of this gulch suggests a fault of Recent age, inasmuch as its location is not what one would expect if it were due to erosion alone. No such indication of faulting was seen on the moraine-covered spur at the north side of the glaciated canyon of Ashley Creek, northeast of Saint Ignatius. The crest of this spur joins the mountain front about 5,000 ft above sea level (fig. 9).

There are high spurs flanking both sides of the mouth of the canyon of Mission Creek east of Saint Ignatius

FIGURE 9.—High peaks northeast of Saint Ignatius and long sloping spur grading down to the drift-covered rock spur north of the canyon of Ashley Creek (at right).

(fig. 19), and it seems quite probable that they are moraine-covered remnants of a dissected piedmont terrace, as are the foothills farther south. The spur on the north side is particularly abrupt and high; it appears to have deflected the great glacier southwestward and to have restrained the ice from spreading out northward until the outer end of the spur had been passed. That the ice did spread in its terminal lobe is shown by the manner in which the north lateral moraine curves to the north just beyond the abrupt outer end of the higher spur. This spur crest joins the steeper mountain front about 4,800 ft above sea level. No transverse notch was noted on this north spur. The north face of the south spur, however, (fig. 19), is cut by a small gulch heading at a transverse notch in the crest, which is quite suggestive of faulting although it is not certainly due to faulting alone.

These relatively high morainelike spurs at the mouths of the canyons of Ashley and Mission Creeks are the piedmont parts of well-graded spurs that extend far up the mountain front as remnants of an old erosion surface (fig. 10), similar to those on the flanks of the Anaconda Range but steeper.

FIGURE 10.—Glaciated gorge of Ashley Creek (left) northeast of Saint Ignatius in the Flathead basin. Long, sloping spur at the right graded down to drift-covered rock spur at north side of the canyon of Mission Creek.

What appears to be a remnant of a corresponding high bench directly across from the canyon mouth of Mission Creek, projects from the slope of the hills south of Saint Ignatius in or near sec. 36, T. 18 N., R. 20 W. This is about 3,800 ft above sea level, or 1,000 ft higher than Mission Creek at Saint Ignatius. It is not known how far the sloping piedmont terrace, of which the several moraine-covered spurs are supposed to be remnants, may have extended west of the front of the Mission Range in Pliocene or early Pleistocene time. Some of the interstream ridges in the Flathead Valley extend 5 to 8 miles from the mountain front on the east before the eroded ends drop to the inner valley of the river, and Snyder Ridge extends clear across the trough to the Belton Hills, north of West Glacier.

Friable sandstone of Tertiary(?) age is exposed north of the Bison Range hills near Moiese and the penetration of a considerable thickness of similar deposits by a deep well south of Polson has been reported. These occurrences suggest that at least in that part of the basin south of Flathead Lake much of the downfaulted pre-Cambrian rocks may have been buried beneath Tertiary sedimentary deposits. The development of an extensive piedmont terrace or pediment across such deposits, even if they themselves had been disturbed by faulting, would have been an easy task for the numerous streams heading in the rugged Mission Range. This plain may have been similar to, and quite as extensive as, the broad smooth sloping benches bordering the west foot of the Ruby Range and Tobacco Root Mountains northeast of Dillon.

South of Flathead Lake the possible piedmont terrace may have sloped continuously westward to the hills of the National Bison Range and to the more northerly ridges of upturned Belt rocks several miles west of Charlo, Ronan, and Pablo. Down this slope the several streams would have flowed westward from the Mission Range through the gaps in the western hills to join a stream not far from the present course of the Flathead River. It is probable that a very considerable amount of erosion occurred in this part of the Flathead basin in Pliocene and early Pleistocene time before the pre-Wisconsin glacial drift south of the lake basin was deposited, and it is quite possible that the valleys of the main stream, the Middle, and South Forks of the Flathead River and the valley of the Swan River were as much as 1,000 ft less deep than now, and that the tributary mountain gorges may have been 1,000 to 2,500 ft less deep.

Fifteen to twenty miles southeast of Saint Ignatius, in the N½ T. 17 N., R. 18 W., there is a somewhat uneven drift-covered benchlike tract 4,000 to 4,500 ft above sea level, around the lower edge of which the irrigation canal from a reservoir on the Middle Fork of the Jocko River flows northwestward through Twin Lakes to Saint Marys Lake (Tabor reservoir). It is possible that this bench also represents a Pliocene or early Pleistocene erosion surface. It is through here that C. H. Clapp located the southeastward extension of the Mission fault. Nine to ten miles east of Arlee there are terrace remnants south of the Jocko River and 100 ft or more above the low outwash gravel terrace on which the road lies.

There is a possible remnant of a Pliocene piedmont terrace 5 to 6 miles southeast of Arlee on the East Fork of Finley Creek. This terrace (4,200 to 4,400 ft above sea level) is at the top of a steep bluff above the irrigation canal, and on its surface lies the moraine of a mountain glacier. Another possible remnant is a high dissected alluvial fan, 4,100 to 4,300 ft above sea level, 1 to 2 miles northeast of Evaro, 200 to 400 ft above the creek near the railroad. This fan is composed of coarse cobblestone gravel, with some boulders, 3 to 5 ft in diameter, of various Belt rocks. The mouth of the gulch at which it heads is V-shaped as though unglaciated. At several places, both north and south of the Jocko Valley between Arlee and Ravalli, there are high benched spurs, or remnants of such, which may perhaps represent a Pliocene or early Pleistocene stage of valley cutting. Two to three miles northwest of Arlee, and due west of the point where the railroad and the highway cross the Jocko River, are similar well-defined remnants, 3,750 to 3,800 ft above sea level or 700 to 800 ft above the river. They are the beveled edges of northeast-dipping Belt rocks and appear to be remnants of a fairly well-defined bench. Their tops are sprinkled with cobbles and boulders of Belt rocks—maroon quartzite, greenish argillite, limestone, diorite, and amygdaloidal lava. Some of these rocks are subangular, others are well-rounded, and some show glacial striae. Apparently these stones, or some of them, were dropped from icebergs floating on the surface of glacial Lake Missoula, as they are below the uppermost level of submergence. The rock bench, however, may be Pliocene, as it seems better defined than the poorly marked lake shorelines lower on the hill slope southwest of Arlee.

East of Ravalli, and 800 to 900 ft above the river 3,650 to 3,750 ft above sea level, there appears to be a well-defined general bench on the upper south slope of the Jocko hills. It is now transected by numerous sharp gulches but is well represented on the crests of the intervening rock spurs by the beveled thin-bedded northeast-dipping argillite and quartzite of the Belt series. Here also, below the upper lake levels, are pebbles and boulders, some of them striated, which were dropped from icebergs onto the older benches on the hill slopes.

It is scarcely to be expected that anything like a continuous bench or terrace, or even remnants of one that could be definitely correlated in age with other Pliocene features, would be found preserved farther west down the Jocko Valley and the valley of Flathead River. At intervals, however, along the sides of the valley between Ravalli and the junction with the Clark Fork, certain features—the smoothly rounded, grassy, benched spurs 800 ft or so above the river—may mark one or more stages of valley broadening which interrupted the progress either of the original deepening of the valley or of the clearing out of such Tertiary deposits as there were in the original valley. In other places between Dixon and Perma the higher and steeper rock slopes are well back from the river, with lower grassed hills and smoothly benched spurs projecting below and beveling the steeply dipping Belt strata. Benches on the rocky slope south of Perma, 600 ft or more high, and a truncated rocky butte 300 ft high in the middle of the valley and around which the river bends near the railroad bridge, 3 to 4 miles below Perma, are suggestive of remnants of late Tertiary or early Pleistocene valley bottoms. Some of these features were referred to by W. M. Davis (1920, pp. 122–132) as "scourd and cleft" or "scourd and bencht" by glacial action. The present writer has found little or no evidence to support this interpretation and is inclined to regard them as the results of intermittent valley deepening and broadening by slope wash and stream erosion, working on upturned rocks, largely thin-bedded, brittle argillite.

One surprising feature is Burgess Lake, a small lake 350 to 400 ft above the south bank of the river at a point 5 miles below Perma. The lake basin is behind the rim of a great mass of rock which looks as though it had broken off and slid down from the edge of one of the rock benches that had perhaps been undercut by the river as it deepened its gorge. The only observed evidence of glacier ice in this part of the Flathead River basin is the presence of scattered striated pebbles and boulders and they were probably dropped from icebergs floating on glacial Lake Missoula.

It is quite possible that the runoff from that part of the Flathead River basin north of what is now the south bay of Flathead Lake did not, in Pliocene time, flow southwestward past Polson, either along or near the present outlet of the lake. There are low, partly drift-covered rock ridges southwest of Polson, and at several places the river is now cascading over rock ledges and flowing in a narrow inner gorge cut into upturned beds of the Belt series. There may have been only a minor tributary here, with others draining the basins of White Clay and Irving Creeks west of Polson, and the main stream may have occupied the Little Bitterroot Valley south of Lonepine. The reason for this supposition is that, as long ago described by Elrod

(1903) and others, there is a capacious abandoned valley, known as the Big Draw (fig. 23), which extends from the head of the west bay, or Big Arm of the lake at Elmo, westward through the hills to the valley of Sullivan Creek. This creek flows southward past Niarada and joins the Little Bitterroot River northeast of Lonepine, where its flat-bottomed valley is 4 to 5 miles wide.

The Big Draw is about 10 miles long, a mile or more wide, and has steep rocky side walls to the nearly flat, gravelly floor, beneath which there is considerable depth of fill. A glacial terminal moraine lies athwart this valley, completely blocking it 2 to 3 miles west of Elmo (fig. 24). The crest of this moraine, where crossed by the road, is about 3,500 ft above sea level, or about 600 ft above the lake. O. E. Meinzer (1917, p. 16) states that a well 560 ft deep, at the Floyd Frye ranch, on the moraine about 2 miles west of Elmo (NE$\frac{1}{4}$ sec. 22, T. 24 N., R. 22 W.) "passed through bouldery unconsolidated deposits and ended at a level considerably below Flathead Lake without reaching bed rock."

From the west front of the moraine the smooth surface of the outwash gravel slopes westward to the valley of Sullivan Creek, where there are finer lacustrine sediments. A well being drilled on the flat 2 miles northeast of Niarada in 1930 was said, by the driller, to have penetrated to a depth of 200 ft without reaching bedrock. Meinzer (1917, p. 15) states that most of the drilled wells in the valley between the west end of the Big Draw and the Flathead River west of the old Sloan ferry are 300 ft deep, ending in gravel which underlies the lacustrine sediments that floor the valley. About a mile above its mouth the Little Bitterroot is now cutting a small gorge in rock at one side of the old drift-filled channel.

There is some indication that Tertiary (Miocene?) deposits, perhaps faulted down, may underlie the Pleistocene sediments that form the present floor of the Little Bitterroot basin, as friable sandstone is reported to have been penetrated by a well northeast of Lonepine.

PIEDMONT FEATURES IN BITTERROOT VALLEY

In the Bitterroot Valley there are certain topographic features that may give some indication of the depth of the broad valley in late Tertiary and early Pleistocene time. With them is perhaps to be grouped a dissected bench or belt of rocky foothills south of Darby and Conner, between the inner valley of the upper main stream of the Bitterroot River and the steep and high mountain front on the west. They have not been traversed throughout by the writer but, judging by cross-country views from an altitude of 5,000 ft above sea level, the high wooded interstream spurs near the point where the forest boundary crosses Chaffin Creek extend westward to the steep, high, and rugged mountain front north of Trapper Peak. These ridges may be erosion remnants of a late Tertiary piedmont belt more than 1,000 ft above the present bottom of the inner valley of the Bitterroot River. Farther north corresponding features are more eroded. Excellent examples of what appear to be moraine-covered rock spurs, similar to those along the Mission Range and those in the Big Hole Basin across the Continental Divide to the southeast, extend for 1 to 3 miles from the mouths of the glaciated canyons of Tin Cup, Rock, and Lost Horse Creeks, as shown on the topographic map of the Hamilton quadrangle. Similar spurs border the glacial valleys of Trapper and Boulder Creeks farther south.

West of the West Fork ranger station and north of Nez Perce Fork there are remnants of dissected sloping benches strewn with cobbles and boulders of granite, gray quartzite, and some limestone, and apparently underlain by disintegrating granite such as is exposed in the bluffs below the lower ends of the benches. These benches and those farther south seem to indicate that cutting of the canyon was interrupted by intervals of valley broadening in late Tertiary and early Pleistocene time.

The lower 2 to 3 miles of the glaciated trough of Boulder Creek (in T. 1 N., Rs. 21 and 22 W.), is flanked by two narrow-crested sloping spurs 100 to 600 ft high. The spurs, which join the higher mountain slopes at altitudes of 5,200 to 5,300 ft, apparently have cores of granite and are covered with very bouldery lateral-moraine drift. It seems that these sloping spurs are interstream remnants of a broad, deeply dissected piedmont bench or belt of wooded foothills, one to several miles wide, that was originally continuous northward for 15 miles or more on the west side of the valley to the vicinity of Darby. The old erosion surface may have been at or near the level of the broad valley bottom in late Tertiary or early Pleistocene time. The lower trough of Trapper Creek, which is about midway between Boulder Creek and Darby, is also flanked on the east and west by similar, narrow-crested spurs 100 to 700 ft or more high. Unlike the trough of Boulder Creek, however, for about a mile below the junction of Little Trapper Creek with Trapper Creek, there are no morainal deposits or big boulders between the steep sides of the trough, and craggy ledges are exposed below the benched slope on the west side, showing that the bench at this side of the glaciated trough is not wholly composed of morainal drift but is an older feature.

Three or four miles west of Darby the mouth of the glaciated mountain gorge of Tin Cup Creek is flanked on the south by foothills but on the north by a curved, wooded ridge or spur nearly 3 miles long (pl. 4*D*). This spur has a smooth narrow top which joins the steep front of the mountain 5,100 to 5,200 ft above sea level, 800 ft above the creek, and about 1,400 ft above the river at Darby. From this altitude the top lowers east-southeastward in about 3 miles to 4,400 ft where it ends abruptly. The south side of this spur is very steep, being the north wall of the glaciated piedmont trough; the north side is somewhat dissected and is cut off from the foothills to the north by gulches draining to Bunkhouse Creek. The northeast side is regular and rises steeply 200 to 700 ft from the broad early Pleistocene piedmont terrace. The ridge is partly, although probably not wholly, composed of glacial drift. No exposures of underlying bedrock were seen, yet it seems very probable that beneath the coating of glacial drift the spur has a core of rock, possibly of Tertiary age such as is exposed in the bluffs in the vicinity of Darby; also, that this core is an erosion remnant of a piedmont terrace of either late Tertiary or early Pleistocene age corresponding to the benched spurs on the opposite (east) side of the Bitterroot Valley.

At the north side of the canyon mouth, east-dipping granite-gneiss is exposed in the south face of the big spur for at least one-eighth of a mile below the national forest boundary. Overlapping this rock, between 4,400 and 5,100 ft above sea level, is a great deposit of boulders and loose arkosic material, derived from granite, gneiss, and schist, during either Tertiary or early Pleistocene time. There are many relatively fresh granite boulders as large as 15 ft in diameter on the slope nearly to the top, but on the top at an altitude of 5,700 ft only small weathered fragments are present and no big fresh glacial boulders. The excavation of an irrigation ditch, which extends out onto the upper terrace near the south end of the spur on the west side, exposed loose, badly disintegrated material mostly of granite and gneiss ranging from fine particles to boulders 10 ft in diameter.

There are similar relations at the mouth of the next glaciated gorge to the north, that of Rock Creek. Here great drift-covered spurs curve both north and south of Lake Como (pls. 4*D* and 5). The longer and larger south spur, 3 miles long, is bisected by the headwater gulch of Waddell Creek. The smooth wooded spurs are about 4,700 ft above sea level at the eastern ends, or 1,000 ft above the river at Como. They join the steep mountain front 5,100 to 5,200 ft above sea level, or 1,000 to 1,200 ft above Lake Como. Exposures of gray and rusty-red arkosic sand in places on the slopes suggest that the spurs may be very largely composed of Tertiary sediments and may be erosion remnants of a late Tertiary piedmont terrace. Tertiary (Miocene?) rhyolite is exposed a mile or so to the east in the lower bluff south of Como.

On Lost Horse Creek, west of Como, there are two similar, high, drift-covered, curved spurs. The southern one (fig. 11, pls. 4*D*, and 5), 3 miles long, was traversed by the writer from end to end, and no evidence of Recent faulting was noted. From a height of 4,400 ft above sea level, near the eastern end and 700 ft above the river at Como, the smooth narrow crest rises westward to a height of 5,100 ft above sea level, where it joins the steep mountain front at the south side of the canyon mouth. The top here is nearly 900 ft above the stream in the glaciated trough on the north and 600 ft above Lick Creek on the south, and hundreds of feet above the bordering lateral moraines formed during the last extension of the Lost Horse glacier. The relations here likewise favor the idea that the cores of the spurs are composed of rock, perhaps Tertiary in age. Tertiary "lake beds" have been mapped for short distances to the north and east, and the lower bluff at the mouth of Lick Creek near Como exposes loose ashen-gray to rusty-yellow rhyolite of Tertiary(?) age. South-dipping rhyolite flows of Miocene(?) age also compose the benched spurs of the hills east of the river near Como. Farther north on the west side of the valley, where the glaciers were somewhat smaller, no such great drift-covered spurs have escaped erosion. There are, however, some small scraps of piedmont terraces at intervals between the gulches that transect the slope at the foot of the moun-

FIGURE 11.—Lateral moraine of Lost Horse Creek glacier. The morainal drift appears to overlie a benched spur or erosion remnant of a piedmont terrace of Pliocene(?) or early Pleistocene age. Glaciated gorge of Horse Creek cuts the fault line scarp at the east front of the Bitterroot Range (right). View south over inner moraines.

tains. There are relatively short benched rock spurs at the south sides of the canyon mouths of both Roaring Lion and Sawtooth Creeks. The former spur, as seen from the north, is notched and its eastern part has an appearance suggestive of faulting, although this appearance may be deceptive.

At the south side of the canyon of Blodgett Creek, 3 to 4 miles northwest of Hamilton, there is a benched spur 400 to 500 ft high and about a mile long, whose narrow sloping crest joins the steeper mountain front about 4,500 ft above sea level. This is similar to the larger spurs flanking the glaciated troughs 10 to 15 miles farther south. A cross notch and a short abrupt drop in the spur crest near the mountain front suggest Recent faulting. To what extent this spur has a rock core was not determined. The deeply weathered condition of some of the drift cover suggests it may be of early Pleistocene age and overlapped by the late Pleistocene lateral moraines of the Wisconsin stage.

At the south side of the canyon mouth of Mill Creek, half a mile from the foot of the mountain slope, there is a similar sloping spur. It is composed of bedrock and is not a glacial moraine. The south lateral moraine of Mill Creek glacier lies along its steep north face and curves around its lower eastern end. Farther north there are similar rock spurs flanking the mouths of the glaciated canyons of Fred Burr and Bear Creeks.

Four or five miles southwest of Stevensville, Big Creek emerges from the mouth of its deep canyon between two short benched rock-spur remnants of an old piedmont slope, about 4,000 ft above sea level and 400 to 500 ft above the creek. It seems probable that these benches mark the approximate level of the valley bottom in late Tertiary or early Pleistocene time.

In the valley of Lolo Creek there are well-defined benched spurs as high as 4,000 or 4,200 ft above sea level at both sides of the mouth of the South Fork gorge and for 5 or 6 miles farther west on the north side of the valley of Lolo Creek. It seems probable that these benches are due to stream erosion and mark one or more stages of broadening and downcutting in late Tertiary or early Pleistocene time, either during the original development of the valley of Lolo Creek or during the removal of any Tertiary deposits that may have occupied it. The well-defined benched spurs bordering the lower 1 to 1½ miles of Mormon Creek southwest of the village of Lolo seem clearly to be of early Pleistocene age.

The benched spurs and terraces on the Burnt Fork of Bitterroot River southeast of Stevensville are described on page 85.

It will be noted that the benched spurs in the Bitterroot Valley are very similar to those in the Big Hole Basin, east of the Continental Divide, described on pages 43–44.

THE REGION OF PHILIPSBURG, DEER LODGE, AVON, AND WEST TO MISSOULA

High-level features similar to some of those in the Big Hole Basin are also to be seen in the Philipsburg quadrangle on the west side of the Continental Divide. From a ridge top about 3 miles south of Georgetown Lake and 1,000 ft above it, there is an excellent view southward across what appear to be much-dissected, benched-spur remnants of an old subsummit erosion surface (8,000 to 9,500 ft above sea level) heading below the high peaks of the Anaconda Range. It seems that such an erosion surface is probably not younger than Pliocene or early Pleistocene, inasmuch as stream-cut and glaciated gorges 1,000 to 2,000 ft deep on the headwater branches of Rock Creek and other creeks were subsequently eroded below its surface. Thirty to 35 miles farther north and to the east of Flint Creek, at places 9 to 12 miles south of Drummond, are gravel-capped remnants of the piedmont terraces at the north end of the Flint Creek Range. The highest of these terrace remnants are probably of Pliocene or early Pleistocene age. They lie upon the beveled Miocene and older sedimentary deposits and are 500 to 600 ft above the bottom lands along Flint Creek in northeastern Granite County, and 5,000 to 5,200 ft above sea level.

Four miles east of Drummond a similar narrow, gravel-capped terrace remnant is on Tertiary "lake beds" 700 to 800 ft above the Clark Fork and 4,700 to 4,800 ft above sea level, in and near sec. 2, T. 10 N., R. 12 W. The quartzite cobblestone gravel capping the butte composed of Tertiary "lake beds" one mile south of Goldcreek 800 ft above the Clark Fork and 5,000 ft above sea level, is also probably indicative of the position of the piedmont terrace of either late Pliocene or early Pleistocene time. With this terrace are probably to be correlated still higher parts of the piedmont terraces and benched spurs bordering the east front of the Flint Creek Range.

Eight miles north of Avon on Threemile Creek, a tributary of the Little Blackfoot, there are short but well-defined benched spurs flanking the glaciated gorges high above the terminal moraines. Like the bouldery tops of the ridge locally known as the Gravel Range, 15 to 18 miles to the northeast, these high spurs on Threemile Creek are probably of Pliocene or early Pleistocene age. They are hundreds of feet higher than the broad terrace of early to middle Pleistocene age, that extends 4 to 5 miles farther south. South of Avon, the higher of the gravelly benches (5,200 to 5,300 ft above sea level and about 600 ft above the Little Blackfoot River) is also probably of either Pliocene or early Pleistocene age. It is capped with bouldery cobblestone gravel overlying Tertiary "lake beds" composed of light-colored clay.

Numerous benched spurs project into the valley along the Clark Fork between Drummond and Missoula as remnants of well-defined terraces; typical of them are Medicine Tree Hill and Beavertail Hill between Bearmouth and Clinton. Each spur is narrow, 200 to 300 ft in height, and projects out more than a mile from the foot of the mountain slope. They are composed of upturned strata whose edges were beveled as the stream cut back the valley sides during an earlier stage. These spurs (whose tops are about 4,000 ft above sea level) and other relatively lower spurs may be remnants of Pleistocene terraces, the Pliocene valley-bottom surface being represented by shorter benched spurs higher on the mountain slopes—for example, the benched spur on the Tertiary "lake beds" east of Drummond. These higher spurs also correspond in relative altitude with the tops of the foothills on the upturned Tertiary "lake beds" north and northwest of Missoula. No careful study of the higher bench remnants has been made, either in the gorge of Clark Fork between Drummond and Missoula or in the equally deep and narrow gorge of the Blackfoot River above and below the mouth of Union Creek. Judging from views from the highway traversing the gorge between Bonner and Union Creek, there are indications, here and there, of high benched spurs which may perhaps be of Pliocene age. There are no known remnants of Miocene sediments in this gorge or in the gorge of the Clark Fork between Bearmouth and Missoula. Such sediments as may have been deposited in these gorges have apparently been completely removed by subsequent erosion.

Two to three miles north of the McNamara bridge, the road north to the ranger station on Gold Creek is graded over a high bench bordering the west side of the creek. Here there are two ponds in hollows due to slumping, perhaps, on yellowish to brownish clay such as is exposed on the road grade at 3,900 ft above sea level. The clay may possibly be of Miocene age corresponding to the deposits exposed to the southeast near Potomac, in Camas Prairie. About a mile southwest of Bonner there is a sloping bench 200 to 300 ft. above the Clark Fork. This bench, which is transected by the inner gorge of Deer Creek, is on beveled quartzite beds and is strewn with cobbles and boulders. Some, faintly striated, may perhaps have been dropped from icebergs that floated down the Blackfoot Valley from glacier fronts on or east of Gold Creek.

THE VALLEY OF THE CLARK FORK BELOW MISSOULA

Tertiary "lake beds" (Oligocene and Miocene) comprise foothills along the northeast side of the Missoula Valley and the valley of Ninemile Creek to heights of several hundred feet above the streams. It might be expected, therefore, that remnants of such deposits would also be found along the Clark Fork and its tributary valleys between Ninemile Creek and Paradise, if those valleys were in existence in Oligocene or Miocene time. So far as known, however, such deposits have not been found—with the possible exception of those near the mouth of Cold Creek, 1 to 3 miles southeast, and those near the mouth of Little Joe Creek, 1 to 2 miles west of Saint Regis. (See p. 32.)

At numerous places there are remnants of well-defined terraces at three or four different heights above the stream that now flows in a constricted inner gorge cut to depths of 30 to 50 ft or more in upturned strata of the Belt series. In many places the edges of these strata are smoothly beveled and overlain by deposits of coarse gravel, sand, or silt. From the terrace remnants it is inferred that this part of the valley between Huson and Paradise, either when originally developed or when later cleared of Tertiary deposits, was eroded at several stages such as characterized the upper Missouri River valley and its tributaries. Inasmuch as the river is now cutting into bedrock in numerous places, it would seem that this part of the valley never has been eroded to greater depths than its present bottom.

There is one well-defined and easily accessible terrace remnant about 4 miles west of Huson, at the river bend east of the mouth of Ninemile Creek. On this terrace, above the highway (U S 10) and about 700 ft above the Clark Fork, stands the tower of Cayuse fire-lookout station. The smooth flat bench that forms a beveled surface on the underlying rock is capped with water-worn, quartzite-cobblestone gravel.

Opposite the mouth of Ninemile Creek east of Alberton, the south wall of the valley is about 2 miles back of the point of the terrace around which the river now flows. Low rock ridges rise above the surrounding Pleistocene terrace deposits, like remnants of a higher terrace or benched spur now worn away.

One place where several terraces may be seen is near Cobden (Lozeau) 8 to 9 miles above Superior. At this place the river is in a narrow inner gorge cut 50 ft or more in upturned rock below the gravel-capped terrace, on which lie the highway and the Northern Pacific Railway, east of the stream. One hundred feet above the railroad is a narrow terrace capped with reddish clay over cobblestone gravel. Behind it and 300 ft high is another terrace on beveled southwest-dipping maroon argillite of the Belt series, about 450 ft above the river. To the south there appears to be a fourth terrace 200 ft or so still higher, or about 3,400 ft above sea level.

Six or seven miles northwest of Superior and hundreds of feet above the highway, which is on the principal Pleistocene terrace, there are some conspicuous shoulders on the side-slope spurs that strongly suggest Pliocene or early Pleistocene stages in the progress of valley cutting, like the bench slopes on Lolo Creek southwest of Missoula.

An uneven, worn-down rock spur projects nearly half way across the mouth of the gorge of the Clark Fork just south of the confluence with the Flathead River above Paradise. The character of the remnants of the cut terraces is well shown on the Clark Fork at a bend south of Quinns, about 6 miles south of Paradise. The river here flows in a narrow, winding, inner gorge cut 200 to 300 ft below the tops of small bench spurs. One, which is cut through by railway tunnel 9, is composed of an upturned sill of diorite. The terrace on top of the adjacent spur on the west forms a beveled edge on the upturned argillite of the Belt series. South of it are other benches mostly higher and older than the adjacent (late Pleistocene) gravel terraces.

One or two miles southeast of Paradise a well-defined bench about 400 ft above the river (2,900 ft above sea level) is backed by a steep cliff to the higher mountain slope. Part of the bench is smooth and flat with loamy soil overlying the beveled edges of upturned argillite strata and a diorite sill. The smoothly rounded cobblestones that are mixed with the angular talus blocks below may have come from terrace gravel originally covering the bench. A belt of rocky foothills that borders the base of the opposite valley wall 2 to 3 miles farther downstream may be worn-down remnants of an old valley floor at the same height as the bench above Paradise. The significance of a conspicuous, high, gravel-capped bench bordering Boyer Creek between Plains and Rainbow Lake to the northeast (fig. 13 *A* and 17) is described on pages 96–97. This bench may be of Pliocene or early Pleistocene age. It is very similar in some respects to relatively high bench remnants near and east of the Rocky Mountain front, which are probably at least as old as Pliocene or early Pleistocene. Bradley (1936, pp. 163–199) described similar benches near the front of the Uinta Mountains in southern Wyoming.

For some distance above the mouth of Thompson River the valley of the Clark Fork is relatively narrow with steep side walls. In this part, sometimes referred to as the Eddy Narrows, the gorge transects an anticline composed mostly of pre-Cambrian quartzite. This part of the Clark Fork gorge may perhaps have been deepened as much as 800 or 1,000 ft since Pliocene time. There appear to be conspicuous benched spurs opposite Eddy and also at the mouth of the gorge of Cherry Creek southeast of Thompson Falls.

One of the most noteworthy, though small, remnants of stream-cut rock terraces is almost directly in front of the mouth of Thompson River gorge, 6 to 7 miles above Thompson Falls on the Clark Fork (fig. 12). The beveled edges of the upturned limestone and quartzite that form the top of this cut-off remnant are about 100 ft above the surrounding gravel terrace and about 300 ft above the Clark Fork. The old grade of State Route 3 crossed the gravel terrace and passed through the gap that separates this small cut-off terrace from the mountain wall on the east (right side of view). The newer grade is at the south edge of the terrace. The inner gorge of Thompson River transects the gravel terraces and separates this small rock terrace from the mountain wall on the west. There appear to be scraps of a corresponding terrace on the opposite side of the Clark Fork. It would seem that the development of such a well-defined terrace by the bevelling of the upturned rock strata must indicate a definite stage in the erosion of the gorges of both the Clark Fork and the Thompson River, probably either of Pliocene or early Pleistocene age. The altitude of this terrace top is about 2,700 ft above sea level—not far above the level to which slack water may have been backed up the Clark Fork valley by the deposition of the Latah formation of late Miocene age and the overlying basalt flows that blocked the Spokane and Columbia Rivers in Idaho and eastern Washington. Whether or not the relative altitudes have any genetic significance or correlative value is not clear. Possibly the terrace at the mouth of Thompson River might be a remnant of the early Pleistocene valley bottom.

FIGURE 12.—Stream-cut rock terrace in Thompson River canyon showing the beveled edges of upturned strata 100 ft above the Pleistocene gravel terrace in the foreground.

About 22 miles north of Plains the Thompson River is joined by an eastern tributary, the Little Thompson River. For 15 miles below the confluence the Thompson River flows southwestward in a narrow rocky gorge traversed only by a trail before 1938. At the upper end, this gorge appears to have been cut several hundred feet below an older and broader valley bottom now represented by benched spurs. Three to four miles north of the Little Thompson, a high bench or older alluvial fan is transected by Bear Creek for a mile below the mouth of its canyon. It is directly opposite a terraced basin known as Big Prairie and is 400 to 500 ft or more above the low gravel terrace bordering the Thompson River near the bridge. The steep bluffs below the smooth, sloping, wooded tops of the bench remnants are largely overgrown and show no rock ledges where examined, only fragments of rocks of the Belt series, quartzite, argillite, and limestone, and some intermingled rounded cobbles and boulders (torrential wash?). It is not certain, therefore, that there is a rock-cut terrace beneath the torrential wash, although it is not improbable. The head of this terrace is beveled across the edges of west-dipping, gray quartzite, and Bear Creek now cascades over a rock ledge in which the narrow inner gorge is cut. It is quite possible that this Bear Creek bench was formed at about the same time (Pliocene or early Pleistocene) as the Boyer Creek bench near Plains, 10 to 20 miles farther south.

There are other benched spurs or high terrace remnants farther north up the valley of the Thompson River. A short distance below the mouth of Thompson River the valley of the Clark Fork increases in width abruptly from a gorge less than 1 mile wide to a valley 2 to 3 miles wide. Here the river crosses the line of the Hope fault, which is thought to extend farther southeastward up the tributary valley of Cherry Creek. Thence northwestward below Thompson Falls the river has cut a narrow inner gorge in the much broader main floor of the valley. The broad valley has apparently been eroded along a zone of faulting or shearing bordering the Hope fault, which is continuous northwestward into Idaho.

A short distance southeast of Thompson Falls there are rather broad gulches cutting the south valley wall and quite definitely hanging above narrow, sharply cut, V-shaped inner gorges of a later stage of erosion. One to two miles east of Thompson Falls, and north of the two gravel terraces bordering the river is a gravel-capped rock bench directly in front of the mountain gorge of Ashley Creek, which hangs about 500 ft above the river. This is about the same height as the tops of some benched spurs south and southeast of Thompson Falls on Prospect and Cherry Creeks.

At many places between Thompson Falls and the mouth of the Vermilion River the Clark Fork is flowing on rock at the bottom of an inner gorge cut 50 to 200 ft in depth below the main, broad, nearly flat floor of the valley. At such places the upturned and beveled edges of the Belt rocks, limestone, quartzite, argillite, and shale, are exposed on the sides of the inner gorge. South of Whitepine several small rock ridges rise above the surrounding benchland or terrace in the midst of the valley. There are well-defined higher benched spurs west of Belknap and at the canyon mouth of Beaver Creek. The Little Beaver Creek turns north, back of a cut-off rock ridge, which stands nearly athwart the mouth of its canyon like an old terrace remnant, and flows thence out across the broad bench. Midway between Belknap and Whitepine the road on the northeast side of the river extends up over five terrace steps above the stream onto the back of the bench at the foot of the mountain in order to get around the bend where the channel is cut 300 to 600 ft deep into upturned, gray and purplish shale. Some of the cuts on the old upper railroad grade south of Whitepine show 10 to 30 ft of loose micaceous sand in places below the upper terrace. Such sand might possibly be of Tertiary age and have been derived from long weathering of granitic rocks like those in the lower parts of the gorges of Vermilion River and White Pine Creek, west and northwest of Whitepine.

Much material, including boulders 1 to 6 ft in diameter, is exposed in several places in the bluff and railroad cuts below the broad bench, such as the bluff near the Trout Creek bridge. Some is unsorted and looks like glacial till but no striated stones were found in it. The mixture also looks like torrential wash. West of the low terrace around which the river swings southeast of Whitepine this material is cemented into conglomerate, ledges of which project from the old bluff face above the railroad. There is, however, so far as noted, nothing to indicate that either the conglomerate or any of these consolidated deposits are older than Pleistocene. Much of the bouldery and gravelly material is spread out opposite the mouths of tributary gulches, as though derived by torrential wash from them and not wholly or largely transported down the river valley from more distant sources. Many of these gulches contained mountain glaciers.

Noteworthy gulch fills on the Vermilion River are described on pages 160–161. As shown on the topographic maps of the Trout Creek and Libby quadrangles, between the mouths of Vermilion and Bull Rivers, there are other small low rock hills rising above the terrace surfaces; there are also large semidetached rock hills west of the river near Trout Creek and Tuscor. There is a conspicuous benched spur at the west side of Rock Creek (2,700 to 2,800 ft above sea level). Another, 2,800 to 3,000 ft above sea level, capped with coarse gravel, projects out into the valley at the west side of Bull River, and still another (3,000 ft above sea level) is 2 miles farther west on the opposite side of the Clark Fork. It seems not improbable, therefore, that there may have been stages of valley broadening in Miocene and Pliocene time along a zone of faulting at levels somewhat above the tops of the intervalley hills and the lower benched spurs, and that they may have been controlled by the levels of the basalt or other rocks across which the Spokane, Pend Oreille, and Columbia Rivers cut new parts of their post-Miocene gorges before the invasions of the Pleistocene glaciers.

In the vicinity of Cabinet and Clark Fork, Idaho, between the Montana-Idaho State line and Pend Oreille Lake, there are several intravalley hills of rock, one of them known as Antelope Mountain. (See Priest Lake topographic map and fig. 13 *B*.) These hills are cut off from the north wall of the broad valley by gaps

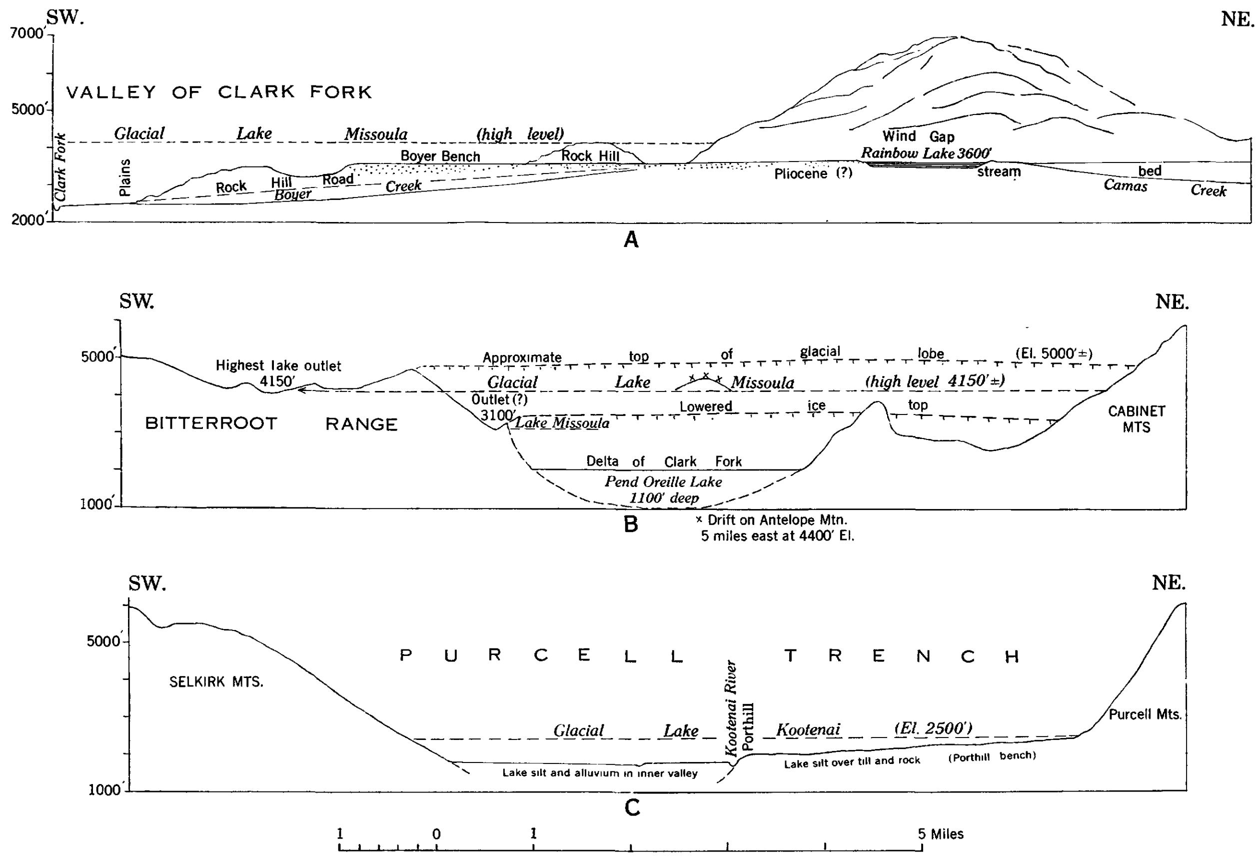

FIGURE 13.—*A*, Profile near Plains, Mont., showing relations of the Boyer bench and the wind gap containing Rainbow Lake. *B*, Cross section of the valley of Clark Fork near Pend Oreille Lake in Idaho, showing relations of the glacier ice dam which impounded glacial Lake Missoula. *C*, Cross section of Purcell Trench (valley of the Kootenai River) near the international boundary, showing relations of the Porthill bench.

eroded along the line of the Hope fault, and they are separated from the mountains at the south by the inner valley of the Clark Fork, which is 1 to 3 miles wide here. The tops of the hills range in altitude from 3,000 to 4,400 ft and are 1,000 to 2,500 ft below the mountain crests north and south of the valley. Under the delta between Clark Fork village and the lake there may be 500 to 1,000 ft of Pleistocene and Recent filling. Whether there is a filled inner gorge south of the small rock gorge above Cabinet is not known to the writer.

HIGHLANDS OF THE BITTERROOT RANGE AND CABINET MOUNTAINS

Most of the writer's study of the highlands of the Bitterroot Range and the Cabinet Mountains bordering the valley of the Clark Fork below Missoula was based on examination of the available contour maps. The few ascents and traverses of crests were made at places accessible by automobile on Forest Service roads. The cross-country views thus obtained yield little, if any, evidence of the preservation of actual remnants of any definite, old, high-level plateau or peneplain of either Tertiary or early Pleistocene age.

From the fire lookout on Two Trees Point (6,000 ft above sea level), about 18 miles north of Thompson Falls, and above Fishtrap Lake, there is a very extensive view in all directions over an area that has been deeply dissected by Thompson River on the east and Vermilion River on the west and their tributaries. The interstream spur ridges have very narrow tops and the rugged cirque-scalloped slopes of the Cabinet Mountains rise to numerous bold peaks on the skyline at altitudes of 6,000 to 8,700 ft, or 3,000 to 6,500 ft above the Clark Fork.

Where seen for several miles east and west of the fire lookout on Mount Bushnell (5,961 ft above sea level), the crest of the Coeur d'Alene Mountains is very narrow and uneven. In view from this crest there is a wilderness of profound V-shaped gorges and narrow-crested, interstream spurs descending on the north toward the Clark Fork and on the south toward the Saint Regis River. Only from the hazy distances south of the latter stream does the observer get any impression of a plateau or a suggestion of an uplifted peneplain.

The same is true of cross-country views as seen from the road near the State line on the very narrow crest of the Bitterroot Range southwest of Noxon and Heron, Mont., and south of Cabinet, Idaho. As seen from vantage points on this crest, the Cabinet Mountains show very rugged flanks and an uneven crest line.

Similar views of the uneven narrow top of the Bitterroot Range and of the deeply dissected flanks of the range west to southwest of Saint Regis were obtained during a traverse of the crest-line road for about 20 miles between Little Joe Mountain and Craddock Peak. Similar conditions were also noted in a drive to the pass near Oregon Peak southwest of Superior and in another to the Ninemile Divide northeast of Superior, within the great **S**-shaped bend of the Clark Fork.

Cross-country views south to west from the narrow crest of the Bitterroot Range near the Lolo Pass, about 45 miles southwest of Missoula, show similar deep dissection of the so-called Idaho plateau by the Lochsa River and its tributaries, with few or no recognizable remnants of a very old, high-level erosion surface. There are some conspicuous and fairly high benched spurs on the slopes of the lower gorge of Lolo Creek, southwest of Missoula. Some may represent late Pliocene to early Pleistocene stages in the deepening of this narrow valley.

PEND OREILLE RIVER IN NORTHERN IDAHO AND WASHINGTON

West of the village of Clark Fork, Idaho, and 9 miles west of the Montana-Idaho State line, the Clark Fork flows into Pend Oreille Lake (2,051 ft above sea level). This lake is very irregular in shape and its northern arm stretches 18 to 20 miles directly across the southward continuation of the great intermontane trough for which Daly (1912, p. 26) has proposed the name Purcell Trench. The great Purcell Trench (fig. 14 and pl. 2) is similar in character to, and nearly parallel with the Rocky Mountain Trench in the southern part of which is Flathead Lake in Montana.

At the outlet of Pend Oreille Lake near Sandpoint, Idaho, the Pend Oreille River emerges from the lake and flows thence in a westerly direction through a rocky valley cut across the southern part of the Selkirk Mountains. (See Priest Lake, Idaho-Mont. topographic map.) Beyond the Idaho-Washington State line, the river continues first westward, then northward in another broad intermontane valley.

As pointed out by Anderson (1927, pp. 7–9), there are some indications that the valley below Newport in eastern Washington was not always occupied by a northward-flowing stream. It may originally—before the Miocene basalt eruptions—have drained southward to the Spokane region. As shown in figure 14, the courses of most of the creeks coming down from the mountains on the east and west are arranged as though originally tributary to a southward-flowing trunk stream. Most of them either join the Pend Oreille River at high angles or are deflected northward only when they reach the lowland near the river. For much of the distance between Newport and Metaline Falls, Wash., the stream is generally, but not everywhere, bordered on one or both sides by bottom land and low terraces 1 to 3 miles in total width. It is narrower north of Ione than to the south. Just north of the town of Metaline Falls rock hills, largely of limestone, close in on both sides and the river enters a narrow gorge 200 to 300 ft deep. It drops about 20 ft over the falls and flows over rapids, having a total fall of 225 ft in 11 miles, to the international boundary (Marshall, 1914, pl. 3d). This gorge is very narrow in places; at one constricted place, known as Z Canyon, there is said to be a minimum width of 18 ft between the vertical limestone walls. On the east side of the stream, an uneven bench and a belt of low hills extend between the river and the mountains.

In places between the hills there is considerable filling of glacial drift and lacustrine silt. About 2 miles north of the international boundary the Pend Oreille River is joined by the Salmo River, also in a narrow gorge, and continues westward about 15 miles, in a broad curve, to its confluence with the Columbia River. In much of the lower part of its course, north of the boundary, the Pend Oreille River flows in a narrow inner gorge cut hundreds of feet below the bottom of a broader and older valley now represented by a sloping bench.

The relations of the river and its tributaries below Newport, Wash., may perhaps be the result of reversal in consequence of blocking of an earlier stream that flowed southward where there were relatively low gaps (2,300 to 2,500 ft above sea level), south of Sacheen and Diamond Lakes and southwest of Newport. The old divide between this stream and a branch of the Salmo River (British Columbia) may have been a few miles south of the boundary in the vicinity of Z Canyon and about 600 to 700 ft above the present stream, or about 2,400 to 2,500 ft above sea level. In Miocene time, southward flow of this stream may have been blocked to such a height by the spreading of the basalt that the water overtopped the northern divide and began to flow down the former lower course of the Salmo River to the Columbia. The present inner gorge below (north of) the site of Metaline Falls may then have been cut in Pliocene and Pleistocene time as the Columbia deepened its present gorge across the basalt and underlying rock. Just when the Pend Oreille River came into this valley at Newport is not certain.

Anderson suggests that prior to the deposition of the Columbia River basalt and underlying lake beds of the Latah formation in Miocene time, the through valley west of Sandpoint, Idaho, was not open to its present depth, and that the Clark Fork joined a river flowing southward through the Purcell Trench and the gorge that is now the south arm of Pend Oreille Lake. This river, he thinks, continued southwestward through the basin known as Rathdrum Prairie, where it was joined by the Priest River from the north and by the Saint Joe River, which then flowed northward through the valley where now Coeur d'Alene Lake lies.

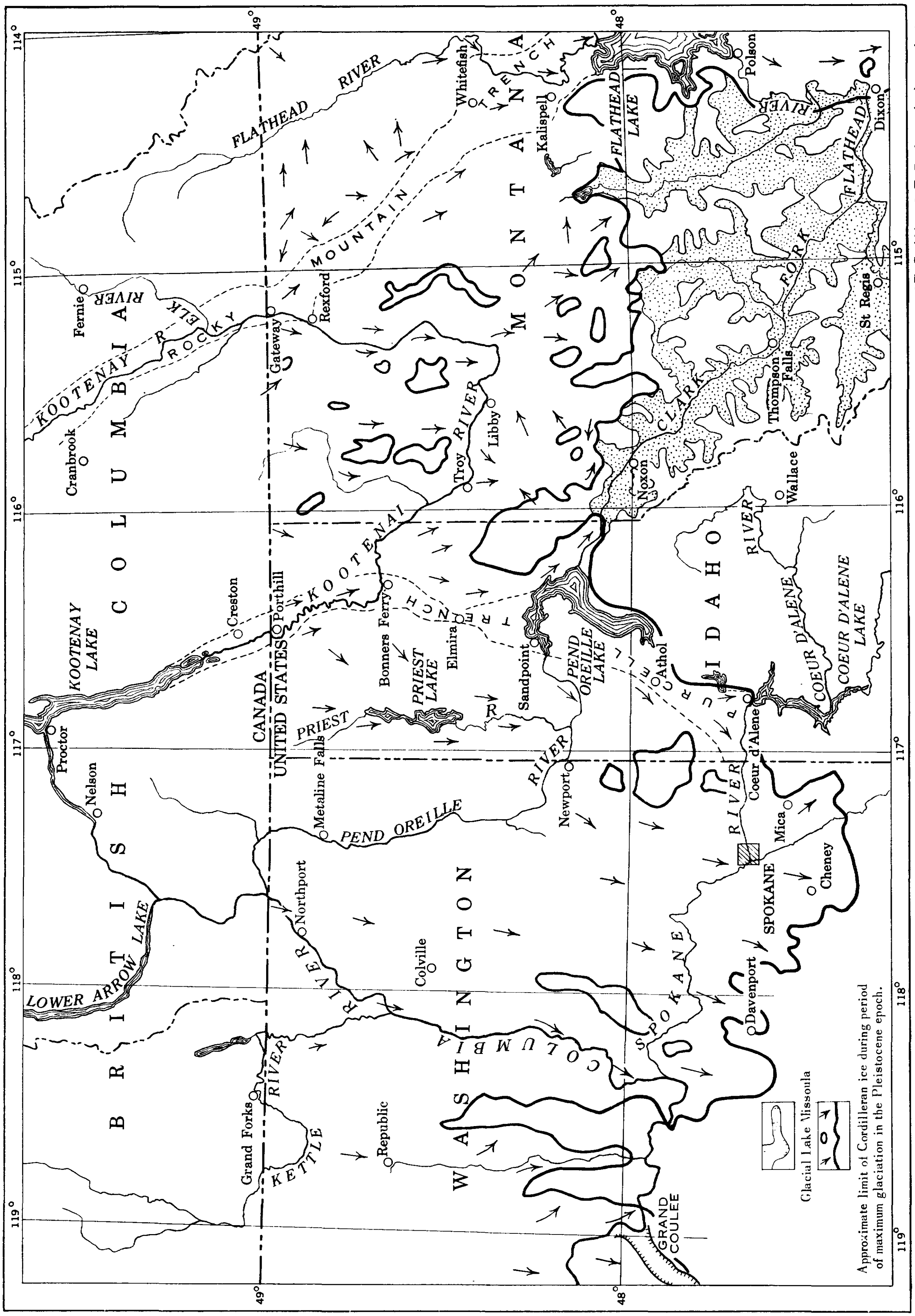

FIGURE 14.—Map of parts of Washington, Idaho, Montana, and British Columbia, showing relations of local Pleistocene glaciers and of part of glacial Lake Missoula.

The outlet from the Purcell Trench was, he thinks, westward down the broad Spokane Valley into eastern Washington and thence past the site of the city of Spokane to the Columbia River.

When the spreading basalt flows blocked this outlet in upper Miocene time (Pardee and Bryan, 1926; Berry, 1929) the fossiliferous beds of the Latah formation were deposited in the ponded waters. The uppermost basalt flows gradually spread eastward over the Latah beds and finally reached a point within 8 miles southwest of the present head, the southwest end of Pend Oreille Lake (pl. 2). At this place, on the east side of the valley and about 5 miles south of the village of Athol, Idaho, an erosion remnant of the basalt "rim rock" unconformably overlaps the upturned edges of argillite of the Belt series on the slopes of the pre-Miocene hills at an altitude about 2,500 to 2,600 ft above sea level. Doubtless the basalt was continuous westward across the valley to the mountains west of the islandlike mass of Lone Mountain near Twin Lakes, inasmuch as there is basalt overlapping quartzite at the southern end of the small ridge north of Garwood between the Northern Pacific Railway and the Spokane International Railroad. The exact depth of the valley previous to the basalt flows is not known to the writer. Sam Yates, the owner of a well at Athol, reported that a point driven in the bottom of this well did not reach bedrock at a depth 380 ft below the surface—that is, 35 ft lower than the level of the water at the Sandpoint bridge. That would be about 600 ft lower than the top of the basalt rim 5 miles south of Athol. A well on the broad bench west of Athol, which is 2,500 to 2,600 ft above sea level, was reported to have penetrated to a depth of nearly 500 ft without reaching bedrock. Anderson (1927, pp. 6, 8) states that wells 470 ft deep in the southern part of the Hoodoo Valley to the north did not reach the bottom of the fill, and that wells dug and drilled to depths of more than 450 ft in Rathdrum Prairie failed to reach bedrock, which there appears to be less than 1,800 ft above sea level. One well not far north of rock exposures east of Post Falls was reported to have penetrated 400 ft of gravel without reaching bedrock. Sampson (1928, p. 12) reported soundings to the depth of 1,100 ft in Pend Oreille Lake, or to levels less than 1,000 ft above sea level. It is doubtful, however, if the valley there was so deep before it was scoured out by the Pleistocene glaciers.

There are ledges of granite in places 2 miles south of Athol and also ledges of quartzite and basalt 5 to 8 miles to the southwest, between the Northern Pacific Railway and the Spokane International Railroad and well out in the broad flat 1 to 2 miles from the southeast side of the valley. Between these ledges and Lone Mountain is an area about 2 miles wide where no rock ledges are known to be at or near the surface. This gap may perhaps have been ample for the southward flow of the ancient Clark Fork before the time of the basalt flow.

As soon as the valley between Pend Oreille Lake, Idaho, and Spokane was blocked by basalt in upper Miocene time, the ponded waters in the Purcell Trench rose until they found another outlet. If the valley west of Albeni Falls was not then deep enough, the drainage of the Purcell Trench north of the Pend Oreille basin may have been reversed, as suggested by Anderson, to flow northward across the divide, entering the Purcell Trench near Bonners Ferry, Idaho, and so have reached the Columbia River by way of the Kootenay [6] River southwest of Nelson, British Columbia (fig. 16). This is on the supposition that the Columbia River itself either had maintained, or soon opened, a sufficiently low channel across the marginal parts of the basalt plateau in eastern Washington to take care of all the drainage of the Clark Fork and Kootenai River basins. If there was an outlet low enough westward past the present site of Albeni Falls, the outflow may have followed the present route past Newport and Metaline Falls to the Columbia. The present topographic conditions are not indicative of the route that was followed.

THE VALLEY OF THE KOOTENAI RIVER AND THE PORTHILL BENCH

The Kootenai River, for 85 miles southward to the 49th parallel at Gateway, Mont., and also nearly to Rexford, 6 or 7 miles farther south, flows in the Rocky Mountain Trench (pl. 2). From the international boundary, where it is 8 or 9 miles in width, this great trench continues southeastward between the rugged Galton Range on the east and the less rugged Salish Range on the west to the broad valley north of Flathead Lake. South of the divide near Dickey Lake, the Stillwater River flows in an inner valley below usually definite, thinly mantled, gently undulating to hilly rock benches 200 to 400 ft high. It is not known that there are any Tertiary sediments in this part of the trench unless they are the laminated silts containing fragments of fossil leaves, which are exposed in cuts along the Great Northern Railway a short distance south of Olney. If these are of Miocene(?) age like those on the Flathead River, the somewhat dissected and heavily glaciated benches may perhaps be regarded as remnants of the Pliocene valley bottom. From the divide at Dickey Lake northwest to the international boundary, the drainage is tributary to the Kootenai River by way of the Tobacco River. In this part the floor of the great trench, known as the Tobacco Plains, is conspicuously fluted with small drumlin-shaped rock ridges as the result of later glaciation. North of Eureka, particularly, the rocky floor is mostly covered by rather thick glacial drift and associated terrace deposits. In its descent to the Kootenai River, Tobacco

[6] Spelled Kootenai in the United States and Kootenay in Canada.

River has cut a narrow gorge in the rock of the Belt series below the drift and terrace gravel. Near Rexford the Kootenai River diverges from the Rocky Mountain Trench and continues more directly southward along the east foot of the rugged Purcell Mountains for about 45 miles to the mouth of Fisher River. The gorge in most places is not more than a mile wide at the bottom, and the mountains on the east are in general not so rugged or so high as those on the west. The Roosevelt Highway (US 2) on the west side of the river was traversed by the writer, but only at certain places close to the road was careful examination made. For most of the way the road is on a low gravel terrace and at many places remnants of terraces 100 to to several hundred feet above it were seen on each side of the river. Some are probably underlain by rock and correspond to the rock benches farther east and west.

The Fisher River flows northward in a gorge to join the Kootenai River east of Jennings, Mont. Here the Kootenai flows westerly in a canyon cut almost directly across the mountain ridges delimiting the Purcell Mountains on the north and the Cabinet Mountains on the south. West of the valley of Fisher River are two other nearly parallel valleys—that of Libby Creek, which joins the Kootenai River at Libby, Mont., and the through valley in which Lake Creek drains northward to the Kootenai River from Bull Lake and the Bull River flows southward to the Clark Fork. In these valleys there are terraces of lacustrine silt; sand and gravel, and glacial drift of Pleistocene age. (See pls. 1 and 2.) For 5 miles near Libby and for 5 miles above Troy the terraces are transected by the Kootenai River. In places these Pleistocene terraces appear to be underlain by rock, but it is not certain that they are well-defined pre-Pleistocene rock terraces, such as might be correlated with the Porthill bench, of probable Pliocene age, north of Bonners Ferry, Idaho.

In the Kootenai gorge between Jennings and Libby well-preserved remnants of the Pleistocene terraces were noted, but there are few indications of older terrace remnants cut on rock. There are high-level benched spurs at the head of the deep and narrow section of the gorge between Libby and Troy. It is probable that there were quite definite stages of valley broadening, perhaps along belts of faulting, north and south of the river in the region of Libby and Troy, but there seems to be no way to determine what was the depth of these parts of the Kootenai and tributary valleys when the basalt flows obstructed the Columbia River in northeastern Washington in late Miocene time. Evidently the several sections of the Kootenai River gorge were not so deep then as now, for the river is now definitely cutting into the narrow rock floor of the canyon at an altitude of 1,900 to 2,000 ft (Erdman, 1941), in places 100 ft or so.

About 9 miles above its junction with the Kootenai River the Yaak River plunges over ledges of gray quartzite at the falls, and flows southward in a deep, narrow, inner gorge cut below the bordering terraces. Above the bridge on U. S. Highway No. 2, the Yaak emerges from a narrow gorge cut about 400 ft deep into the rock below the upper terraces. Some creeks on the opposite side of the Kootenai River appear to have cut sharp inner gorges below the mouths of broader hanging gulches.

Near and below the Montana-Idaho State line, the Kootenai River flows in a narrow inner gorge, no wider than the stream, cut 600 ft below a broad upper bench on which is the highway (US 2) at the northeast side of the valley. (See pl. 2 and Priest Lake topographic map.) The lower 400 ft, at least, of this depth is cut through upturned rocks of the Belt series, largely maroon and green argillite with some interbedded diorite. This bench, which is probably the correlative of the Porthill bench, is somewhat uneven, with small hills of rock rising above surrounding flat tracts comprising deposits of gravel, glacial drift, and lacustrine silt of Pleistocene age overlying the rock.

About 6 miles west of the State line the Moyie River transects the broad bench. Between Moyie Falls and the junction of the Moyie with the Kootenai River, the Moyie flows more than 2 miles in a narrow gorge cut several hundred feet into the upturned rocks of the Belt series. West of the mouth of the Moyie River the outer valley—that is, above the level of the Porthill bench—broadens to a great recess in the hills, 8 miles or more in width, at the east side of the Purcell Trench. Here the inner gorge of the Kootenai broadens to a width of 1 to 2 miles where it transects the Porthill bench. At several places, as far as Mission Hill west of Bonners Ferry, bedrock is exposed near the river banks, so that it is probable this part of the inner gorge never was much deeper than now, even if the Porthill bench is as old as Miocene or Pliocene.

The main body of Kootenay Lake in British Columbia occupies part of an elongate, nearly straight trough, which diverges from the valley of Columbia River in latitude 51°31′ N. and extends about S. 10° E. into the United States. Curving slightly around Bonners Ferry, Idaho, this trough known as the Purcell Trench (pl. 2 and fig. 16), continues slightly west of south past Pend Oreille Lake to the basin of Coeur d'Alene Lake. It is bordered on the east and west through most of its extent by steep slopes of rugged, nearly parallel mountain ranges—the Purcell and Cabinet Mountains and Bitterroot Range on the east, and the Selkirk Mountains and lesser mountains and hills on the west.

The Purcell Trench as thus defined has a length of about 180 miles in British Columbia and about 120 miles in Idaho, a total of about 300 miles. In the southern part are the basins of Coeur d'Alene and Pend Oreille

Lakes and parts of the courses of some minor streams. (See topographic quadrangle map of Priest Lake, Idaho.) At Bonners Ferry, Idaho, Kootenai River emerges westward from a terraced, transverse valley into the Purcell Trench and, curving to the right, flows northward in a meandering course, through the broad flat bottom lands, known as Kootenai flats, for about 50 miles to the head of Kootenay Lake, about 18 miles north of the boundary. Kootenay Lake itself occupies 65 miles of the length of the trench. It ranges in width from 2 to 5 miles and has an area of 180 sq mi, including the West Arm, which branches from the west side of the main lake nearly at right angles, near Proctor, British Columbia, about 40 miles below the head of the lake. One sounding about 10 miles below the head of the lake showed 380 ft of water, and another about the same distance north of Proctor showed the maximum depth (so far as known to the writer) of 450 ft (McConnell and Brock, 1904).

Kootenay River emerges from the lower end of the West Arm about a mile below Nelson, British Columbia, and flows thence southwestward 20 miles to join the Columbia River. Between the West Arm and the head of the lake, the Selkirk Mountains rise abruptly from the shore; southward, to the vicinity of Bonners Ferry, they border the west margin of the broad flat bottom lands through which the river meanders. The lake is closely bordered on the east by the similarly steep Purcell Mountains. A short distance south of the lake this mountain front is a few miles to the east and lowers to ridges and hills. South of Creston, British Columbia, where Goat River comes in from the east, these hills lower and flatten to a broad terrace, or bench, above which, on the east, rises the abrupt west front of the Moyie Range. Near the international boundary this terrace, to which Daly has applied the name "Port Hill bench" (fig. 15*C*), has a width of nearly 3½ miles—that is, it here occupies the eastern half of the Purcell Trench, the western half being occupied by the Kootenai flats, the bottom land through which the river meanders.

The surface of the bench near the boundary is gently undulating, where not cut by ravines, and is partly cleared and farmed. It ranges in altitude from 2,100 to about 2,300 ft above sea level and is mostly 300 to 400 ft higher than the Kootenai flats down to which its western margin drops with a generally abrupt slope. Many of the cuts of the Great Northern Railway, which is graded along the foot of this marginal slope, expose the underlying rock, mostly intrusive gabbro with some quartzite and argillite. This rock extends about 4 miles south of the boundary to a point about 2 miles north of Copeland, and in this distance the bench narrows gradually to a width of about 1 mile, although the width of the bottom land continues to be about 3 miles. Southward to Bonners Ferry the bench has about the same altitude and is underlain by intrusive granite; it broadens gradually to a maximum width of about 4 miles, while the bottom land ranges from 1½ to 3 miles in width. For convenience of reference in this paper, the name "Porthill bench" is applied throughout the whole extent from Goat River near Creston, British Columbia, to Bonners Ferry, Idaho. The irregularities of the surface of the rock underlying the bench are mostly smoothed over by a coating of glacial drift and lacustrine silt, which in places have a combined thickness of 100 to 200 ft or more. A few low hills of rock rise above the general surface of the bench. North of the vicinity of Bonners Ferry there are no hills in the Kootenai flats and, so far as known to the writer, no ledges of bedrock are exposed or have been encountered in boring or excavating on the bottom land.

About 3 miles west of Bonners Ferry the Indian Mission stands on the south slope of a hill about 200 ft high, above the surrounding flat north of the river. Granite is exposed on the lower west slope of this hill and rock was encountered 7 ft below the surface in drilling a well at the Mission. The bottom lands also extend about 3 miles south of the river, and in this part there are several low rock ridges and knolls.

South of the valley of Mission Creek, which crosses the Porthill bench and joins the Kootenai River near Copeland, the mountains on the east are several miles to the eastward and a broad ridge 500 to 600 ft in height flanks the bench with a slope less steep near the boundary. An arc of 180° with a radius of 4 to 5 miles, centering on Bonners Ferry and drawn from a point northeast of that place around to the east, southeast, south, and southwest, roughly outlines a broad embayment between the foothills of the Purcell Mountains and the Cabinet Mountains, into which extend the continuation of the Porthill bench and its correlative on the south. Through it, Kootenai River has cut its inner valley to a depth of about 500 ft. Upstream from a point 1½ miles below the mouth of Moyie River the inner valley is a narrow rock gorge cut below the high terrace on the north. Between that point and Bonners Ferry the river has meandered in cutting downward, so that the width ranges from half a mile to 2 miles, including some low terrace remnants.

From the maps and from the above description it is apparent that, from the vicinity of Bonners Ferry northward to Goat River near Creston, British Columbia, the inner valley, across whose flat bottom Kootenai River meanders, forms approximately one-half to three-quarters of the bottom of this segment of the Purcell Trench. The bottom land terminates in the shallow basin (formerly Mirror Lake) 3 to 3½ miles southwest of Bonners Ferry. Encircling this lowland on the southeast, south, and southwest is an abrupt bluff rising 100 to 400 ft to the eroded margin of the broad high bench (2,300 to 2,400 ft above sea level) or to the margin of lower erosion remnants.

It is evident that the high terrace or bench was originally continuous from side to side in that part of the Purcell Trench between Moravia and the pass near Elmira, and that the minor gulches dissecting it, and the narrow valley of Deep Creek which transects it from south to north, are due to subsequent erosion. Just how far north of Moravia the high bench was continuous clear across the Purcell Trench is not known. South of Moravia the walls of the Purcell Trench are less regular and less well defined than farther north. The valley sides converge until their bases are only 1½ miles apart near Elmira. Farther south they diverge again until they are about 11 miles apart at the north shore of Pend Oreille Lake. The next segment of the trench to the south may either be considered as delimited by the abrupt slopes bordering the **S**-shaped basin of Pend Oreille Lake, or as embracing also the through valley to the west, which is mostly drained by Cocolalla Creek, and the adjacent rock hills on either side of it. From the lake southwest to the Spokane River and west down the latter's valley is a continuous broad open trough which had considerable control over the development of the features of the Kootenai River valley near Bonners Ferry.

Daly (1912, p. 600) concluded that the Purcell Trench was a graben due to the dropping down of an elongate block or prism between two parallel faults in post-Laramie and pre-Miocene time, and that it was later subjected to fluviatile and glacial erosion. He did not, however, actually locate either of the faults, and S. J. Schofield found no evidence of such a graben. Schofield summarized his conclusion as follows:

> The region now traversed by the Purcell Trench was peneplained in the Cretaceous, uplifted in the early Tertiary, and the Purcell Trench was eroded by one of the rejuvenated Cretaceous rivers during Tertiary times. No uplift is recorded in [later] Tertiary or Recent times. The Tertiary valley was glaciated in Pleistocene times, giving rise to the faceted spurs and hanging valleys so prominent in the architecture of the Purcell Trench.

Kirkham (Kirkham and Ellis, 1926, p. 32) indicates that the "basic granitic" rock underlying the Porthill bench near and south of the boundary is the extension of one of the sills interbedded in the series east of the valley, that it is not a downfaulted block distinct from the rocks exposed in the cliff to the east, and that "it appears evident that glaciation is entirely responsible for the width and depth of the trench and its present physiographic characteristics." He appears to include under this statement the denudation of the Porthill bench, together with its southerly continuation, and also the excavation of the inner valley below the western edge of this bench.

The present writer has no evidence bearing on the question of Daly's supposed faulting. It seems improbable that the full depth and width of the Purcell Trench above the level of Kootenay Lake and the Kootenai flats are due to glacial excavation alone. It seems more probable, in the light of regional physiographic studies, that the major part of the excavation above the level of the bottom of the present lake outlet (about 1,730 ft above sea level) is due to preglacial and interglacial erosion by one or more streams, perhaps working along a zone of fracturing and faulting. Very likely the 400 to 500 ft of depth of the lake basin below the level of the bottom of the outlet is due to glacial scour (unless some of the depth is due to Recent faulting), and there has probably also been a good deal of glacial excavation in that part of the trench prism above the level of the outlet.

An indication of the relatively great age of the Purcell Trench is found in the fact that the southern part of it in Kootenai County, Idaho, was already a deep valley when the Columbia River basalt was being deposited in Miocene time. When the successive lava flows gradually filled the great basin west of Spokane in eastern Washington (pp. 56–58) the valleys of streams flowing southward and westward into that basin were so blocked as to pond the waters within them and cause the deposition of the lake beds of the Latah formation, which were later covered by the lava as it advanced up the valley toward the Pend Oreille Lake region.

From the relations cited above it appears that the part of the Purcell Trench southwest of Pend Oreille Lake was probably 500 to 1,000 ft deeper in early or middle Miocene time than it is now, and the part now submerged beneath the water of Pend Oreille Lake may then have been about half as deep as the present lake basin, which, as Sampson states, is 1,100 ft. There is no evidence, however, so far as is known to the present writer, that in Miocene time the part of the Purcell Trench between Pend Oreille Lake and Bonners Ferry was anywhere near as deep as it was farther south. Then, as now, waters in it may have parted to flow southward and northward. It is probable, however, that Kootenai River was commensurate with its neighbor, the ancestral Clark Fork when the Clark Fork was flowing through the Spokane Valley, both in length and volume, although farther up the Columbia River system, and it may be that by upper Miocene or Pliocene time the Kootenai had so widened and deepened the part of Purcell Trench north of Bonners Ferry that its bottom was not much if any above the present top of the Porthill bench.

So high is the top of the basalt remnant southwest of Pend Oreille Lake that if it extended as a dam westward clear across that valley to the mountains between the basins of Twin and Spirit Lakes at approximately the same relative height as now (2,600 ft above sea level), it may have forced the water ponded in the valley of Clark Fork to overtop the divide in the Purcell Trench near Elmira, join Kootenai River and flow that way to reach Columbia River during later Miocene or Pliocene time. It is possible, however, if one may judge by present relative altitudes, that the basalt composing the Columbia River plateau between Spokane and the Okanogan Valley in northeastern Washington backed up the water in the upper Columbia Basin and into the Kootenai valley almost as high as in the valley of Clark Fork. Present altitudes of the basalt near the north edge of the plateau between Spokane and Grand Coulee are also about 2,500 to 2,600 ft above sea level, where the plateau has not been trenched by subsequent erosion. Even if the overflow from the valley of Clark Fork was diverted to the valley of the Kootenai River, it could not be of much assistance in deepening the latter valley below the level of the Porthill bench until the Columbia had trenched the basalt plateau in Washington below the level of that bench (which is now 2,200 to about 2,400 ft above sea level).

It seems probable from the study of the Columbia River terraces that by the end of Pliocene time, the Columbia River was flowing in its present course around the big bend in eastern Washington and had already cut down 1,000 ft or more below the rim of the basalt plateau. This downcutting by the major stream, especially if concurrent with a regional uplift, must soon have induced trenching of the broad bottom of the lower valley of the Salmo and Pend Oreille Rivers north of Newport, Wash., and the bottom (Porthill bench) and lower valleys of the Kootenai River in and east of the Purcell Trench.

PLEISTOCENE EPOCH

POSSIBLE PRE-WISCONSIN GLACIAL DEPOSITS EAST OF THE CONTINENTAL DIVIDE

As described in Professional Paper 174 (Alden, 1932, pp. 14–40), the oldest known deposits made by the Rocky Mountain glaciers of Pleistocene age are found on the highest remnants of the piedmont terraces or benches close to the east front of the Rocky Mountains in the Glacier National Park region—those deposits of supposed Miocene to Pliocene age. At a few places farther south in Montana and northern Wyoming there are similarly located bouldery deposits which probably were also made by Rocky Mountain glaciers in early Pleistocene time. Most of these high-level glacial, and supposed glacial, deposits near the east front of the mountains are on streams tributary to the Missouri River, including the Musselshell and Yellowstone Rivers.

The deposits cited here may seem to the reader relatively insignificant and not to warrant detailed description; however, as they constitute about the only available evidence bearing on early Pleistocene glaciation of this part of Montana, it seems essential to assemble descriptions of them in this paper for record. This is advisable even though it involves some repetition of description and though definite conclusions as to their early Pleistocene age are not warranted.

HELENA REGION

The most northerly remnant of the upper terrace in the intermontane basins tributary to the Missouri River is the so-called Gravelly Range (p. 34) between Canyon and Little Prickly Pear Creeks, 25 miles northwest of Helena. The stones constituting the gravel deposit capping the ridge 5,500 ft above sea level are fairly well rounded, and no glacial striae were seen on them; yet the abundance of included boulders 3 to 6 ft in diameter suggests the possibility that an early Pleistocene glacier may have assisted in the transportation northeastward from the parent ledges. However, material may be a torrential stream deposit formed when the creek was flowing nearly 1,000 ft higher than now. It was higher than the tops of the present shale hills between this deposit and the head of the basin to the southwest.

In the Big Belt Mountains, east of the Missouri River and the Townsend Valley there are some glacial deposits possibly of early Pleistocene age. Pardee (1925, pp. 37, 38) has described them as follows:

> Near Smith's ranch, at the foot of Mount Baldy, in sec. 13, T. 8 N., R. 3 E., a small moraine lies on top of bench No. 1. It forms a semicircular ridge about half a mile long and 50 ft high that shows the uneven topography, unassorted rock debris and large boulders characteristic of glacial material. The exposed material appears considerably weathered, and no striated surfaces were seen. At the back or east of the deposit a small valley extends part way up Mount Baldy. At the north and south are longer valleys, occupied respectively by branches of Gurnett and Ray Creeks that are cut well below the bench level. If at the present time a glacier should form on the upper slope of Mount Baldy, it would flow down either of these valleys rather than the one leading to the moraine. Therefore it is concluded that the moraine was deposited at an early stage of glaciation, before the deeper valleys were cut. Though no direct evidence of glaciation was found in the neighborhood of Cave Creek, the unusually large boulders in the bench gravel adjacent to that stream suggest the possibility of glaciation at a similar early stage.
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> The mountains surrounding Townsend Valley have not been examined in detail, but it is evident from distant views and available maps that they contain several cirques from which at a late stage small glaciers may have descended for moderate distances. Glaciers of this type are indicated to have existed at the heads of Boulder Creek, Crow Creek, and Beaver Creek, and the unusually coarse and bulky gravel along the lower courses of these streams is thought to be chiefly outwash of the late stage.

There are also bouldery deposits, probably of early Pleistocene glacial drift, capping high-level benches 40 to 50 miles east of Townsend at the south front of the Castle Mountains, on one of the headwater tributaries of the Musselshell River a few miles west of Lennep. (See p. 188; also, Alden, 132, p. 40; and Weed and Pirsson, 1896, pp. 144–145.)

BOZEMAN REGION

North of Reese Creek, 18 miles north of Bozeman near the mouth of a canyon cut in the west flank of the Bridger Range, there are many subangular to rounded boulders 5 to 10 ft in diameter on the head of an alluvial fan, 5,700 to 6,300 ft above sea level. The boulders are west of a morainelike ridge in the lower part of the canyon which may mark the limit of a late Pleistocene glacier at 6,500 to 6,700 ft. Peale (1896, p. 3) referred to the big boulder deposit on the piedmont terrace and suggested the possibility of its being glacial drift. It may, however, be the product of torrential waters. No other probable glacial deposits of early Pleistocene age have been observed on the Gallatin River or its tributaries farther south.

MADISON VALLEY AND VICINITY

Certain high-level bouldery deposits farther south in the Madison Valley may be the results of early Pleistocene glaciation. On the high bench (about 7,400 ft above sea level) north of Ward Peak, about 10 miles northwest of McAllister, the south lateral moraine of North Meadow Creek glacier lies on the northwest edge of the smooth, sloping benched surface. Traced northeastward, this moraine lies on the side slope of the gorge, which has been cut some hundreds of feet below this bench, showing that the moraine was deposited long after the piedmont terrace, of which the bench is a remnant, was formed. There are numerous 5- to 10-ft boulders on the bench outside the moraine and a gully, cut 10 to 30 ft deep into the bench, exposes a deposit of angular to subangular boulders of granite, gneiss, and schist 1 to 6 ft in diameter, which is probably much older than the adjacent lateral moraine. This deposit either may be part of an ancient alluvial fan or it may be early Pleistocene glacial drift. The possible correlation of the high bench remnant on which this bouldery deposit rests with the Pliocene(?) terrace bordering the Madison River northeast of Norris has been suggested on page 35. Insufficient examination of the big lateral spurs bordering the glacial trough on South Meadow Creek prevents determining whether they are composed of rock and pre-Wisconsin drift or contain only lateral moraines of Wisconsin age. The narrow spur tops join the steep mountain front 7,100 ft or so above sea level, and about 400 ft above the intervening creek bed.

If there was an early Pleistocene glacier on the high bench north of Ward Peak, there was probably also one on the high bench 6 to 8 miles farther north between the gorges of North and South Willow Creeks, southwest of the village of Pony. There are numerous big boulders of granite porphyry strewn over the partly wooded bench between 7,000 and 8,000 ft above sea level, which may be glacial, but ledges of the same rock are also exposed so that it seems probable that some of the boulders are residual. If, however, there was an early Pleistocene glacier heading in the cirques on and near Mount Jefferson, it probably extended out onto this bench, which is 1,000 to 2,000 ft or more above the bottoms of the gorges to the north and south and 1,000 ft above the terminal moraine of the glacier of North Willow Creek.

A conspicuous spur at the west front of the Madison Range, 6 to 8 miles south of Cameron (p. 35–36) extends northward from the foot of the mountain, known as The Wedge, on the west side of the glaciated valley of the South Fork of Indian Creek. A lateral moraine lies along the upper east face of this spur, like a north-sloping shoulder. Above the 7,300 ft contour the crest of the spur rises gradually above the moraine to join the slope of the mountain. It is quite possible, if not probable, that the upper part of this spur is composed of glacial drift much older than the lateral moraine for its steep west slope, 500 to 600 ft below the top, is thickly strewn with boulders of granite and gneiss 1 to 10 ft in diameter. Many of them may have rolled down to the lower levels from a capping of pre-Wisconsin drift on the rock spur. The top of the spur is high above the terminal moraine which spreads out on the piedmont at the north end of the spur and it is 600 to 1,200 ft above the adjacent part of the early Pleistocene piedmont terrace on the west. Peale (1896, p. 3 and map) mapped this spur as glacial drift, but did not differentiate the several parts of the deposit. It seems probable that the spur has a core of solid rock.

Southward to Wolf Creek all remnants of a Pliocene terrace or of early glacial drift lying thereon appear to have been destroyed during the development of the very extensive Pleistocene terraces. Beyond Wolf Creek the surface east of the river rises southward to a gently rolling upland between Moose and Squaw Creeks, which is underlain by lava. East of Sprague ranch (in T. 10 S., R. 1 E.) barometric readings show this surface to be 800 to 1,000 ft above the river. This lava-capped bench or upland is preserved for about 6 miles southward nearly to Hutchins bridge, except where transected by the lower gorges of Squaw and Papoose Creeks. As indicated on page 36, the bench probably represents the bottom of the Madison Valley in Pliocene time. Between it and the foot of the mountains to the east the surface has been lowered somewhat by erosion. Scattered over this bench 1 to 3 miles outside (west) of the terminal moraines of the late Pleistocene glaciers there are many boulders of granite and gneiss 1 to 6 ft in diameter; a few 10 to 15 ft in diameter were seen. Some have slid or rolled down the steep side of the inner valley to the river bank. Similar boulders also lie on one of the lower terraces on the southwest side of the river, 3 miles south of Hutchins bridge. They may have been let down by erosion. The size, character, and distribution of the boulders suggest that those on the high bench are remnants of a deposit of drift carried out by the glaciers that headed in the canyons of the Madison Range in early Pleistocene time, before the present inner valley, which is 800 to 1,000 ft deep, was eroded by the Madison River. The distribution of these erratic boulders was first pointed out by J. T. Pardee, who suggested that they represent very old glacial drift. From the south side of the mouth of the mountain gorge of Papoose Creek a high narrow ridge or spur projects diagonally across the direct line of the canyon to the east (fig. 4). The top of this ridge, 7,400 to 7,500 ft above sea level and 1,600 to 1,700 ft above the river two miles away, is 500 to 600 ft above the sag in the upland to the west. Like the high drift-covered spur flanking the South Fork of Indian Creek this spur also may be either an early glacial moraine or a drift-covered remnant of the late Pliocene piedmont terrace which sloped westward to, and merged with, the boulder-strewn bench underlain by lava at the top of the river bluffs. There are indications of the presence of similar old moraines or drift-covered spurs at the canyon mouths farther north on Squaw and Moose Creeks.

Nowhere else on the headwater branches of the Missouri River west of the Madison Valley have deposits been observed by the writer that appear probably to have been made by early Pleistocene glaciers, unless it be: in the northeastern part of the Dillon quadrangle near Grace, east of the Continental Divide, on the Chicago, Milwaukee, St. Paul & Pacific Railroad west of Whitehall; near Argenta, 10 to 15 miles west of Dillon in the southwestern part of the same quadrangle; or in the Big Hole Basin, 40 to 60 miles west to northwest of Dillon. It is quite possible that further examination of the dissected benchland between the headwaters of the Ruby River and the east front of the Snowcrest Range may reveal the presence of early Pleistocene glacial drift.

PRE-WISCONSIN DRIFT NEAR GRACE, MONTANA

About 14 miles southeast of Butte, where the Chicago, Milwaukee, St. Paul & Pacific Railroad and the highway (U S 10 S.) cross the Continental Divide at Pipestone Pass, there are abundant granitic boulders of disintegration. In sec. 27, T. 1 N., R. 6 W., near Grace (5,650 ft above sea level), 5½ miles southeast of the pass, certain deposits exposed in railroad cuts have been described by Atwood (1916, pp. 717–719). They have also been examined by Pardee and the present writer. A short distance south of the railroad and at levels several hundred feet lower Fish Creek flows in a narrow gorge cut in much weathered granite. A tramp of a mile or two up this gorge revealed no evidence of this part having been traversed by a Pleistocene glacier. The presence of cirques on the north flank of Red and Table Mountains indicates that there was a branching glacier at the head of Fish Creek in late Pleistocene time, but it did not extend within 2 miles of Grace.

West of Grace, at an altitude of about 6,900 ft, is a large excavation about 20 ft deep in a partly sandy and very bouldery unstratified deposit which has the general appearance of glacial till. The stones are angular to subangular, many of them 1- to 3-ft boulders of granite, deeply weathered and crumbling, but not mashed. There are also 1- to 2-ft boulders of quartzite. Search of both sides of the cut revealed faint striations on one of the stones. Near the southeast end there is either a buried ledge of granite or a group of protruding boulders 5 to 10 ft in diameter. Granite is also exposed on the ridge top south of the cut, with some boulders, perhaps of disintegration, on the surface. Atwood reported finding striated stones in the railroad cut and suggested that the deposit may be early Pleistocene till laid down before the present gorge of Fish Creek was eroded. It seems quite probable that this till is at least as old as early Pleistocene.

More recently the Atwoods (1938, pp. 243–244) described other exposures of what may be parts of the same or a similar deposit, as follows:

> One and a half miles north of the little railroad station at Grace, Montana, which is southeast of Butte, there are exposed along the newly built highway several sections in an ancient till that is far removed from and unrelated to the modern canyons or modern cirques. . . . At this locality all the physical characteristics of glacial drift are displayed and striated stones are abundant.
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> In 1915 the senior author found other remnants of bouldery deposits on the highlands northeast of Butte. These were not revisited in 1936, but they are now believed to be of Cerro age. At the two best localities, the one south of Silver Bow and the one near Grace, the old glacial deposits rest upon eroded surfaces in the Bozeman beds which have been judged to be of Oligocene or Miocene age. This evidence makes it clear that the Butte deposits do not correspond in age to the Eocene till found near Ridgway, Colorado.

The character and relations of the deposits south of Silverbow are described on page 65. The present writer has not seen the "bouldery deposits on the highlands northeast of Butte."

DEPOSITS NEAR ARGENTA AND IN THE BIG HOLE BASIN

Near Argenta there is a large remnant of a smooth, high bench south of Rattlesnake Creek, 200 to 500 ft above the stream. Examination of bouldery gravel on this bench, however, revealed no granite boulders, such as the large and abundant boulders on the terminal moraine in the gorge a short distance farther north. The bench is in such a position that an early Pleistocene glacier heading in the Pioneer Mountains to the north might have extended out onto it before the gorge of Rattlesnake Creek was cut, but no evidence was noted that there was glaciation of the bench.

It was anticipated that examination of remnants of high-level piedmont terraces in the Big Hole Basin southwest of Anaconda would yield definite evidence of early Pleistocene glaciation of the Anaconda and Beaverhead Ranges. Examination of parts of the high gravel-capped spurs in the Big Hole Basin above and outside of the bouldery lateral moraines on the east and west sides of La Marche Creek and on the east side of Pintlar Creek did not reveal the presence of any early Pleistocene glacial drift where it might be expected. For a mile or more on the smooth-topped benched spur east of Howell Creek and north of the boundary of Beaverhead National Forest (secs. 26 and 27, T. 1 N., R. 15 W.), and in a similar position west of Howell Creek and outside the forest boundary (secs. 31 and 32), there are numerous much-weathered granite boulders, 1 to 8 ft in diameter. These boulders are high above the intervening smooth outwash plain and are 1 to 2 miles outside the well-defined terminal moraines. It is possible that they are remnants of early Pleistocene glacial drift, but it is equally possible that they are residual boulders left by the disintegration of granite as they overlie deeply weathered granite.

About 5 miles farther west there are weathered granitic boulders similarly located on the ridge between Plimpton Creek and Mussigbrod Creek (secs. 10, 14, and 15, T. 1 S., R. 16 W.) and outside of the terminal moraines on the latter stream. One of the boulders measures 6 by 8 by 12 ft. It is possible that some of these boulders may represent old glacial drift although it is not entirely certain that they are not residual.

A whole series of interstream benched spurs and other remnants of a relatively high piedmont terrace appear south of Swamp Creek in the western and southwestern parts of the Big Hole Basin, which extend northeastward from the Beaverhead Range and border the several glaciated troughs. They may contain remnants of early glacial drift. These spurs do not, so far as noted, extend out beyond the well-defined later moraines, so that no early Pleistocene drift has thus far been differentiated from the later drift on them. There are low outer moraines on La Marche, Mussigbrod, and Lake Creeks, which may be of pre-Wisconsin age, but not so old as early Pleistocene.

POSSIBLE PRE-WISCONSIN GLACIAL DEPOSITS WEST OF THE CONTINENTAL DIVIDE

OLD DRIFT IN THE REGION OF ANACONDA AND SILVERBOW

West of Anaconda there is a high-level deposit of glacial drift which is shown on the maps in the Philipsburg folio. This deposit is between 1 and 4 miles south of Georgetown Lake in T. 4 N., R. 14 W. It is between 7,200 and 7,400 ft above sea level, and 800 to 1,000 ft above the lake, on top of one of the ridges between Blodgett Creek on the east and the East Fork of Rock Creek on the west. Instead of being directly in line with either of the glaciated gorges that head in the cirques near Mount Tiny on the flanks of the Anaconda Range, this drift is opposite the north end of a higher part of the interstream spur. This anomalous position suggests that if this drift was laid down by the glacier in East Fork of Rock Creek, it may have been deposited when the gorge of that stream was about 1,000 ft less deep than now, so that, instead of being confined to the gorge, the ice deployed more to the northeast than it did at the last, or Wisconsin, stage of glaciation. If so, this drift may be of early Pleistocene age. The plateau on which this deposit lies may be part of a Pliocene erosion surface. The pebbles and boulders in the deposit consist mostly of argillite, quartzite and limestone, and the surfaces of the limestone are considerably etched by solution. The surface of this deposit is, in part, gently undulating and, in part, shows well-defined knobs, kettles, or swells, swales, and small ponds like those on late Pleistocene terminal moraines. The preservation of such a surface configuration even in this place on an interstream ridge may well raise some doubts as to the drift really being of early Pleistocene age.

The occurrence 1 to 6 miles south of Silverbow of abundant granite boulders 1 to 5 ft or more in diameter scattered over the eroded surface of Tertiary deposits (Bozeman "lake beds") has been described by W. W. Atwood (1916, pp. 717–719; 1938, pp. 242–243), who thinks that these boulders are remains of a very old deposit of glacial drift derived from the upland south of Butte.

Examination of this foothill belt by the present writer shows the ridges to be the result of dissection of low-dipping Tertiary "lake beds", which are very largely composed of semi-indurated sand and grit derived from disintegration of the granite in the adjacent highlands to the east and southeast. None of the ridges examined appears to be composed of glacial drift. The crests and slopes are sprinkled with pebbles and small boulders of siliceous rock (aplite?) and with boulders of granite 1 to 5 ft or more in diameter.

One of the ridge spurs about a mile north of the Continental Divide, between 6,000 to 6,600 ft above sea level, has on it great numbers of granite boulders, some of them 10 to 20 ft in diameter. From this spur a steep slope rises to a narrow top about 7,000 ft above sea level, on which are abundant large granite boulders of disintegration. There is no broad smooth upland here, but erosion slopes drop steeply east of the narrow crest. The relations seem to indicate that the boulders in the foothill belt to the west may have been swept down by torrential wash after the Tertiary beds were tilted and beveled by erosion. Some of the larger ones near the flanks of the highland may have slid or rolled down some distance on the finer material resulting from disintegration of the granite. There seems to be no clear evidence of the boulders having been transported by glaciers heading on the highlands.

Some indications of an early Pleistocene extension of the glaciers that headed in the Flint Creek Range between Anaconda and Goldcreek are found at certain relatively high places along the west side of the Deer Lodge Valley. About 8 miles north of Anaconda between Lost Creek and Modesty Creek, there is a smooth grassy butte or bench whose top is about 7,000 ft above sea level, or more than 2,000 ft above the Clark Fork near Warmsprings. The top and upper slopes are strewn with pebbles and boulders, largely quartzite and red and green argillite, and deeply etched limestone pebbles and much-weathered granites. Some of the argillites show glacial striations suggesting that the material is the residuum of early Pleistocene glacial drift. It is quite possible that ice of the Racetrack glacier spread over this high bench in early Pleistocene time. The glacial material is 1,000 to 1,500 ft or more above the well-defined late Pleistocene moraines near the Deer Lodge-Powell County line on Racetrack Creek to the north.

There is a similar old bench, 7,000 to 7,200 ft above sea level, 5 to 6 miles farther north, between Racetrack and Dempsey Creeks north of the Powell County line. There is a loop in the well-defined late Pleistocene lateral moraine, showing that the later ice spread southward a short distance into a sag at the head of the high bench but did not override the higher part of the bench to the east. Traced around the north slope, this lateral moraine slopes for about 4 miles farther east to the terminal loop on Dempsey Creek nearly 2,000 ft below the high bench top. Examination shows that on the top of this high bench, above and outside the well-defined later moraine there is a remnant of a much older moraine loaded with many rusty and badly weathered boulders of granite and other rocks. This moraine is directly in front of the high cirque of Dempsey Creek and the relations suggest that the early Pleistocene glacier extended out onto this bench, but that by late Pleistocene time Dempsey gulch on the north had been deepened so much that it diverted the later glacier to a more easterly course. Some of the argillite pebbles on the top and for several hundred feet down the grassy southeast slope show glacial striations.

OLD DRIFT NEAR DEER LODGE AND PIONEER

Nine to ten miles northwest of Deer Lodge evidence of pre-Wisconsin glaciation was noted near the gate of the Deer Lodge National Forest (sec. 18, T. 8 N., R. 10 W.) and below the relatively high bench at the south side of the glaciated valley of Rock Creek, which is tributary to the Clark Fork at Garrison. The bench here, more than 6,000 ft above sea level, is probably a remnant of the Pliocene or early Pleistocene piedmont terrace. Glacial till is exposed in the road cut below the bench top and above what appears to be the wooded south lateral moraine of the Rock Creek glacier of Wisconsin age. Many of the granite boulders included in this till are badly decomposed, but some of them are sound; many pebbles of a very dense dark rock show glacial striations. There are numerous boulders 3 to 10 ft in diameter of porphyritic granite on the bench above this road. The surficial parts of many of these boulders are disintegrating to such a degree that the large feldspar phenocrysts protrude like warts until they too loosen and fall away. There seems little reason to doubt that this glacial drift is of pre-Wisconsin age, possibly early Pleistocene. Some large granite boulders are scattered down the slope to the east and southeast as far as the road on the early Pleistocene terrace.

Farther northwest, at a point 5 miles south of Goldcreek, is the old placer mining village of Pioneer. South of this village Pardee found exposures of what appears to be glacial drift of an intermediate stage (pre-Wisconsin) several hundred feet below a remnant of a high gravel bench (Pliocene?) known as Gold Hill. About a mile southwest of Pioneer and more than 1,000 ft above it there is a benched spur locally known as Ballard Hill, which is separated from the east lateral moraine of the Gold Creek glacier by a narrow gulch. On Ballard Hill, Pardee discovered what appears to be early Pleistocene glacial drift. Following Pardee's directions, the writer examined an exposure at old placer diggings in the woods (about 5,700 ft above sea level) on Ballard Hill, near sec. 33, T. 9 N., R. 11 W. The absence of granite pebbles in this deposit of stony drift is noteworthy, inasmuch as the east lateral moraine of Gold Creek glacier across the gulch to the west contains abundant fresh boulders of granite. The rocks in the old drift include angular to subangular, pebbles and boulders of schist, quartzite, argillite, and deeply etched limestone. Many of the denser and less readily weathered rocks show well-marked glacial striae. The location of the deposit and the presence of pebbles of diabase, derived according to Pardee, from a rock identical with that in a dike exposed in the canyon of Gold Creek a few miles to the west, indicates that this old drift also was deposited by the Gold Creek glacier.

The amount of erosion that has occurred subsequent to its deposition and the absence or scarcity of granite pebbles or boulders indicate that the drift is probably of early Pleistocene age. The failure to find granite pebbles in this old drift may be due, in part, to their decomposition as the result of such long exposure to weathering. Only the upper canyon of South Gold Creek, however, is excavated in granite, so it is quite possible that in early Pleistocene time South Gold Creek had not yet pushed its cirque head beyond the limits of the overlapping Paleozoic and Mesozoic sedimentary rocks and so had not invaded the granite. There are granite boulders in the "intermediate" pre-Wisconsin drift 500 ft lower down, in Pioneer Gulch south of the village. This intermediate drift, however, appears to have been deposited by a lobe of the Pikes Peak glacier, whose head eroded the granite more extensively and probably earlier than did the head of the Gold Creek glacier.

The coarse, bouldery gravels capping remnants of smooth north-sloping terraces or benches 8 to 12 miles south of Drummond (p. 52) on the east side of Flint Creek overlie deposits of Oligocene to Miocene age and are probably the product of Pliocene, or early Pleistocene stream deposition. The gravelly top is about 500 ft above the "intermediate" pre-Wisconsin terminal moraine of Boulder Creek glacier, 2 miles north of Maxville on which are abundant granite boulders. No granites were observed in the bouldery bench gravel. Pardee reports the finding of striated boulders of quartzite on the gravelly hills 1 to 2 miles northeast of Maxville at points more than 1,000 ft above the moraine in the valley. These high-level striated boulders may have been deposited by an early Pleistocene advance of Boulder Creek glacier before the glaciated gorge of Boulder Creek was eroded and possibly before the glacier heads had invaded the granite area south of Princeton.

EARLY PLEISTOCENE(?) DRIFT IN BITTERROOT VALLEY

Several curved ridges or spurs flanking sides of the glaciated troughs of Tin Cup, Rock, and Lost Horse Creeks (fig. 11, pl. 4*D*, and 5) are described on pages 49–50. It is probable that these spurs are not simply and wholly great lateral moraines but that they are primarily interstream remnants of a relatively high piedmont terrace of Pliocene or early Pleistocene age, covered with glacial drift. Their tops are high above the well-defined lateral moraines formed by the late Pleistocene glaciers. They are also high above what appear to be terminal moraines of an intermediate pre-Wisconsin stage of glaciation. It may be that in early Pleistocene time glaciers extended out onto the piedmont terrace, before the streams had cut much, if any, below the sloping plain of which these spur ridges are supposed to be remnants. On these spurs there are many weathered boulders of granite and gneiss 5 to 10 ft in diameter and some even larger. One boulder on a ridge south of the head of Waddell Creek measures about 15 by 18 by 30 ft. It is quite possible that these boulders are remnants of early Pleistocene glacial drift. They are much more weathered than the boulders on the late Pleistocene moraines. Where examinations have been made farther north down the Bitterroot Valley and in the Missoula Valley no indications of early Pleistocene glacial deposits have been noted.

EARLY PLEISTOCENE(?) DRIFT IN THE JOCKO VALLEY

In many places northwest of Missoula and below the upper limits of submergence by the waters of glacial Lake Missoula (4,000 to 4,200 ft above sea level) erratic boulders are scattered in the valleys of the Clark Fork, Jocko, and Flathead Rivers, but apparently their distribution can be accounted for as droppings from icebergs floating on the waters of the glacial lake at various times during the Pleistocene. It is quite possible, however, that there may be early Pleistocene deposits preserved in many places, and not all of these places need necessarily be at such relatively high altitudes as those cited above. Farther west from the Continental Divide erosion of the piedmont terraces or slopes may have been carried to relatively lower levels before the early Pleistocene glaciers extended out onto them.

Southeast of Saint Marys Lake (Tabor Reservoir) in the N½ T. 17 N., R. 18 W., there is a large uneven drift-covered tract between North and Middle Forks of Jocko River that seems to have a somewhat anomalous relation to the surrounding hills and mountains. Around the southwest slope of this area the irrigation canal that extends northwest from a dam on the Middle Fork through Twin Lake to Saint Marys Lake is excavated wholly in glacial till. A short traverse on the higher part of the tract northeast of the canal showed some swells-and-swales either of a mild morainal or landslide topography. There seem to be no mountain gorges or cirques directly upslope from which glacier ice would have extended to this tract during the Wisconsin stage of glaciation. The drift may have been deposited at an early Pleistocene stage. This locality should have further study.

Two to five miles south of Ravalli on the lower part of Valley Creek there are not only scattered boulders, some showing well-marked glacial striae, but also some exposures of glacial till. The relations of this till are not entirely clear. There are no indications that the great Flathead glacier at any time crossed the hills east of Ravalli and entered this part of the Jocko River basin. It seems more probable that the till was deposited by ice heading on the mountains to the south in the vicinity of Squaw Peak. The mountain gorge on upper Valley Creek, however, was not examined by the writer. Some of the boulders scattered on the surface were probably dropped from icebergs floating on the waters of glacial Lake Missoula. The till may have been deposited directly by a piedmont glacier at a time when this part of the basin was not flooded by the lake. It is possible that some of it may be of early Pleistocene age, especially that exposed on or near the Shoemaker ranch in sec. 8, T. 17 N., R. 20 W., at the bend of the Jocko River above the Midway bridge. When this place was examined a fairly clean exposure, due to slumping, showed the following section:

Pleistocene and Tertiary(?) deposits south of Ravalli

	Feet
Pleistocene:	
E. Silt of glacial Lake Missoula, laminated; unconformably overlying lower deposits	5–10+
D. Glacial till, massive, stony, compact; mostly oxidized to buff; where thickest, lower part is gray and unoxidized; included pebbles of Belt rocks subangular to rounded, some well-striated; some diorites badly decomposed; some included fragments of lignite	0–30
C. Gravel rusty, cemented, and interbedded rusty clay and gravel	5–20
Tertiary(?):	
B. Sand gray, compact, or friable sandstone, with thin seams and pockets of lignite	a few feet
A. Clay, massive, jointed; extends down to the river bank; only a few feet exposed above talus.	

In one place the sandstone (*B*) appears to be bent or thrust up in a sharp little fold possibly as the result of being overridden by glacier ice. The degree of oxidation of the glacial till suggests that it may be of pre-Wisconsin age. No clear evidence of early Pleistocene glaciation has been observed farther northwest down the Jocko Valley or the valley of the Flathead River.

Although the evidence of early Pleistocene glaciation cited above seems very meager, it is enough to show that there probably were early Pleistocene glaciers on both sides of the Continental Divide, at least as far south as latitude 45° N. This conclusion is in harmony with the evidence of early Pleistocene glaciation in the front ranges of the Rocky Mountains presented in Professional Paper 174, pages 32 to 44.

EARLY AND MIDDLE PLEISTOCENE TERRACES

GENERAL RELATIONS

Along some of the headwater branches of the Clark Fork west of the Continental Divide, as well as along the upper Missouri and its headwater branches, there are extensive and well-preserved remnants of two or more sets of piedmont terraces that appear to be of Pleistocene age. The upper members of these sets, in places the most extensive, are in general several hundred feet below those described above as probably erosion remnants of similar high-level terraces of Pliocene or early Pleistocene age. So great has been the amount of erosion in the intermontane valleys of western Montana since Pliocene time that the remnants of these higher terraces are relatively small and so widely scattered as to make their identification and correlation uncertain. It is on these highest terraces and benched spurs that the meager remnants of glacial drift of early Pleistocene age are found.

Just as in the piedmont belt bordering the east front of the Rocky Mountains in Montana (Alden, 1932, pp. 12–16, 31–40), so also here in the mountains and intervening basins of western Montana, the development of the supposed Pliocene terraces and the extension of the early piedmont glaciers out onto some of them was followed by a long period of erosion during which the canyons were deepened hundreds of feet in the harder rocks but not greatly broadened. Outside the canyon mouths, however, and especially in the basins occupied by the friable or poorly consolidated Tertiary deposits (Bozeman "lake beds") the streams shifted from side to side, transecting the Pliocene piedmont and narrowing and cutting away most of the intervening terraced and gravel-capped remnants of it. This process of canyon cutting in the mountains and of combined downward cutting and lateral planation in the intermontane valleys probably resulted, in large part from a nearly continuous period of regional uplift. Cessation of the uplift permitted the streams to complete the planation of the piedmont belts and the spreading over a wide area of alluvial fan gravels composed mostly of pebbles and cobblestones derived from the harder rocks composing the mountains.

If the meager remnants of the Pliocene or early Pleistocene terraces and correlated benched spurs described above be regarded as representing the first of the terraces in the intermontane basins, the main upper terrace now present in any one valley is generally the second terrace in the order of formation. This terrace is transected by numerous small gulches and valleys heading in the mountains and in many places the transecting valleys have been so broadened as to develop one or more lower terraces. The distribution of the second and later terraces, so far as mapped, is shown on plate 1. The best-preserved terrace remnants are in the southern half of western Montana, mostly in the Missouri River valley and in other valleys south of the Clark Fork and the Blackfoot Rivers, where they have not been greatly obscured by the encroachment of the glaciers and the deposition of glacial drift upon them. The relations of the second and later terraces to the terminal moraines and outwash of some of the glaciers are such as to indicate that the second terraces are older than the Wisconsin stage of glaciation. They may also antedate an "intermediate stage" of glaciation. They appear to be the correlative of Blackwelder's (1915, pp. 310–319) "Circle" terraces bordering the Wind River in Wyoming and similarly situated terraces (Fryxell, 1930, pp. 36–42) in Jackson Hole, Wyo.

TERRACES ON THE MISSOURI RIVER

As indicated in Professional Paper 174 (pp. 32–40), it appears that the upper or bench 1 in the Blackfeet Indian Reservation, east of Glacier National Park, had not been very deeply dissected before the extension of the first of the mountain glaciers onto it. It seems probable that Pleistocene time in this region began with the uplift, which caused the streams to cut below the Flaxville plain and the correlated piedmont terraces—that is, the Pleistocene began a long time prior to the completion of the second set of terraces (bench 2), by planation and spreading of the gravel thereon. From the evidence now in hand, it seems necessary to regard the second set of terraces as representing the first of the Pleistocene benches.

From study of the relative altitudes of the terraces and benches west and southwest of Great Falls, in Teton, Cascade, and Lewis and Clark Counties, and their relations to the glacial moraines it appears that, while flowing on the upper level of the second set of terraces, the Missouri River, at the north end of the Big Belt Mountains above Cascade, cut a notch in the Tertiary and Cretaceous lava down to a level about 400 ft or more above the present stream. The flat, gravel-capped, triangular butte between the mouth of Little Prickly Pear Creek and the village of Wolf Creek probably represents the second set of terraces. The cap is 400 to 500 ft above the Missouri River and consists of 10 to 15 ft of pebbles and boulders that reach a maximum of 2 ft in diameter. It may be an old alluvial fan of Little Prickly Pear Creek. Whether or not there are remnants of this terrace above the lower terrace in the gorge to the south of the Holter Lake dam cannot now be stated. The sharp bends or incised meanders in the southeastern part of T. 14 N., R. 3 W., may have been formed when the river was flowing on this second terrace level and later cut down as the channel was lowered farther north. A hilltop within this bend has an altitude of over 3,900 ft. It seems probable that the broad gravelly plains constituting the higher parts of the floors of the intermontane basins north, northeast, and northwest of Helena (4,000 to 4,400 ft above sea level) represent this same stage of terrace formation. The north end of this plain near Canyon Creek is 400 to 1,100 ft below the high bench capped with bouldery gravel (Gravelly Range) in the angle between Little Prickly Pear and Canyon Creeks, which is regarded by the writer as a remnant of bench 1 and is probably of Pliocene age. The lower parts of the basin between this and the Scratchgravel Hills north of Helena have been graded down to join the later terrace 3 on the Missouri River. That there has not been deeper dissection is probably due to the fact that the streams have had to cut in hard rock on their way down to the Missouri.

South of the canyon head of the Little Prickly Pear Creek, near Mitchell, a wide gap 50 to 100 ft above the highway and the creek and over 4,000 ft above sea level is floored with gravel and opens southeastward to the Missouri River valley, as though a stream had flowed through there on the grade of the second terrace.

TOWNSEND VALLEY

In his paper on the geology and ground water resources of Townsend Valley, Mont., Pardee (1925, pp. 6–8, fig. 3, p. 14, 35–36) described a series of gravel-capped benches and terraces that lie on the bevelled, faulted and tilted Tertiary beds (Miocene and Oligocene). This valley is an elongate intermontane basin between the Big Belt and Elkhorn Mountains. It is traversed for 40 miles by the Missouri River from the sinuous gorge between Lombard and Toston to the vicinity of Canyon Ferry, 16 to 18 miles east of Helena. Beginning with the highest of the benches, Pardee designated them as 1, 2, and 3, the fourth and lowest plain being the valley bottom or flood plain. Judging from the relative altitudes of the benches and terraces farther north and south along the Missouri River, it seems probable that the upper terrace in the Townsend Valley is not as old as bench 1 and the terraces east of the mountains. The highest of the benches near the river in Townsend Valley are 300 to 400 ft above the stream, whereas the highest gravel terrace south of Three Forks is 800 to 1,100 ft above the Missouri. It is suggested, therefore, that Pardee's terraces 1 and 2 in the Townsend Valley may correspond, respectively, to the upper and lower levels of the second set of terraces east of the mountains. It is possible that the highest of the headward parts of these piedmont remnants may not have been cut much, if any, below their Pliocene(?) positions. The following description is taken from Pardee's paper:

Bench Gravel

On the higher benches north of Deep Creek a layer of gravel from 10 to 20 feet thick is exposed near the mountains. It contains many rough and moderately water-worn boulders that range from 1 to 3 feet in average diameter, and its matrix is an abundant sandy clay. It lies on a surface of erosion that cuts across the Tertiary and older rocks, and the pebbles it contains are of the same kinds as the rocks that crop out in the adjoining mountains. Away from the mountains the gravel becomes thinner and finer textured. Somewhat similar gravel is exposed on the bench south of Confederate Creek near the point at which the stream leaves the mountains. In the neighborhood of Diamond City, several miles above this point, gravel that lies on narrow benches bordering Confederate Creek has been extensively mined for gold. The benches apparently are to be correlated with Nos. 1 and 2 of Townsend Valley. The gravel, though evidently deposited by a stream, is not as a rule highly water-worn nor, except for the presence of a few large boulders, very coarse textured. It consists mainly of quartzitic rocks similar to those common in the Belt formation of the surrounding area. In a low bench at the mouth of Boulder Creek this gravel is overlain by a coarse-textured gravel that is barren of gold and is made up chiefly of granitic material. This gravel is much fresher looking than the other and presumably belongs to the younger valley gravel.

For a considerable distance north of Confederate Creek the surface of the bench lands is thinly overspread with alluvium that apparently was brought out from the adjoining mountains in comparatively recent time. Probably the most of it is to be classified with the bench gravel. Near the north end of the valley, on Magpie Creek and Cave Creek, the bench gravel has been mined for gold. Here, as a rule, it is of moderately coarse texture, moderately water-worn, and, as elsewhere, made up of materials derived from the mountains nearby. The gravel adjacent to Cave Creek, however, is distinguished by the presence of unusually large boulders distributed here and there for a distance of a mile or more out from the foot of the mountains. These boulders are rough or subangular, consist mainly of quartzite, and range from 4 to 8 or 10 feet in average diameter. Their size is so much out of agreement with the general texture of the gravel that incloses them that they could hardly have been transported and deposited by the same stream. Probably they were carried out from the mountains by some unusual flood or by a glacier, and in that event they composed part of a deposit that was afterward reworked by streams into the gold-bearing gravel described.

In the western part of the valley rather coarse gravel is exposed by placer-mining excavations on the benches north of Indian Creek and west and south of Radersburg. It is composed of materials carried out from the adjacent mountains and otherwise is like the bench gravel described. South of Winston the bench lands are covered with a sheet of gravel composed of extensive coalescing fans deposited by ephemeral streams from the adjoining mountains. Probably the upper part of this sheet is made up of bench gravel and later deposits.

The bench gravel was deposited after the Tertiary beds had been deformed and eroded and therefore is considerably younger than Miocene. Because of its close association with a relatively old glacial moraine described on the following pages, it is regarded as chiefly of early Pleistocene age.

North of Three Forks, in the intermontane valleys of the Missouri River and its tributaries, no terminal moraines of Rocky Mountain glaciers have been found at such low altitudes as to permit determination of their relations to these early Pleistocene terraces. Farther north it is clear that the last of the mountain glaciers did not advance and build their terminal moraines until after these terraces, as well as those correlated with the Flaxville plain, had been greatly dissected. It also appears that the Keewatin ice sheet did not divert the Missouri River and reach the vicinity of Great Falls until after the second terraces were mostly eroded away in that region.

GALLATIN VALLEY

The sinuous gorge between Toston and Lombard has been cut by the Missouri River to a depth of 800 to 1,000 ft or more below what was the probable grade of the Pliocene (terrace 1) river bottom. This gorge, which is so narrow as barely to afford room for the river and the Northern Pacific Railroad, is cut in upturned and faulted pre-Cambrian, Paleozoic, and Mesozoic rocks. South of Lombard the valley opens out in a broad-bottomed basin in which the three main tributaries, the Gallatin, Madison, and Jefferson Rivers, unite at Three Forks to form the Missouri.

The lower or piedmont slope, on the west border of the abrupt Bridger Range north of Bozeman, is composed of higher and lower gravel-covered segments, or alluvial fans. Most of the higher segments appear to correspond to the second set of terraces. The lower ones are graded down to the third terrace. They are transected by later gulches, mostly narrow and sharply cut. In places sand, gravel, and volcanic ash belonging to the Bozeman "lake beds" (Miocene?) are exposed on the steeper slopes below the Pleistocene gravel.

North of Reese Creek the terraced surface slopes steeply and is strewn with smooth waterworn boulders, 1 to 2 ft in diameter. About 19 miles from Bozeman the crest, at 5,700 ft above sea level, is nearly 1,000 ft higher than Reese Creek. The higher surface of the piedmont slopes steeply from the road eastward to the mountain front at the canyon mouth of North Cottonwood Creek at 6,300 ft above sea level. The surface is thickly strewn with subangular to rounded boulders, many near the canyon mouth being 5 to 10 ft in diameter. In the lower part of the canyon just above an old logging camp is an uneven ridge that may be the terminal moraine of a glacier that headed below Hardscrabble Peak. The boulder fan west of the mountain front is either a torrential deposit or the residuum of older and more extensive glacial drift. To the west and also north of Pass Creek long piedmont slopes appear to be graded down to the second terrace and transected by sharp narrow gulches. The several terraces are not differentiated on the map (pl. 1). At many places the Bozeman "lake beds" are exposed below coarse terrace gravel in the lines of bluffs bordering Dry Creek and the other streams. Much of this dissected upland is farmed—partly by irrigation and partly by "dry land" farming methods.

Over a great area along and between the main Gallatin River and the East Gallatin the second terrace has been almost entirely cut away. The second set of terraces is best represented at the west side of the valley, and there may be a few small remnants of it near the mouths of the mountain gorges of South Cottonwood Creek, Hyalite Creek, and other creeks.

The smooth high terrace west of Gallatin Gateway (formerly Salesville) has a very striking appearance as seen from the highway on a lower terrace bordering the river. The upper terrace, at the top of a steep bluff 150 to 400 ft high slopes gently northward for 10 miles or more from the mouth of the canyon. Where examined by the writer just west of Gallatin Gateway, the bluff is about 300 ft high. Along its foot above the road is an irrigation canal. The upper terrace here is not very wide, and above it on the west rises the undulating surface of a somewhat higher upland of pre-Cambrian gneiss and the Palezoic rocks. Beneath a thin soil the terrace is floored with a deposit of coarse, waterworn, gravel, consisting of pebbles of granite, gneiss, schist, lava, and quartzite.

Where crossed by the road west of Shedds bridge, which is 6 miles north of Gallatin Gateway, the narrow second terrace is about 150 ft above the river. Here, a pit from which road gravel was taken exposes coarse gravel similar in composition to that farther south. The largest stones are about 1 ft in diameter. Further north the terrace and upland to the west are much dissected. Comparison of its position with similar features in the Madison Valley to the west indicates that this terrace west of Gallatin Gateway belongs to the second set (early to middle Pleistocene). A view southward indicates that it slopes toward, and is to be correlated with benchlike shoulders at the top of the cliffs at the sides of the lower and inner canyon portal. Apparently the shoulders are remnants of the bottom of the somewhat wider early Pleistocene portal. In places long slopes are graded from terrace 1 down to terrace 2, and valleys that are cut in both lead down to the late Pleistocene, terrace 3. The village of Manhattan is located on terrace 3, bordering Gallatin River. The stream channels cut below this terrace grade to the present flood plain of the river.

At numerous places along the Gallatin River there are evidences of earlier stages in the deepening of the valley. Seven miles above the canyon portal, Squaw Creek has cut an inner and lower gorge at the north side of what appears to be a hanging valley; farther north are hanging gulches. How much the hanging character of these gulches is due to the character and attitude of the rock formations was not ascertained, but the impression gained by observation from the road is that they represent former stages in the deepening of Gallatin Valley. Moose Creek also has cut its narrow lower gorge in the bottom of a broader, older one marked by a broad bench, which is about 300 ft above the Gallatin River. Fifteen miles north of Taylor Creek the Gallatin leaves a broad basin and enters a wonderful canyon that it has cut for 15 miles across the pre-Cambrian gneiss and schist. It emerges from this canyon near the mouth of Squaw Creek.

SECOND TERRACE IN THE MADISON VALLEY

In the Madison Valley, as elsewhere in Montana, the broadest and best-preserved terraces are generally those of the second set (early to middle Pleistocene).

A short distance southeast of the town of Three Forks the southeast bluff along the Jefferson River joins the west bluff along the Madison River. These abrupt bluffs, in which the tilted and eroded sands and clays of the Oligocene and Miocene beds are exposed overlain by terrace gravel, range from 100 to several hundred feet in height above the broad lower flat. Between the crests of the converging bluffs is an extensive, smooth, sloping, somewhat dissected upland, or bench, on which there are many "dry land" farms. This bench comprises the early Pleistocene terrace 2 of the Madison and Jefferson Rivers and some tracts not wholly graded down to the terrace. The north edge of the bench is about 350 ft above the Northern Pacific Railway on the flat at Three Forks. The bench extends southwestward nearly to the village of Willow Creek and southward along the west side of the Madison River for 10 miles or more. In this part it gradually narrows as the higher slope rises to the cut-off north end and east edge of the great Pliocene(?) terrace 1. This second terrace is evidently the correlative of the upper terrace at the west side of Gallatin River and of the uppermost of the three well-preserved terraces in the Townsend Valley. It is mostly cut away on the east side of Madison River, nearly as far south as the mouth of Elk Creek.

Just below the mouth of Elk Creek the river flows for a short distance through a narrow gap cut in vertical beds of gneiss. The rock cliffs here rise about 200 ft above the highway on the river bank. Above the cliff on the west side, and extending thence northward down the valley for several miles, are the almost disconnected remnants of two dissected terraces, the lower and the upper terraces of the second set (early to middle Pleistocene). The upper levels of these terraces are several hundred feet above the broad bottom lands and, in places toward the south, are as much as 400 or 500 ft above the river. When the great second terrace was formed in early to middle Pleistocene time the three forks of the Missouri River were flowing at levels about 300 ft or more above their present channels. Evidently most of the valley deepening before and since the development of the great second terrace was the result of stream erosion during Pleistocene time. The character of these several terraces is not evident from an inspection of the generalized contours (with 200-ft interval) on the Three Forks topographic map.

Probably a large part of the smooth gravelly benchlands bordering the branches of Willow and Norwegian Creeks, west and south of Harrison, are to be correlated with the terraces of the second stage.

Between Ennis Lake and Cherry Creek the Madison River flows in a narrow rugged gorge for 13 miles. For more than 30 miles south of the head of the gorge east of McAllister—that is, as far south as Wolf Creek in T. 10 S., R. 1 E.—the river and its tributaries are bordered by extensive remnants of Pleistocene terraces. The highest is the great second terrace of early Pleistocene age. It is most extensive on the east side of the valley where it appears as a piedmont terrace composed of great coalescent alluvial fans heading at the mouths of the several canyons and gulches that cut the steep west flank of the Madison Range. Most creeks that transect this smooth piedmont flow out directly to join the river. Bear and Burger Creeks, however, swing northward and flow down the middle of the basin, nearly parallel to the river, for about 10 miles before they converge and join the main stream near Ennis. The steep sides of the gulches and the bluffs on either side of the bottom lands along the river rise abruptly to heights of 100 to 200 ft or more to the great cut-off second terrace. Here and there these bluffs, the whitish clay, sand, and gravel of the Tertiary beds of Oligocene and Miocene age are exposed. These strata are generally tilted at low angles and are beveled and overlain by a capping of coarse alluvial gravel and boulders, some as much as 3 to 6 ft in maximum diameter.

The Cameron post office near Bear Creek (NE¼ sec. 26, T. 7 S., R. 1 W.) stands on this terrace about 10 miles south of Ennis. So extensively is this second terrace preserved where traversed for long stretches by the main highway both north and south of Cameron, that the name "Cameron terrace" might well be used to designate it.

From the vicinity of Wolf Creek, near latitude 45° N., southward to Hutchins bridge, 2 miles above Lyon, there are only narrow strips of the second and third terraces, and the upper bluffs slope to the higher lava-capped benchlands which are probably remnants of the Pliocene valley bottom (see p. 36). This is also true for 5 miles farther south on the west side of the river. There are also some terrace remnants on the west side of the river. In places they are partly covered by landslides. Near Hutchins bridge the lower level of the second terraces is about 100 ft above the river. Most of the cobblestones in the lower half of the bluff below this terrace are smoothly rounded quartzites and most of those in the upper half are granite and gneiss. Much of the quartzite gravel was doubtless derived by erosion from gravel layers in the Bozeman beds underlying the lava caps, or it may be Tertiary gravel in situ, as on Elk River south of Hutchins bridge. The granitic material that was brought in later may be mostly outwash from early glacial deposits farther up the river and in the tributary valleys.

South of Squaw Creek the upper level of the second set of terraces, which is irrigated and farmed, slopes from the foot of the higher bluff at 300 ft to its cut-off lower edge 150 ft above the road near the river.

At the salient about 1½ miles south of Ennis, and between the river and Bear Creek, and also the part of the gravel immediately above, the friable whitish Tertiary sandstone contains more quartzite cobblestones and less granitic material than the higher gravel immediately below the flat top of the terrace.

At numerous places northeast of Bear Creek a somewhat peculiar relation was observed. The line of bluffs along these valleys as far north as Ennis appears to be topped by this eroded great second terrace. At intervals, however, there are gaps in the line of bluffs through which lower terraces come down to the valley below the bluffs. The segments of the main lower terrace, as traced back from these gaps, rise to and above the grade of the big second terrace and near the mountains merge with the great alluvial fans, which are such conspicuous features especially on the east side of the basin. Some of these fans are quite distinct, not having merged completely into one continuous piedmont slope. Evidently the grades were steepened above those of the fans of earlier stages. This was due to the river having cut down 100 to several hundred feet, and perhaps also to the Madison Range having been elevated east of the fault line, thus raising the level at which streams discharged from their canyons to form the fans. These two terraces are grouped together in the second set because they cannot everywhere be distinguished one from the other, at least without much more detailed study than the writer has given them. Moreover, in part, they probably do actually so merge as to be inseparable.

As the Madison River deepened its canyon northeast of McAllister, the courses of the tributary streams were so shifted, where necessary, as to run into the head of the canyon, and the terraces of the second and third sets were developed during the progress of this shifting. Thus the North Meadow Creek, which probably first flowed northeastward from Ward Peak in the Tobacco Root Mountains, has shifted to a northwest-southeast course above McAllister and there is a second terrace, in part well preserved on the north side of its valley, 100 to 200 ft above the bottom land. In developing the second set of terraces a vast amount of material, mostly friable Tertiary sediments, was removed from the broad basin south of the transverse belt of gneiss and granite hills—that is, from near North Meadow Creek as far south as Wolf and Moose Creeks, about 35 miles.

Near Wolf Creek the eroded, northward-sloping surface of the rhyolite extends under cover of the second terrace gravel in the west bluff. South of Wolf Creek, where the higher uplands above the river bluff are underlain by lava, a less, but still large, amount of material has been removed. Through most of the distance between McAllister and Wolf Creek, State Route No. 1 is on the second set of terraces. So far as seen throughout the valley, the terraces are floored with coarse gravel and the Tertiary beds are only exposed at intervals in the steep bluffs below the terraces. There are many boulders intermixed with the terrace gravel, especially in the great alluvial fans which merge with the river terraces. These boulders generally range from 1 to 3 ft in diameter, but boulders having long diameters of 5 or 6 ft are not uncommon near the mountains.

It is probable that the "Missouri flats" at the south end of the Madison Valley, between the river and Reynolds Pass north of Henrys Lake, Idaho, correspond approximately with the main second set of terraces (early to middle Pleistocene) farther north. These "flats" show evidences of erosion on lava and on the Bozeman "lake beds." They are covered with alluvial gravel. Between 3 and 5 miles west of the mouth of the Upper Madison Canyon (in the southern part of T. 11 S., R. 2 E.) the automobile road north of the river is on a lower level of the second set on which numerous large boulders of gneiss are scattered near the road, but upstream and downstream from this place it is on the still lower terrace 3 (late Pleistocene). South of Hutchins bridge on the southwest side of the river there are four intermediate terrace steps below the main terrace top. One boulder of pink granite 15 ft in diameter and other smaller boulders were noted on one of the lower gravelly terrace steps. These and other boulders on the lower terraces west and east of the river may have been brought down from the front of Beaver Creek glacier in the Upper Madison Canyon on floating ice, unless they are erosion remnants of early Pleistocene drift like those on the upland north and east of Hutchins bridge.

SECOND TERRACE IN JEFFERSON RIVER BASIN

The second (early to middle, Pleistocene) terrace is preserved to a large extent along some parts of most of the tributaries of the Jefferson River examined by the writer, indicating general uniformity in conditions of erosion and deposition for a long time.

RUBY RIVER

There are remnants of the early Pleistocene terrace 2 above the sides of the inner valley of Ruby River, south of the narrow gap where the stream cuts through the Snowcrest Range in T. 9 N., R. 3 W. As seen in a general view, narrow strips of the second terrace appear to grade down to the top of the lower bluff and some are below interstream remnants of a higher terrace 1. The inner valley is cut down about 100 ft below the lower edge of the second terrace. Cobblestones from gravel, which cap these terrace remnants, are seen in places along the road. The pebbles are largely of quartzite and well rounded, and mixed with pebbles of various crystalline rocks, limestone, and lava. It is probable that much of this gravel was derived from older Tertiary or Cretaceous conglomerates.

For several miles below the gap cut through the Snowcrest Range, the second terrace is very well preserved between the top of the lower 100-ft bluff and the eroded lower margins of the upper terrace 1 remnants near Willow and Greenhorn Creeks, in the southeastern part of T. 8 S., R. 4 W. Some parts of this terrace are irrigated and used for grain fields. Beneath thin top soil the terrace is capped with coarse alluvial gravel composed of pebbles and cobbles, very largely of quartz, quartzite, and crystalline rock, overlying beveled Tertiary (Bozeman) "lake beds."

North of the mouth of Sweetwater Creek the second terrace on both sides of the river is very much dissected, although there are some smooth gravel-capped remnants.

BLACKTAIL CREEK

The West Fork of Blacktail Creek heads northeast of the pass, on the south flank of Sawtooth Mountain and adjacent parts of the south end of the Snowcrest Range in T. 12 S., R. 5 W. From the head, the creek flows directly toward a gravelly bench in the pass as though when flowing at much higher levels, it might have continued southward across the bench. The stream now swings westward to northwestward in its present deep gulch cut for several miles mostly in Cretaceous shale and sandstone. Where it cuts through the upturned Paleozoic limestones and quartzite, the gorge narrows and, in places, displays picturesque erosion buttresses. From the narrows to Dillon the valley is broader and mostly cut in Tertiary deposits.

Northeastward from the mouth of the East Fork is a piedmont terrace which is graded across the Bozeman "lake beds" and probably capped with the gravel of coalescent alluvial fans. Later it was partly eroded. The highest part of this piedmont terrace heads at the west front of the Snowcrest Range between Blacktail Creek and Ruby River valley at about 7,000 ft above sea level, and is probably of late Tertiary age (terrace 1).

No other remnant of this terrace has been noted farther northwest down the valley of Blacktail Creek. The next lower terrace (2), probably of early Pleistocene age, is very well developed and not greatly dissected. This second terrace borders the East Fork of Blacktail Creek and spreads out to the northwest between the eroded edge of the upper terrace 1 and the crest of the 50- to 100-ft bluff above the broad bottom lands of Blacktail Creek. This terrace is transected by the valley of East Fork and both the terrace and the bluff below are cut at intervals by narrow Recent gulches.

Farther northwest the piedmont terrace is well preserved on the Tertiary deposits along the southwest side of the Blacktail valley, nearly to the Beaverhead River south of Dillon although not shown in detail on plate 1. This terrace lowers northwestward down the valley and also slopes northeastward, 100 ft or so per mile, from the foot of the abrupt hills on the southwest to the top of a low bluff bordering the Blacktail bottom lands. In places the slope continues down to the bottom lands. The terrace is capped with, or composed of, coalescent alluvial gravel fans heading at the mouths of gulches with which the hills are gashed. It is possible that the lower part of the terrace has been somewhat steepened by later Pleistocene erosion. It is transected only by shallow channels of intermittent streamlets and is so smooth that it is traversed for 10 or 12 miles by a road, with very few cuts and fills. About 9 miles south of Dillon the Blacktail Creek enters the Beaverhead River basin, and the lower flat broadens and merges with the broad bottom lands bordering the river. No glaciers appear to have contributed outwash to the formation of the terraces along Blacktail Creek.

What is probably the early Pleistocene piedmont terrace south of Armstead is composed of the remarkably smooth alluvial fans that head at the mouths of the gulches in the hills to the east and, coalescing, slope down to the low marginal bluff east of Red Rock River. This piedmont bench is transected by narrow gulches and in a few places, as on Buck Creek 2 miles north of Kidd, a well-defined secondary alluvial fan was developed by widening of the lower part of the gulch in late Pleistocene time. The lower edge of this later fan is an eroded bluff rising 30 to 50 ft above the broad bottom lands. The Horse Creek fan, of late Pleistocene age, in two miles slopes from the mouth of the gulch, 6,450 ft above sea level, down to 5,700 ft above sea level at the top of the low bluff east of Armstead, a slope of about 300 to 450 ft per mile. No exposure of deposits underlying the alluvial gravel was seen. There are no such extensive remnants of the early Pleistocene terrace in 20 miles of the narrower Beaverhead Valley, between Armstead and Barratts (8 miles southwest of Dillon), although there is some benching along the lower part of the slope on the east.

For 8 or 10 miles south of Armstead the range of hills on the east appears to be carved from Tertiary deposits. Near Armstead, Horse Prairie Creek and Red Rock River unite and form the Beaverhead River. Between Armstead and Barratts the Beaverhead has cut a gorge through a range of hills. At two or three places the gorge is constricted, the narrowest place being a vertical-sided gap 100 ft or more in depth, cut through northwest-dipping heavy-bedded sandstone. Above the vertical walls are bench remnants of a higher and wide valley (Pliocene to Pleistocene). The difficulty of cutting down at these constricted places has doubtless retarded dissection of the Pleistocene terraces farther upstream.

GRASSHOPPER AND RATTLESNAKE CREEKS

There are extensive remnants of the smooth, flat, gravelly Pleistocene terrace preserved in Grasshopper Creek basin 20 to 25 miles west of Dillon. Most of the remnants are distinctly above and separated from the broad lowest terraces, on which are the extensive meadow lands, by abrupt, eroded, marginal bluffs ranging in height from 25 ft at the west to 300 ft or more near Grasshopper Creek. At the east side of this basin south of Polaris, dissected remnants of a relatively high piedmont terrace are 200 to 300 ft or so above the broad bottom lands, bordering the creek. This terrace, or bench, between Farley Creek and Tash Ranch appears to be capped with weathered cobblestone gravel and boulders composed principally of quartzite and granitic rocks. It is evidently a remnant of an old alluvial fan formed by a stream, perhaps Farley Creek, which flowed southwest from Baldy Mountain down through foothills either in Pliocene or early Pleistocene time. There are more extensive remnants in the southern part of the basin near Buffalo and Reservoir Creeks, in adjacent parts of Tps. 7 and 8 S., Rs. 12 and 13 W.

These terraces appear to be underlain by Tertiary sand and whitish clay, and are capped with coarse quartzite gravel of Pleistocene age. The smooth, flat surface of one south of Buffalo Creek slopes eastward, in about 4½ miles, from 6,900 to 6,450 ft above sea level—that is, about 100 ft per mile.

Later in Pleistocene time the streams cut broad valleys through these early Pleistocene benchlands. The later valleys have smooth, flat bottoms a half to 1½ miles or more wide and are bounded by the bluffs which rise to the benchlands as abrupt erosional margins. From a depth of 300 ft the valleys become shallower rapidly upstream until the bottoms are but little below the Pleistocene terrace.

Leaving this broad upper valley at Bannack, Grasshopper Creek flows southeastward for 15 miles through a gorge several hundred feet deep, which is so constricted that no road traverses it beyond a point 3 miles southeast of Bannack. The creek joins the Beaverhead River 12 miles above Dillon. The extensive development and striking preservation of the early Pleistocene terrace in the valley of Grasshopper Creek above Bannack are probably due to the retardation of downcutting in the 15-mile gorge below Bannack. Such retardation along the lower course, however, may have facilitated the lateral planation which removed all trace (so far as noted) of a higher or Pliocene terrace. As seen below Bannack, there appears to be a lower and inner gorge cut below the bottom of an older and wider valley, which is represented by longer slopes above the lower bluffs. The upper and wider valley may be older than the extensive upper, dissected, gravelly terraces farther north and west of the village.

Southeast of the village of Argenta the upper (Pliocene or early Pleistocene?) terrace 1 has been cut away and the roads are on a broad lower terrace 2 (early Pleistocene) which slopes southeastward, flattening gradually from 200 to 100 ft per mile from an altitude of 6,200 ft above sea level near the village until it merges with the piedmont terrace north of Barratts at the mouth of the canyon of Beaverhead River southwest of Dillon.

TERRACES ALONG RED ROCK RIVER AND ITS TRIBUTARIES

From such reconnaissance studies as have been made it appears that there are in southern Beaverhead County, along the sides of the valleys of Red Rock River and its tributaries near the roads leading to the villages of Dell, Lima, and Monida and on the flanks of Garfield Mountain and along the State line on the Continental Divide, a variety of features which, if more carefully studied, would give clues to the late Tertiary and early Pleistocene conditions of erosion and deposition. These features cannot as yet be wholly differentiated. Certain significant features, however, may be indicated.

Five to ten miles south-southeast of Monida, in the northeastern part of T. 15 S., R. 5 W., the Montana-Idaho State line is on a narrow but smooth, gently sloping upland, 7,500 to 8,000 ft above sea level. This upland, near the head of Corral Creek, is capped with lava—rhyolite and basalt. Erosional slopes below the lava rim are strewn with quartzite cobbles, which appear to come from beneath the lava cap. In places where there is no lava the upland is capped with the coarse gravel composed of smoothly rounded quartzite pebbles. The purplish rhyolite appears to underlie some of the gravel, and the basalt, where present, caps the gravelly upland as though it might be of late Tertiary or early Pleistocene age.

For about 3 miles southwest of the pass near Monida is a remnant of a north-sloping, relatively high terrace about 7,200 ft above sea level, which appears to have once headed in highlands to the south but from which it is now separated by the headward erosion of the branches of Beaver Creek, Idaho, which is tributary to Snake River. The surface of this bench remnant (on which State line monuments 620 M, 621 M, 622 M, and 623 M are placed) is a deposit of smooth, waterworn cobblestones and 1- to 1½-ft boulders of pink, gray, and yellow quartzite and quartz underlain by ledges of purplish vesicular lava probably of Tertiary age. There may be similar piedmont remnants to the southwest and west, with slopes converging northward to northeastward from Garfield Mountain and adjacent rugged mountains in the southeastern part of Beaverhead National Forest, south of Lima.

About 5 miles west of Monida there is a basalt-capped butte near Beaver Creek (secs. 2 and 3, T. 15 S., R. 7 W.) about 400 ft high. No gravel was noted on top of the lava (about 7,100 ft above sea level), but the clay slopes below the basalt, are so strewn with quartzite cobbles as to suggest that there is gravel under the lava. Two to three miles north of this butte, near Snowline, there is a dissected but somewhat definite sloping bench above the bluff. Here, in places, is an upturned bed of conglomerate (Higham conglomerate of Kirkham), the pebbles of which appear to consist of limestone. The hill slopes and benched spurs (up to 7,550 ft above sea level), however, are sprinkled with smoothly rounded and polished cobbles and boulders of quartzite, like those on the bench southwest of Monida. Apparently these cobbles and boulders have been let down by erosion from some Tertiary(?) deposits.

Across the valley, 4 to 5 miles west of Snowline, is a high benched spur extending northeastward from the vicinity of Garfield Mountain. The narrow smooth top, of beveled upturned beds of sandstone (8,000 to 8,450 ft above sea level) is 1,500 to 2,000 ft above the bottom land along the creek to the northeast. This top may be a remnant of a late Tertiary erosion surface corresponding to terrace 1. There are similar high benched spurs between this and Little Sheep Creek, 6 miles to the west, north of Garfield Mountain.

By the time of the deposition of the basalt (in late Tertiary or early Pleistocene time), which overlies coarse gravel and caps the butte near Beaver Creek, 5 miles west of Monida, the valley was cut down fully 1,000 ft below the highest bench tops (8,000 to 8,450 ft above sea level) for another basalt-capped butte (6,900 to 6,950 ft above sea level) stands in the angle formed by the convergence of Truax Creek and Junction Creek in the broad valley between 1 and 2 miles southeast of Lima. Like the basalt capping the butte 7 miles farther southeast, this basalt also overlies coarse gravel consisting of smoothly rounded cobbles of varicolored quartzite, as though the lava flowed northwestward down an old valley about 500 ft higher than the present streams.

This broad old valley appears to have been cut across the upturned edges of an older conglomerate whose constituent pebbles consist solely of limestone. The older conglomerate and the associated limestone strata are also exposed higher than the basalt in the slopes to the north and south, as well as in lower slopes near the railroad, the highway, and the streams. These strata are upturned on the flanks and in the end of a spoon-shaped anticline, which plunges northwestward in the hills southeast and south of Lima.

Another remnant of basalt caps a low hill half a mile to one mile southeast of Lima. This basalt has either been tilted or else it originally flowed down a slope to a lower level, inasmuch as it now plunges northwestward beneath the gravelly flat, the site of the village of Lima.

Three miles south of Lima, Birch Creek has cut a narrow gulch through a basalt cap and about 300 ft into underlying strata. The basalt dips northward down the slope from an altitude of 7,200 ft, nearly 1,000 ft higher than the stream at Lima, and 650 ft higher than Little Sheep Creek 2 miles to the west. Adjacent slopes are strewn with smoothly rounded cobblestones and 1- to 2-ft boulders of white, gray, pink, and reddish quartzite and pinkish porphyry. This gravel appears to underlie the small lava cap; the top and sides of the ridge, which rises southward about a mile from the lava butte to the higher hills bordering the mountains, are covered with similar cobblestones as though they were either lowered by erosion of a high gravel-capped bench or were derived from an older conglomerate. In the short traverses made by the writer, no ledge of conglomerate was seen in situ except a small exposure in the bottom of a gulch tributary to Little Sheep Creek. At this place (about SW¼ sec. 24, T. 14 S., R. 9 W.) pebbles of all these different kinds of rock are embedded in a friable sandstone matrix; this conglomerate may be of Tertiary or Cretaceous age. Between Birch Creek and Little Sheep Creek a dissected bench or old alluvial-fan terrace of early Pleistocene(?) age is capped with coarse gravel and slopes down to the marginal bluff which drops abruptly 50 to 100 ft to the later alluvial fans. The upper canyon slopes of Little Sheep Creek and the steep mountain front to the north and east appear to have been graded to slope down to this upper dissected piedmont terrace or fan, which was probably formed in late Tertiary or early Pleistocene time.

There is a remnant of a similar high, sloping, gravelly bench several hundred feet above the creek at the canyon mouth of Sheep Creek, 8 miles northwest of Lima. It lies across the beveled edges of southwest-dipping reddish conglomerate of Tertiary(?) age similar to that composing the Red Butte 3 to 4 miles to the northeast across Beaverhead Valley, near the village of Dell. The pebbles in the conglomerate are mostly of gray limestone with a smaller percentage of smoothly rounded, varicolored quartzites. The high bench at Sheep Creek is probably an old dissected alluvial fan or remnant of a late Tertiary or early Pleistocene terrace which bordered the foot of the abrupt mountain front to the north and south. About 2 miles farther up Sheep Creek, Hidden Pasture Creek, near the ranger station, cuts through a similar old, but somewhat lower, alluvial fan. Several miles farther south there are similar remnants of an old valley floor near Patterson Canyon.

There is also a remnant of a terrace on the upturned beveled edges of the limestone beds in the angle between Rock Creek and Nicholia Creek, 2 miles west of the sharp bend in Sheep Creek. This terrace is about 75 ft above the creek and is strewn with pebbles of limestone, red and gray quartzite, granite, and lava. Cobbles and small boulders of similar rocks, but no limestones, are strewn on the slopes near the road southeastward up to the pass, about 7,500 ft above sea level, at the State line and on the higher slopes northeast of the pass as far as the base of a cliff of porous white travertine at an altitude of 8,500 ft. None was seen, however, near the State line, on the smooth grassy upland above this cliff at an altitude of 8,650 ft. This upland is 2,000 ft above Sheep Creek at the bend in the gorge, 4 miles to the northwest.

The travertine was probably deposited on a middle- or late-Tertiary erosion surface by waters from the limestone hills or peaks that rise above this upland level a short distance to the northeast. There appear to be similar smooth upland tracts (largely grassed but probably not on travertine deposits) above the walls of the canyon of Sheep Creek.

TERRACES IN THE BIG HOLE BASIN

In the crescent-shaped Big Hole Basin north, west, and south of Wisdom there are extensive smooth, flat, gently sloping tracts of gravelly benchland separated by broad, shallow, flat-bottomed valleys 50 to 100 ft or more deep and ranging from a mile or less to more than 5 miles in width. The benchlands appear to be remnants of the great second terrace or Pleistocene floor of the basin. They are several hundred feet lower, and distinctly younger, than the high moraine-capped spurs that have been described above as possible remnants of a late Tertiary piedmont terrace, and they are distinctly older than the well-defined moraines of the last, or Wisconsin, stage of glaciation.

So extensive are the remnants of the second terrace that it is probable that a very large part of the bottom of Big Hole Basin was graded down by erosion to this remarkably smooth surface, in early to middle Pleistocene time, and floored with coarse gravel.

Near the point where the river leaves the lower (northeast) end of the Big Hole Basin and enters the narrow gorge east of the mouth of Sullivan Creek, in or near sec. 33, T. 2 N., R. 12 W., nearly 500 ft above the north river bank at the top of the steep quartzite bluff, there is a well-defined narrow bench remnant capped with gravel at an altitude of about 6,100 ft. It may represent the bottom of the river gorge in early Pleistocene time. In this same township there are numerous well-preserved, smooth, gravel-capped remnants of the early Pleistocene terraces between 3 and 8 miles north of the mouth of Sullivan Creek. They cover the Tertiary lava and tilted friable sandstone beds of Tertiary, possibly Miocene, age on the tabular ridges between French Gulch, Tenmile, Twelvemile, Sullivan, and Seymour Creeks. These ridges extend northwestward to higher slopes at the ends of the long benched spurs representing the late Tertiary(?) piedmont of the Anaconda Range. Between them are hay meadows in broad, flat-bottomed valleys, 50 to more than 100 ft deep, below the Pleistocene gravel terrace tops, which are clearly older than the terminal moraine that lies across the valley of Seymour Creek. There are not such well-preserved remnants of this second terrace to the west on La Marche Creek.

For 3 or 4 miles west of Fishtrap, the broad, flat inner valley of Fishtrap Creek transects a remarkably well preserved early Pleistocene terrace 2 about 5 sq mi in extent. This terrace slopes smoothly southeastward, over Tertiary and older rocks. A short distance above the boundary of Deerlodge National Forest the wooded terminal moraine of the Fishtrap glacier lies across the inner valley, which is floored with outwash gravel between the lines of steep bluffs rising 100 ft or so to the older second bench or terrace. The relations show clearly that this upper terrace is of pre-Wisconsin age. At one place in another gulch transecting this upper terrace, near the southwest corner of sec. 30, T. 2 N., R. 13 W., a landslide scarp exposed 15 ft or more of cobblestone gravel underlying the terrace.

Disintegrating granite is exposed for several miles south of Fishtrap in the lower part of the bluff along the highway at the river side below the eroded southeast margin of the big gravel-capped terrace 2. The Big Hole River flows through a narrow inner valley cut below the upper terrace on the west and smaller and somewhat lower remnants of a similar alluvial fan terrace on the east. Between 3 and 6 miles southwest to west of Fishtrap the somewhat dissected terrace 2 borders a northwestward trending upland. At the southeast end there is a 50-ft bare scarp exposing light-buff, semi-indurated, stratified, sandy clay—Tertiary "lake beds," of possible Miocene age—such as overlie the disintegrating granite nearby. The "lake beds" dip northwestward into the hill at an angle of 15° and the top edges are smoothly beveled and capped with coarse quartzite bench gravel. Two miles farther northwest a small hill of dense dark basalt (6,400 ft above sea level) rises above the adjacent part of the ridge. There is no gravel on top of this butte but farther northwest the Tertiary "lake beds" are exposed in the bluff facing the valley of Mudd Creek, with vesicular basalt at the top and quartzite gravel strewn upon it. From the crest there is an extensive view northeastward over the several segments of the great gravelly terrace 2. No moraine is in view in the valley of Mudd Creek, which heads in the foothills and may not have been glaciated.

West of Big Hole River the line between Beaverhead and Deer Lodge Counties follows the valley of Pintlar Creek (pl. 1). For several miles outside the glacial terminal moraine near the boundary of the national forest this valley transects the large second terrace. It is a quarter to half a mile wide and about 50 to 100 ft or so deep. The section of the terrace northeast of Pintlar Creek is about a mile wide and slopes gently southeastward from the vicinity of the outer terminal moraine nearly to the river. This terrace is separated from low hills to the north by a broad spillway channel, which was probably occupied by glacial waters but now contains no stream.

The remnant of terrace 2 between Pintlar Creek and Howell Creek is somewhat wider and longer. Both the remnants of the terrace transected by Pintlar Creek are probably underlain by Tertiary "lake beds", although no exposures were seen by the writer. The smooth flat tops are underlain by coarse cobblestone gravel composed mostly of quartzite.

There are large areas between Howell, Thompson, Plimpton, and Mussigbrod Creeks and the North Fork valley where, so far as seen, neither the late Tertiary nor the early Pleistocene terraces were preserved. South of the valley of the North Fork the second, or early Pleistocene terrace, was remarkably well developed and, though transected by gulches and by the broad valley of Swamp and Moose Creeks, is well preserved over many square miles. For 6 miles the road between Swamp Creek and Ruby Creek, west of Wisdom, crosses the smooth, gravelly, little dissected top of this great alluvial terrace, 6,300 to 6,400 ft above sea level. For 8 or 9 miles the road up Swamp Creek skirts the foot of the abrupt marginal 100-ft bluff between the eroded southeast edge of this part of the terrace and the hay meadows on the broad bottom land. Beyond this the road extends up onto and southwest on the smooth, sloping, gravelly flat for several miles toward Big Hole Pass. In 2½ miles the flat slopes northeastward from an altitude of 6,750 to one of 6,450 ft above sea level, or at the rate of about 120 ft per mile; farther northeast the slope decreases.

Two to three miles north of Wisdom the road east of the river extends up over part of the second terrace on which the cemetery is located. In the 75-ft bluff below the cemetery there is an exposure of about 20 ft of coarse gravel overlying an erosion surface of beveled Tertiary deposits having a low dip southward. These beds consist of whitish to ashen-gray, semi-indurated. gritty clay and arkose with, perhaps, some volcanic ash.

Southwest of Wisdom the second terrace is well preserved between Swamp Creek and Rock Creek, where it extends over nearly two-thirds of a township. Where examined at the eroded southwest end above the old stage road, the smooth sloping top and the face of the abrupt erosional bluff below the terrace are covered with coarse gravel composed of smoothly rounded pebbles and cobbles of quartzite and granite. The head of this part of the terrace is about 6,650 ft above sea level.

The broad, smooth lower terrace, which is the bottom land traversed by the creeks, slopes upward to the southwest and west with a grade somewhat steeper than that of the upper terrace. Below the bluff it encircles the eroded head of the upper terrace. Near the forest boundary, where it contains numerous boulders, it rises above the upper terrace, attaining an altitude of 6,750 ft above sea level. Here the terrace appears to merge with the front of the wooded, bouldery terminal moraine of Moose Creek glacier as an outwash terrace. The moraine therefore appears to be younger than the upper terrace to the northeast.

Farther south on Miner and other creeks, either the early Pleistocene terrace has been almost entirely cut away or the later Pleistocene bottom lands merge with or overtop the older terrace.

About a mile south of Wisdom the highway extends onto the second terrace east of the river and continues thereon for 10 miles toward Jackson. South from Wisdom the broad bottom lands slope upward gradually until in places near Jackson they are near the lower edge of the second terrace. Apparently the Big Hole region has been elevated so recently that, despite its relatively high altitude, the headwaters of the streams have not yet been able to cut deeply below the early Pleistocene terrace. It is possible that the very extensive lateral planation with only moderate downcutting by the streams in this basin has been due in large part to slowness of cutting the narrow outlet gorge below the mouth of Wise River, where much hard rock was encountered at the north end of the Pioneer Mountains. At the village near its mouth, Wise River is now flowing about 100 ft below what appears to be a remnant of the second terrace. Farther south, up Wise River, the second terrace is either mostly eroded or is obscured by glacial deposits.

For several miles below Wise River the valley of Big Hole River is fairly wide, with low gravel terraces. At one place bouldery gravel overlies rhyolite above the road. For several miles farther southeast to the power plant the gorge is narrow with high walls of granitic rock. East of the dam there are many large boulders on the slopes, possibly due to disintegration of the granitic rocks.

Near the village of Divide where the river swings southward there is a well-preserved remnant of the second terrace on the north side in the angle between the river and Divide Creek, and about 200 ft from the bottom land. The village cemetery is on this terrace and in the abrupt bluff face below the cemetery a thick deposit of coarse cobblestone gravel that contains some 1- to 2-ft boulders. This deposit of smoothly rounded pebbles of varicolored quartzite and granite overlies lava near the narrow-gauge railroad. The long, smooth, but dissected upland slope to the northwest seems to have been graded down to the early Pleistocene valley, of which the flat terrace top is a remnant.

The bluff below the large terrace of early Pleistocene age east of Melrose and north of Camp Creek is 50 to 75 ft above the adjacent flat bottom land and is notched by numerous gulches. North of Soap Creek the surface rises to the hills south and north of Moose Creek. North of these hills another segment of the second terrace extends northward past Divide. Here also the great gravelly fan terrace is cut off at the crest of the bluff that rises 100 to 150 ft above the highway on the east side of the broad flat bottom land along Big Hole River. At one place the bluff exposes a ledge of coarse, granitic grit and conglomerate of Tertiary(?) age containing well-rounded, varicolored pebbles and cobbles up to a level of 100 ft above the road; above this is loose quartzite cobblestone gravel with 1- to 2-ft boulders that may be of Pleistocene age. This fan terrace slopes smoothly down from the mountain front at the east to the top of the eroded bluff.

The east terrace, though transected by several gulches, is well preserved for several miles south of the village of Divide. The lower west edge of this bench at the top of a bluff is 150 to 200 ft above the flat bottom land east of the river. In this bluff and also in the road cuts north and south of Moose Creek, Oligocene(?) or Miocene(?) beds are exposed. Overlying these deposits and capping the terrace is coarse gravel of Pleistocene(?) deposition, composed of smoothly rounded cobblestones of varicolored quartzite and coarse-grained granite.

For several miles between Divide and Melrose, the Big Hole River has the appearance of having been superimposed across two spurs projecting from the east front of the Pioneer Mountains. It flows in a constricted gorge about 1,000 ft deep along two hard rock ridges, one north and one south of Moose Creek. The river may have taken its present course while flowing in the late Tertiary terrace 1 valley when the hard rock ridges were buried beneath the Tertiary "lake beds." The river is now flowing about 200 ft below the eroded lower edge of the second (early Pleistocene) terrace.

South of the narrow gorge, the river cut a broad, flat-bottomed, inner valley during later Pleistocene time for several miles south beyond Melrose, but the second terrace is well preserved east of the bottom land and its somewhat dissected surface slopes gradually and merges into the long piedmont slope of the hills to the east. About 5 miles south of Melrose the river, in places, flows below low cliffs of volcanic rock. South of Browns is remnant of terrace 2 above one of these rock cliffs on the east side. On the opposite side, for some miles north and south of Rock Creek, the second terrace is much dissected and nearly destroyed. The valley broadens southward and merges with the broad Beaverhead Valley. From the vicinity of Reichle, Big Hole River swings eastward and northeastward and joins the Beaverhead north of Twin Bridges to form the Jefferson River.

About 12 miles northwest of Dillon, Birch Creek emerges from its canyon mouth at the east front of the Pioneer Mountains and flows in a northeasterly direction to Big Hole River below Reichle (4,975 ft above sea level). In this part of its course it transects an extensive piedmont terrace. The flat, gravelly-bottomed inner valley is about half a mile wide and becomes shallower gradually from a depth of several hundred feet near the canyon mouth (5,850 ft above sea level) to 100 ft or less east of the Oregon Short Line Railroad and north of Apex (5,400 ft above sea level). South of Birch Creek valley the smooth, gravelly, piedmont terrace is very well preserved with an extent of many square miles. Northeast of Apex the land surface is somewhat higher and some rock hills project above the surrounding Tertiary deposits. From the foot of the mountains east to the railroad near Apex the smooth sloping surface is that of a great alluvial gravel fan capping the truncated Oligocene(?) or Miocene beds. This surface continues southeastward across the railroad and beyond the main highway north of Dillon. The grade of the fan ranges from about 100 ft per mile near Apex (5,450 ft above sea level) to

200 ft or more per mile near the mountain front, where its head is 5,900 to 6,000 ft above sea level. The alluvium is coarse gravel, largely cobblestones of quartzite with a thin soil coating the fan.

Where Birch Creek leaves the mountains near the east boundary of the Beaverhead National Forest there is a narrow craggy portal cut through upturned strata of limestone that has evidently not been glaciated. Farther northwest the mountain valley is somewhat broader. Above the old mining village of Farlin there are several benched spurs 100 to several hundred feet above the creek, some of which may be erosion remnants of the old early Pleistocene(?) valley bottom correlated with the great second terrace on the piedmont. Some may be remnants of an older, late Tertiary valley bottom. None of these bench remnants has been examined by the writer.

TERRACES IN THE VALLEYS OF THE BEAVERHEAD AND JEFFERSON RIVERS

From a point about 6 miles south of Dillon, northeastward about 15 miles to the Ruby River near Sheridan, there is a similar Pleistocene piedmont terrace or smooth sloping bench of great extent bordering the west front of the Ruby Range. This bench, which is transected by numerous gulches, appears to be largely underlain by Tertiary "lake beds" and capped by alluvial fans of coarse, bouldery gravel. The alluvial fans head at the mouths of the several mountain gorges and spread thence over a wide extent to coalesce in one smooth sloping plain. Subsequent to the deposition of this gravel, when Beaverhead River eroded its broad, shallow, inner valley, the tributary creeks eroded the transecting gulches to depths of 50 to 150 ft or more. In several of these gulches, such as that of McHessor Creek which joins the river below Beaverhead Rock, downcutting was interrupted at least once and lateral planation developed an intermediate set of Pleistocene terraces. Later, continued downcutting and lateral erosion produced the flat bottom lands. At the McHessor ranch (about 5,500 ft above sea level), 7 to 8 miles southeast of Beaverhead Rock, the gulch has a total depth of 60 to 150 ft or more. The intermediate terrace is well preserved on the south side and on it are irrigated hay meadows. About 3 miles above the McHessor ranch house, garnetiferous schist is exposed between 6,000 and 6,300 ft above sea level on the sides of the canyon mouth. West of this place, the sides of the gulches, where seen by the writer, are either overgrown by vegetation or covered with cobblestones and boulders. Tertiary deposits are exposed farther down the gulches, however, and in the 50- to 75-ft bluff beside the highway under the lower west margin of the great bench. Where it is transected by Ruby River near Sheridan, the profile of the piedmont bench of the south bluff ranges from 5° near the mountains to 2° or less west of the road, a decline of about 1,000 ft in about 7 miles.

Near Sheridan, the Tobacco Root Mountains are bordered by a similar but somewhat less extensive piedmont bench, which slopes down to the bluff, 50 to 100 ft or more in height east of the bottom lands of the lower Ruby, Beaverhead, and Jefferson Rivers. In places, there is a slope of 3° on the bench near the road that the writer traversed between Sheridan and Parsons bridge on the north. The only deposits seen in this traverse were coarse gravel and 1- to 3-ft boulders of dark-gray limestone, gneiss, and porphyry. The bench is transected near this road by shallow gullies that farther west become gulches 50 to 100 ft or more deep. No exposure of deposits underlying the bouldery gravel were seen by the writer in the 1½-mile stretch below the road crossing Dry Boulder Creek. Near the mountain the head of the coalescent gravel fan has been built to a steeper grade by coarser material and the runoff from this fan has cut a conspicuous gorge through the lower part of the bench. It is probable that much of the gravel-capped bench is underlain by Tertiary deposits like those exposed between Ruby River and Dillon. The relations of this great terrace and the configuration of the west front of the Tobacco Root Mountains are described as follows by Tansley and Hart (1933, p. 5):

> The western margin of the range, facing Jefferson River, presents a steep and rugged front, deeply dissected by streams which tumble down short, narrow, and sharply inclined canyons. This mountain front plunges into the sweeping slope of a great composite alluvial fan along a smooth, gently curved line. The spurs between canyons terminate in sharply truncated facets as though they had been sliced off evenly with a knife. The crest line loses altitude gradually northward, finally merging with the flat alluvium of the Jefferson Valley. The southern portion of the western front, however, slopes steeply into the huge fan which stretches from Sheridan to Twin Bridges. Here the range is cut off along a line extending from the mouth of Dry Gulch to Virginia City.
>
> The west front is characterized by two distinct types of topography which are separated approximately by Mill Creek. South of Mill Creek, between Sheridan and Laurin, the topography is subdued; hills and ridges have gently curving slopes; valleys are relatively wide with gentle stream gradients; the mountains merge southwestward into the Ruby Valley almost imperceptibly. North of Mill Creek a marked difference is apparent. Peaks and ridges are high and rugged; valleys are narrow with steep gradients; and the higher summits reach approximately the same elevations—10,000 feet above sea level.
>
> It is difficult to explain by any other theory than that of faulting, the combination of abrupt change in slope along a straight course, the development of alluvial fans, and the presence of faceted or truncated spurs. Thus, these features in combination are abundant evidence of faulting, even though actual fault exposures are wanting. A fault, then, is inferred to extend along the western front of the range from Renova Hot Springs to Dry Georgia Gulch near Twin Bridges, where observed faults cut obliquely to it and produce a sharp angular bend in the mountain front.

In a general way, the mountains may be likened to a block hinged on one side and thrust up on the other, producing a long gentle east slope and a steep westward-facing scarp.

The uplift of this earth segment rejuvenated the streams, causing them to cut deep, narrow canyons into the higher portions of the range, and to spread the detritus along the base of the mountain front over the flat valley floor of Jefferson River.

Northeast of Silver Star the early Pleistocene terrace is quite largely cut away on the east side of the river but is preserved on the west where, as far north as Pipestone Creek, it merges westward with the long slope graded on Tertiary "lake beds" and traversed by the Chicago, Milwaukee, St. Paul & Pacific Railroad and U. S. Highway 10 west of Whitehall. Near Pipestone Creek, W. D. Matthew and Earl Douglass found Oligocene fossils in the so-called Pipestone Creek beds. The great second terrace was also finely developed and is preserved along Whitetail Creek north of Whitehall on the broad lower bottom land.

In the valley of Boulder River north of Cardwell and Jefferson Island railway stations two terraces of the second set are preserved, and there is also a narrow strip of a third terrace 15 to 20 ft above the stream. In adjacent parts of the Three Forks and Fort Logan quadrangles the upper terrace of the second set is well preserved on the west side of the valley, as is the lower level of the second set on the east. Thirteen to fourteen miles north of the mouth of Boulder River the lower edge of the upper level is 200 ft above the stream. Coarse cobblestone terrace gravel is exposed at this lower edge. The pebbles consist of quartzite and various volcanic rocks. Farther north the upper terrace is mostly cut away on the west side and the lower level is well preserved and very broad. This terrace is very little dissected. Farther northwest the flood plain is but little below the third terrace, and gradually it nearly merges with the broad lower terrace of the second set.

From Elkhorn Creek, southeast of the town of Boulder, a great, smooth, piedmont terrace, composed of coalescent alluvial fans, extends southward for miles on the northeast side of Boulder River. It is similar to the much more extensive piedmont terrace bordering the east foot of Bull Mountain on the west side of Boulder River south of Elkhorn Creek. Between its mountain gorge and the river, South Boulder Creek flows in a narrow inner valley cut below the second terrace that truncates Tertiary and older rocks.

Apparently for a very long time in the early and middle Pleistocene, there were relatively stable conditions suitable to the development of the great second terraces in all the region tributary to Jefferson River while the river was slowly cutting its gorge across the upturned Paleozoic and Mesozoic rocks east of South Boulder Creek and while the tributaries were cutting their gorges.

TERRACES ALONG THE CLARK FORK AND ITS TRIBUTARIES

AVON AND DEER LODGE VALLEYS

West of the Continental Divide several of the valleys and intermontane basins with terraces below the oldest high-level remnants are similar to those east of the Divide. One place where the early to middle Pleistocene (second) terraces were well developed and are still well preserved, though dissected, is in the Avon Valley, a small intermontane basin north of Avon, in and adjacent to T. 11 N., R. 8 W. This basin is drained partly northwestward by Nevada Creek to the Blackfoot River and partly southward to the Little Blackfoot River by Threemile Creek. From the base of Black Mountain broad strips of smooth-surfaced gravelly terraces slope southward, southwestward, and northwestward like remnants of great coalescent alluvial fans. There are two fairly distinct levels that transect them: the higher in the interstream tracts and the lower bordering the gulches 50 to 150 ft deep. They appear to represent the upper and the lower levels of the great second terrace of early to middle Pleistocene age. The tops of bluffs are 75 to 175 ft above the creeks. Seven miles north of Avon, Threemile Creek cuts through an outer and an inner glacial moraine not far from the canyon mouth. From the outer moraine the shallow stream cuts in a flat gravelly valley train half a mile to a mile wide, that trends southward to Avon as the floor of the inner valley. This relation shows clearly that the broad composite upper terrace or gravelly benchland is older than the last stage of glaciation. The bench gravel capping the Tertiary sediments, which are exposed in the bluffs below the broad second terrace, consists principally of smoothly rounded pebbles and cobbles, with some 1- to 3-ft boulders of quartzite, argillite, and considerably etched limestone. Most of the bench gravel is derived from rocks of the Belt series and show no evidence of glaciation. The head of the second terrace is several hundred feet lower than the high-level, benched spurs described as possible remnants of a late Pliocene piedmont terrace. The second terrace is undoubtedly the correlative of the moraine-covered terrace on the lava near Elliston, 5 to 7 miles east of Avon. North and west of Helmville the second terraces have been either eroded or obscured by glacial drift.

From the vicinity of Avon southwest to Garrison, along the gorge of Little Blackfoot River, remnants of the second terrace have not been distinguished. They are, however, extensively preserved to the south in the Deer Lodge Valley, especially along the west side of the valley bordering the front of the Flint Creek Range. They are comparable to those terraces east of the Continental Divide in the valleys of Jefferson and Boulder Rivers. The several terraces are more easily identified than would be inferred from the old topographic map of the Helena quadrangle. There are well-preserved remnants of the second terrace 3 to 4 miles west of Anaconda on both sides of the inner valley of Warm Springs Creek. The lower eroded edge of the north terrace is at the top of the bluff, 150 to 200 ft above the bottom land. This second terrace is capped with cobblestone gravel. The opposite corresponding terrace south of Warm Springs Creek is partly overlain by the terminal moraine of Gray Gulch glacier. This moraine, the moraine of Lime Kiln Gulch glacier, and the outwash gravels from them, occupy the gulches that transect the glaciated part of the second terrace. The cobblestone gravel that caps this terrace, where it was examined, is mostly composed of dark red quartzite. The material constituting the moraines and the outwash gravel is largely granitic. This outwash gravel merges with that underlying the bottom land and the latter gravel heads at the terminal moraine 2 to 3 miles farther west up Warm Springs Creek. All these moraines appear to have been formed during the last or Wisconsin stage of glaciation, so that the second terraces appear to be of pre-Wisconsin age (early or middle Pleistocene). The terrace or bench gravel, in places, overlies the truncated edges of similar upturned earlier gravel (Tertiary) and was probably partly derived therefrom by erosion.

Between Warm Springs Creek near Anaconda on the south and Kohrs, about 6 miles north of Deer Lodge, there are several extensive, well-preserved remnants of the great second terrace in the tracts between the streams heading in the Flint Creek Range. The piedmont slope gradually flattens eastward to a grade of about 100 ft per mile on the smooth gravel-capped benches. This slope is transected by several flat-bottomed creek valleys that head at the well-defined terminal moraines of the mountain glaciers and are floored with outwash gravel. At some places the moraines themselves extend down the inner valleys between the lines of bluffs below the benchlands; at others the outwash heads at or near the level of the adjacent benchland margins gradually lowering downstream between the bluffs until it is 100 ft or more below the cutoff margins of the second terrace remnant. It is thus clear that the second terrace is of pre-Wisconsin age. Tertiary deposits, largely sandy clay and gravel, are exposed in the bluffs below the capping of coarse bench gravel.

At Kohrs there is a well-defined third terrace 20 to 25 ft above the marshy bottom land. The lower edge of the second terrace at the top of the bluff just south of Sage Creek is 300 ft above the railroads near the west bank of the river. Between Kohrs and Garrison the second terrace is mostly cut away near the river and farther back some hills of lava rise above its gradient. The bench gravel at Kohrs appears to be 20 to 25 ft thick, and its constitutents range in size from pebbles a quarter of an inch to small boulders 2 ft in diameter. Most of the stones are of either quartzite or lava; a small percentage consists of granitic rocks, some of which is partly disintegrated. Some of the stones are well rounded and show percussion marks; no glacial striations were noted on them.

TERRACES WEST OF GARRISON, MONTANA

The valley of the Clark Fork below Garrison is, in general, much narrower than the Deer Lodge Valley and in it not many or extensive remnants of the second terrace have been noted by the writer. There are, however, places where the character and attitude of the rocks permitted considerable meandering of the stream, as shown by well-defined terrace remnants 100 to several hundred feet above the stream. One is a smooth-topped, benched spur half a mile or more in length and 100 to 200 ft high in the river bend 1 to 2 miles west of Garrison. Near the south side of the valley the two railroad tunnels through the upturned and smoothly beveled Cretaceous shale and sandstone underlying the gravel cap of this terrace. The foot slope of the hills on the north is graded down to this general terrace level (about 4,500 ft above sea level). The lower bluffs here rise steeply from the smooth bottom land. These features and similar ones farther west toward Drummond appear to mark fairly definite stages in the Pleistocene development of the Clark Fork valley, like those on the Missouri and its tributaries. It is probable that in Pliocene time the valley bottom at this place was at or near the height of the top of the higher bluff.

South of Drummond and Hall the dissected gravel-capped benchlands east and west of Flint Creek appear to have been graded down to the second terrace in early or middle Pleistocene time, before being greatly dissected and before the outer terminal moraine of the Boulder Creek glacier was deposited in the Flint Creek Valley, north of Maxville (in adjacent parts of Tps. 8 and 9 N., R. 13 W.).

The material underlying the smooth terrace is exposed in old placer diggings. Just below the abrupt west edge of the bench 2 miles south of Hall and 200 ft above Flint Creek there is 20 to 30 ft of very coarse brownish gravel of Pleistocene age, largely composed of quartzite and argillite. Intermixed with cobblestones, mostly 2 to 8 in. in diameter, are finer gravel and sand and some boulders measuring as much as 1 by 2 by 4 ft. The material is not well sorted or bedded. The boulders, though mostly waterworn and showing percussion marks, are not well rounded. Under this coarse gravel, which looks like a torrential deposit, is rusty gravel interbedded with pinkish sandy material of the Tertiary "lake beds" (Oligocene and Miocene). No granitic material, such as is so plentiful in the glacial drift north and south of Maxville, was noted in the bench gravel at this place. Either the granitic material has almost entirely disintegrated since this early(?) Pleistocene bench gravel was deposited or the rocks overlapping the granite on the headwaters of Boulder Creek and its tributaries were not so extensively eroded away as to uncover the granite at the time this bench gravel was washed out by streams from the mountains. Conditions here were similar to those on Gold Creek to the east near Pioneer.

Nearly 50 miles below Drummond, the Clark Fork is joined by Rock Creek, which heads in the Anaconda Range south of Georgetown Lake. The lower part (35 miles) of the deep gorge through which Rock Creek flows parallel to the Sapphire Mountains on the west has not been carefully examined, although the road was traversed by the writer. That part between Stony Creek and the Potato Lakes west of Georgetown Lake was also traversed. From such features as were seen on these traverses, it seems clear that the gorge of Rock Creek was cut to nearly its full depth by early or middle Pleistocene time.

The East Fork of Rock Creek flowing north-northwest from the Anaconda Range cuts a gorge through the foothills and transects a smooth piedmont terrace several square miles in extent. The steep upper slope of this terrace heads about 6,400 ft above sea level and drops 300 to 400 ft in a mile; beyond this the grade decreases northward and in 2 to 3 miles the terrace is 5,700 to 5,900 ft above sea level. The East Fork has cut through this smoothly sloping gravel bench, forming a valley 200 to 300 or more ft deep and about half a mile wide. The bench remnants are capped with coarse gravel composed of pebbles, cobbles, and boulders of igneous rocks and quartzite. In the Philipsburg folio this gravel is shown overlying Tertiary volcanic ash and quartzite of the Belt series, and is described as of late Tertiary or Pleistocene age. The relations suggest that at first the drainage across this gravel bench was down Trout Creek past Philipsburg, and that in early Pleistocene time it was captured and diverted by Rock Creek through the narrow gorge in sec. 8, T. 5 N., R. 15 W. Down the inner valley below this gravel bench, the East Fork glacier advanced to a point 5,966 ft above sea level about 4 miles southwest of Georgetown Lake in sec. 31, T. 5 N., R. 14 W.

The Middle Fork glacier, 3 to 4 miles to the west, was considerably larger and advanced 2 miles farther north and down to a point 1½ miles above the junction with East Fork (5,500 ft above sea level). For a mile the northern part of the ridge between Middle and Ross Forks is narrow, and 200 ft high, and its flat top is capped with coarse, waterworn gravel and boulders composed mostly of quartzite, with some of granite 2 to 3 ft in diameter. This gravel overlies the upturned and beveled edges of beds of siliceous limestone, but little limestone is seen in the gravel. The many boulders seen along the highway below this terrace remnant may have rolled down from it.

Near the junction of East, Ross, and West Forks, Rock Creek is bordered by cliffs of yellowish to reddish limestone, with picturesque pinnacles and buttresses and was evidently not glaciated. Farther north the valley widens somewhat and there are remnants of a well-defined terrace 200 to 300 ft above the broad, farmed, lower terrace which forms the main bottom land. The latter is underlain by outwash and alluvial gravel of Wisconsin(?) age. The terrace 200 to 300 ft higher, where examined, is capped with 50 ft of quartzite—cobblestone gravel. In places this terrace has been displaced by landslides on underlying red shale. This terrace is probably of early Pleistocene age. Tertiary gravel has been mapped (Calkins and Emmons, 1915) on the upland to the east in the western part of the Philipsburg quadrangle, 500 to 1,000 ft above Rock Creek. Below the mouth of Willow Creek, the valley of Rock Creek increases in depth and its sides in places are precipitous.

At the confluence of Rock Creek with the Clark Fork there is a small butte, so cut off from the valley walls on the north, the east, and the west, that it stands out in the midst of the valley like a tabular remnant of a Pleistocene terrace isolated by shifting of the streams. Except for being cut off, it is similar to the benched spur at the railroad tunnels west of Garrison and to the spur at the mouth of Harvey Creek 2 miles west of Bearmouth. It is possible that there was some shifting of the streams as the waters of glacial Lake Missoula were drawn down in middle or late Pleistocene time from the maximum altitude of 4,200 ft above sea level. Several other spurs may be worn-down narrow remnants of higher terraces of late Tertiary or early Pleistocene age. They include such long, narrow, and uneven-topped rock spurs as Medicine Tree Hill near Nimrod, a somewhat lower rocky spur about a mile farther west, and the benched spur known as the Beavertail Hill which is crossed by the highway and tunneled through by the railroads at Cramer Creek, 5 miles east of Rock Creek. Some of these narrow, rocky, benched spurs extend out half a mile to a mile or more from the higher side slopes of the valley.

BITTERROOT VALLEY

In the Bitterroot Valley the great second terrace is as well preserved as anywhere in western Montana. West of Sula the East Fork of the Bitterroot River enters a deep winding gorge, in which it flows for about 14 miles northwestward to its junction with the Bitterroot at Conner. Four to five miles below Sula the East Fork is joined by Warm Springs Creek, which comes from the south through a similar deep mountain gorge. The mouth of this gorge, below Medicine Hot Springs, is flanked by benched rock spurs; the one on the east, 250 ft or more above the streams, may be of early Pleistocene age. The spur on the west side extends so far into the valley of the East Fork that it forces the river to flow near the north side of its gorge. Two steps cut into the granite forming this spur are capped with coarse granitic cobblestone gravel at levels about 125 and 150 ft above the streams. These steps are well above the lowest gravel terrace at the road and are probably of early to middle Pleistocene age. The lower 2 miles or so of the Warm Springs Creek is bordered by steep walls of granite with numerous rock towers and pinnacles. Large quantities of talus and many big granite boulders are present, but there is no evidence of glaciation in the area.

No detailed study of the East Fork gorge between Sula and Conner has been made by the writer, though the highway has been traversed several times. In places, smoothly rounded crests and uplands appear above the steep and high canyon walls.

Above the low granite bluff at Conner a dissected slope or bench probably of early Pleistocene age rises southward to the higher hills. Northeast of Conner and 200 to 500 ft above the stream the granite is overlain by a Tertiary rhyolite.

South of Tin Cup Creek there is a broad belt of foothills that extends eastward for several miles from the high east front of the Bitterroot Range to the Bitterroot River north of Conner and to the narrow inner valley of the river farther southwest. This foothill belt is largely wooded and has not been traversed by the writer. Bordering these foothills, between Tin Cup Creek and Bitterroot River, there are several remnants of the gravelly upper and intermediate terrace levels that have been transected by McCoy and Chaffin Creeks and terminate at the tops of the lower bluffs about 200 ft high west of the river. There are exposures of gneiss in these bluffs below bench gravel composed largely of smoothly rounded quartzite cobblestones capping the terrace remnants south of Darby. This gravel, like the upper terrace gravel farther north, is probably of early Pleistocene age.

From the vicinity of Tin Cup Creek south of Darby northward for about 8 miles, nearly to Lost Horse Creek, either one or both levels of the great second terrace are extensively preserved, although transected by several creek valleys and shorter gulches. On these benchlands are some irrigated grain fields and large apple orchards. The general altitude of the second terrace decreases northward and the smooth interstream remnants slope eastward to northeastward to the low line of bluffs half a mile to a mile west of the river, where they have been cut away by erosion. In this part of its valley, the Bitterroot River has shifted to the east side of the inner valley, so that the east side terrace if once extensively developed, has been mostly cut away, and there is a steep slope to the higher levels of the hill. The short interstream spurs along this slope are definitely benched at different levels on granite in the vicinity of Darby and on overlying early Tertiary rhyolitic lava farther north. The school and the west part of the village of Darby are on a terrace step 25 or more feet above the low flat (3,832 ft above sea level), the level on which the business street and the railroad are built. The approximate altitudes, where the grade of the slope bordering the Bitterroot Range flattens to the main second terrace, range from 3,800 ft at the north to 4,200 ft above sea level at the south. The dissected upper terrace was therefore probably submerged, though not greatly modified, by the waters of glacial Lake Missoula at its highest stages. In general, the bench gravel appears to overlie Tertiary "lake beds", largely arkosic sand, gravel, and boulders, and in places north and south of Como rhyolite is exposed in the bluff below the gravel. The loamy soil covering the coarse bench gravel in some of the fields and orchards may have been deposited, in part, while the region was submerged by glacial Lake Missoula.

About two miles southwest of Darby there is what appears to be a remnant of a partly eroded outer terminal moraine of Tin Cup Creek glacier in or near the W½ sec. 27, T. 3 N., R. 21 W., on or below the second terrace. The outwash gravel train of Wisconsin age extends through the gap in this outer moraine and floors the rather broad bottom of the inner valley of lower Tin Cup Creek 100 ft or more below the bordering remnants of the transected second terrace. These relations seem to indicate that the second terrace is of pre-Wisconsin age, probably early to middle Pleistocene, but is not as old as the big, curved, drift-covered north spur described on page 49. The relations here, however, have not been as clearly determined as might be desired.

The outermost terminal moraine of Rock Creek glacier is about a mile outside the big terminal moraine of the Wisconsin stage of glaciation just below Lake Como. This outer moraine, in sec. 27, T. 4 N., R. 21 W., is low and somewhat eroded; it lies in the inner valley between the outer ends of the north and south spurs and about 100 ft or more below the heads of the bordering remnants of the gravel-capped second terrace. From the relations here it seems clear that this terrace is of pre-Wisconsin age, perhaps early or middle Pleistocene.

North and south of the lower mile or two of Lost Horse Creek the second terrace has been cut away and the stream is bordered on each side by a lower terrace floored with glacial outwash, whose maximum width is about 1 mile. This outwash terrace extends westward up to the front of an outer, partly eroded terminal moraine of the Lost Horse glacier. About half a mile farther upstream the terminal moraine of the Wisconsin stage of this glacier lies athwart the valley and is cut through by a narrow stream channel 3,900 to 4,000 ft above sea level. About 100 ft above the north side of the outwash terrace and outside of the outer moraine the valley is bordered by a narrow strip of the second terrace; on it are apple orchards. This upper terrace extends eastward to the top of a rhyolite bluff more than 100 ft above the river, which flows at its base south of the Charlos Heights bridge. North of this rhyolite cliff for 4 miles or more in T. 5 N., R. 21 W., the second terrace has largely been cut away, leaving a lower flat terrace 1 to 1½ miles wide west of the river and 20 to 50 ft above it. The railroad is on this lower terrace.

At several places north of Charlos Heights gneiss is exposed in the bluff west of the railroad, but the overlying bench gravel is largely composed of quartzite cobblestones intermingled with granitic material. The source of this quartzitic material and also that in the bench gravel near Darby is not known to the writer. It is not glacial drift, and quartzite is not known to be present in that part of the Bitterroot Range immediately to the west. It may have been derived from quartzite ledges that were exposed in early Tertiary time but are now covered, or were removed by erosion and incorporated in the Miocene "lake beds," later to be released and redeposited as Pleistocene bench gravel.

From the vicinity of Grantsdale and Hamilton the mountain front on the west is continuous almost directly northward, but the hills on the east are several miles eastward, thus broadening the Bitterroot Valley and the belt of Tertiary sediments which it contains. On these soft and friable deposits long slopes have been graded down to extensive benchlands, most of which have not been traversed by the writer. Some of these benches are between Skalkaho Creek near Grantsdale and Willow Creek near Corvallis. They are sharply cut off at the lower edges forming lines of abrupt bluffs 50 to 100 ft high bordering the broad bottom lands of the Bitterroot River. The benchlands are also transected by broad, shallow, flat-bottomed valleys bordered by similar lines of low bluffs. Some of the benchland near Hamilton is irrigated and under cultivation.

From the outer terminal moraine of Roaring Lion and Sawtooth Creek glaciers a great fan of bouldery gravel (or coalescent fans) slopes eastward to the top of a 100-ft bluff near the river. The head of the fan is about 4,000 ft above sea level at the moraine fronts and the gradient, which is 250 ft in the first mile, decreases to 100 ft in the second mile. The surface consists of coarse cobblestone gravel and boulders, resembling a torrential deposit, thinly covered with soil. Boulders, which are very numerous near the moraines, decrease in number farther out, and some areas have been cleared of stones for meadows and orchards.

There are some indications that the outer moraine of Roaring Lion glacier is older than the inner one and may be of Illinoian or Iowan age (p. 86), like the outer terminal moraines farther south. The bouldery surface of the fan slopes downward from the outer moraine front as though built up, in part at least, by vigorous outflow of glacial waters. The terrace as a whole is evidently as old as the outer moraine if not older. Northward to Canyon Creek, the second terrace appears to have been much eroded. If the relative altitudes were then about the same as now, the whole of this fan must have been submerged during the highest stages of glacial Lake Missoula, and it is possible that many of the boulders were dropped upon its surface from icebergs floating away from the glacier fronts. The present stream courses from the canyon mouths are northeastward and were apparently established as the lake waters were lowered. The streams have only slightly eroded the great fan terrace.

A short distance west of the Hamilton bridge a lower terrace, a low bluff, and a second terrace or bench extend westward. The second terrace extends northwestward also as though formed, in part at least, by torrential water from the canyon of Blodgett Creek. Oxidized sand and gravel were seen at one exposure, but in general the capping of the bench below the top soil consists of coarse cobblestone gravel with many boulders on its surface. The relations to the terminal moraine of the Canyon Creek glacier were not clearly determined. The terrace is transected by gulches and it is sharply cut off by erosion on the south, east, and north. In the N½, sec. 22, T. 6 N., R. 21 W., the terminal moraine of the Wisconsin stage of the Blodgett Creek glacier extends onto the head of this second terrace; thence, curving northward, it continues downward over the marginal bluff, which is about 100 ft or more high, and across the head of the lower outwash terrace, which slopes downward to the river, lowering 250 to 300 ft in about 2 miles. It is therefore evident that the upper, or second, gravelly bench is of pre-Wisconsin age. Blodgett Creek does not flow directly eastward through the narrow gap in the outer moraine, which is used by the road and the irrigation ditch; instead, it cuts through the north lateral moraine near the mountain front.

It is possible that here, as along Sawtooth Creek and Roaring Lion Creek to the south, the northeasterly course below the canyon mouth was assumed when the water of glacial Lake Missoula dropped from the high levels that submerged the upper terrace. It is also possible that some of the abundant boulders on both the upper and lower terraces were dropped from icebergs.

The second terrace is fairly well preserved and about 1½ miles wide on the north side of Mill Creek west of Woodside. From an altitude of about 3,900 ft above sea level at the terminal moraine, about a mile outside the canyon mouth of Mill Creek, the bench slopes eastward about 300 ft in about 1¾ miles to the top of the 100-ft bluff a mile or more west of the river, where it is cut off by erosion. At the south side of Mill Creek a coarse gravel terrace, probably the Wisconsin outwash terrace, heads at the moraine and drops more rapidly, so that it merges with the terrace below the bluff southwest of Woodside. The upper, or second, terrace, therefore, seems to be of pre-Wisconsin age. Rusty sand and gravel and granitic arkose sand exposed in places under the second terrace may be, in part, of Tertiary age.

Northward, from Bear Creek south of Victor, remnants of the second terrace have been less clearly distinguished from the general slope of the piedmont, which is considerably dissected and slopes down to the broad lower flat. The glacier of Bear Creek appears to have extended out a short distance between narrow benched rock spurs that flank the canyon mouth and to have deposited one or more morainal loops. A narrow, gravel-capped bench 4 miles north of Victor on the south side of McCalla Creek at Indian Prairie is about 100 ft above the lower terrace and is probably a remnant of the second or pre-Wisconsin terrace, 3,400 to 3,700 ft above sea level.

About a mile west of the village of Lolo and south of Lolo Creek, there are conspicuous remnants of a smooth, well-defined bench transected by the lower gorge of Mormon Creek, which is about 300 ft deep. From the ends of the mountain spurs on each side, these bench remnants extend northward about a mile, with decreasing gradient, to altitudes of 3,500 to 3,600 ft. They correspond in height approximately to benches on the east slopes of the Bitterroot Valley, both north and south of the mouth of Lolo Creek.

An irrigation ditch along the steep side of the lower gorge of Mormon Creek appears to be dug partly in stratified alluvial material composed of fine, angular chips of buff limestone. The east bench top is covered with waterworn gravel. In places below the bench ledges of thin-bedded limestone crop out. Although this bench on Mormon Creek was undoubtedly washed by glacial Lake Missoula, it was probably first developed by stream erosion in early Pleistocene time.

A bench at about the same level is transected by Lower Mill Creek, 5 to 6 miles farther west. These benches were probably completed by Mill Creek and Mormon Creek, sweeping alluvial material into the Lolo arm of glacial Lake Missoula about the same time (early Pleistocene?) as the upper or silt terrace was formed in the broader part of the lake west of Missoula. There was undoubtedly a small glacier in a high cirque on the north flank of Lolo Peak at the head of Mill Creek. Whether or not there was any glacier in the Mormon Creek gorge is not known.

Unlike the west side of the Bitterroot Valley, the east side south of the mouth of Lolo Creek is not as clearly and regularly defined by a fault line. In some places there are fairly good indications of the probable depth of the tributary valleys and declivity of their side slopes in late Tertiary or early Pleistocene time. One of these localities is in the environs of Burnt Fork southeast of Stevensville in and adjacent to T. 8 N., R. 19 W. There may have been some small glaciers in the Sapphire Mountains on the headwaters of this creek, but no evidence was noted in the part examined by the writer that the creek valley had been modified by glacial ice as far down as 12 miles above Stevensville, and no terminal moraine was seen as far down stream as sec. 24 of the above-named township. The valley bottom is narrow as far down stream as sec. 11, where a very narrow portal is cut from an altitude of 4,500 ft to about 4,300 ft above sea level through rocks of the Belt series which form the low bluffs on either hand. Below this portal the inner valley, eroded in Tertiary (probably Miocene) "lake beds", opens abruptly to a width of three-quarters of a mile and gradually broadens to nearly 3 miles at its mouth, a mile east of Stevensville, where it is about 3,400 ft above sea level. In this area, the slope of the broad irrigated bottom land ranges from 100 to 200 or more feet per mile. The flat land has a thin loamy soil underlain by coarse gravel.

From the margins of the bottom land, short slopes or bluffs rise steeply for 100 to 200 ft or more to a smooth, broad, sloping, upper bench on the north and on the south. The lower parts of this great dissevered upper bench are nearly flat where not cut by gulches, and the grade of the surface ranges from more than 200 ft per mile at the east down to 75 ft per mile in the lower parts. These benches are underlain by coarse gravel composed of subangular to smoothly rounded cobbles and small boulders as much as 2 ft in diameter, mostly of quartzite, with some of rhyolite and granite. The bench surface south of Burnt Fork, where traversed by the writer, is in general characterized by two levels, one somewhat lower than the other. The lower one is irrigated in places. Apparently they represent two stages in the development of a great alluvial fan overlying the eroded surface of the Tertiary "lake beds." The fan as a whole appears to be the westward continuation of the upper and broader valley of Burnt Fork, which is represented by the smooth bench above the narrow portal. Judging from the relations of the outer terminal moraines to similar terraces elsewhere in the Bitterroot Valley, this bench is probably a remnant of the early Pleistocene valley of Burnt Fork, down which the long, smooth, adjacent, grassy slopes are graded. Very similar conditions, though perhaps at higher levels than here shown, probably existed in late Tertiary time.

There are somewhat similar conditions farther north, where Ambrose, Threemile, and Eightmile Creeks emerge from their gorges in the Sapphire Mountains and cut across the broad piedmont to the river. The writer has not examined them in detail, but distant views and study of topographic and geologic maps show that there are long slopes graded to the heads of remnants of great dissected piedmont gravel terraces developed on Tertiary (probably Miocene) "lake beds" and that the lower valley bottoms are broad, flat, and gravelly, sloping to the river like alluvial fans between lateral lines of bluffs 75 to 100 ft or more in height. Not all of these features are differentiated on the map (pl. 1).

So similar in character and in topographic relations are these terraced benchlands ("second terraces") west of the Continental Divide to those in the upper Missouri River basin both east and west of the Rocky Mountain front that there is little doubt that they were practically contemporaneous in origin and indicate widespread general similarity of conditions of development. The terraces are probably of interglacial stream origin. The great bouldery fans in the Bitterroot Valley may be of either glaciofluvial or of interglacial torrential stream origin, sprinkled with boulders dropped from glacial icebergs floating on the waters of glacial Lake Missoula.

Although many of the terrace remnants and alluvial or glaciofluvial fans in the Bitterroot Valley were probably submerged either wholly or in part at the highest stages of glacial Lake Missoula, they were not, strictly speaking, either lacustrine terraces or deltas. They would probably have had practically the same form and structure if there had been no glacial Lake Missoula. In the valley of Clark Fork below Missoula insufficient study has been made by the writer to differentiate other early or middle Pleistocene features from those which are clearly the result of submergence of the valley by this Pleistocene lake.

ILLINOIAN OR WISCONSIN (IOWAN) GLACIAL DEPOSITS WEST OF THE CONTINENTAL DIVIDE

DRIFT ON FLINT AND BOULDER CREEKS NORTH OF PHILIPSBURG

At numerous places west of the Continental Divide and outside of the several well-defined terminal moraines of glaciers of the last or Wisconsin stage, there are certain deposits of glacial drift that appear to be somewhat older than late Pleistocene, yet not so old as the meager remnants of early Pleistocene drift described above. They are regarded as probably the correlatives of moraines of Blackwelder's (1915, pp. 324–328) Bull Lake stage of glaciation in the Wind River and Gros Ventre Ranges of Wyoming, and of the Illinoian or early Wisconsin (Iowan) drift of the Keewatin ice sheet in eastern Montana and North Dakota, described in Professional Paper 174 (pp. 69–89).

It should be noted that under present usage of the U. S. Geological Survey the Iowan drift of northern Iowa is classed as of early Wisconsin age (Cooke, Gardner, and Woodring, 1943, p. 1714 and chart). The outer drift in eastern Montana and the drift here under consideration may be somewhat older than the "Iowan drift" of northern Iowa.

There are some indications that by middle Pleistocene time Flint Creek Valley, south of Drummond, from the vicinity of Stone (6 miles south of Hall) southward through the Philipsburg Valley was cut down nearly or quite to its present depth and that glaciation occurred soon after. (See topographic maps of Drummond and Philipsburg quadrangles.) South of Stone an enormous number of granite boulders ranging from 1 to 10 ft in diameter are spread on the flat valley of Flint Creek. This boulder deposit extends southward 2 to 3 miles past the village of Maxville and into the canyon mouth of Boulder Creek. The boulders are not confined to the flat but also lie up along the hill slope on the east. They do not extend farther southward up the valley of Flint Creek. They were evidently transported by a glacier whose tributaries headed 7 to 10 miles southeast of Maxville on the granite uplands east of Philipsburg. In spite of the fact, however, that a glacier about 1,000 ft thick extended out of the canyon of Boulder Creek, the edges of upturned limestone strata in the cliffs at either side of the portal are not scoured smooth as is usual where late Pleistocene glaciation has occurred. On the contrary, these cliffs are characterized by towers and pinnacles of limestone such as are indicative of long and uninterrupted exposure to weathering. There is also a considerable accumulation of talus, and 2 miles below the old mining village of Princeton, there is what may be a moraine of a later glacier. The walls of the canyon above (southeast of) this moraine have a more scoured and smoother appearance. These conditions indicate that in the late Pleistocene (Wisconsin stage of glaciation) the main Boulder glacier extended only 2 miles below Princeton (an altitude of about 5,150 ft) and was not at that time joined by the South Boulder glacier; and that the glacier that advanced 6 miles farther, to the vicinity of Stone (about 4,525 ft above sea level) did so at an earlier time—either at the Illinoian stage or when the Iowan drift was deposited in northeastern Iowa and adjacent states. It is probable that the boulders deposited on the lower terrace of the second set as developed in the broad basin between Stone and the Clark Fork.

The following description of pre-Wisconsin glacial deposits on Fred Burr Creek and other creeks south of Philipsburg (Calkins and Emmons, 1915, p. 11).

Earlier moraines.—The fragmentary remnants of the earlier moraines are not all readily distinguished from stream deposits and later moraines. The locality at which the earlier glacial drift is most easily identifiable is at the mouth of Fred Burr Creek. At this place the later moraine appears to have covered nearly all the older one, only a little of the northwestern margin of which is left exposed. An old railway cut through both moraines reveals a striking contrast in the preservation of their materials. The bowlders of granodiorite in the later moraine are fresh and smooth; those in the earlier are rusty and defaced by scaling. The diorite bowlders in the later moraines are but slightly weathered; those in the earlier are thoroughly softened by decay.

The Fred Burr glacier, one of those heading on the west flank of the Flint Creek Range, extended a short distance into the Philipsburg Valley and down to a level about 100 ft above Flint Creek, where this older drift is exposed outside the later moraine.

On Warm Spring Creek the earlier moraine seems to have been covered even more completely than on Fred Burr Creek; the terminus of the rough recent moraine is sharply defined, and the valley floor below is smooth and free from large bowlders. The later glaciers of the two large branches of Rock Creek, however, were considerably shorter than the earlier ones. For about a mile from the north end of the area mapped as morainal on the Middle Fork, there is feebly accented morainal topography, which gives way abruptly to the very much rougher topography about the Potato Lakes. Similar extension of older terminal moraines beyond the later may be observed just beyond the eastern boundary of the [Philipsburg] quadrangle, on Mill Creek [south of Anaconda] and perhaps also on Lost Creek. It is doubtful what proportion, if any, of the bowlders beyond the recent moraine of Lost Creek [north of Anaconda] should be considered as old moraine rather than outwash, and similar doubt exists as to the exact limits of the terminal moraines of Grays Gulch and Big Gulch south of Warm Spring Creek.

Among the larger isolated areas of drift that apparently belong to the earlier glaciation is one about 2 miles south of Georgetown Lake. Some smaller patches not mapped may be ascribed with more or less certainty to the older drift, even though few of their bowlders consist of the granitoid rocks that are so abundant in the later moraines. Although highly resistant to attrition the granite is less resistant to weathering than the tough metamorphic rocks. It has withstood decay fairly well for the period subsequent to the last advance of the ice, but the phenomena observed at Fred Burr Creek make it seem probable that in small mounds exposed to weathering and erosion since the first advance much of it would crumble to sand and be washed away.

DRIFT AT PIONEER AND IN THE VALLEY OF THE LITTLE BLACKFOOT RIVER

Pardee found exposures of what appears to be drift of intermediate age, 5 or 6 miles south of Goldcreek in Pioneer Gulch south of the old mining village of Pioneer. The drift was exposed in placer mining pits about 500 ft below the level of the early Pleistocene "Pioneer drift" on Ballard Hill and some distance outside (north of) the lateral moraine of the Pikes Peak glacier, which crowded up onto the remnant of an old gravel bench south of Pioneer at the Wisconsin stage. In 1927 the section in Pioneer Gulch was obscured by slumping. However, a much-weathered glacial drift was exposed in which granite boulders were so badly decomposed that they were readily broken to pieces in hydraulic mining. Underlying the drift were Tertiary "lake beds" with some gravel. Pardee suggests that Pikes Peak Creek originally flowed northward past the site of Pioneer, rather than in its present course farther east, and that the "intermediate drift" exposed in Pioneer Gulch was deposited by a glacier heading in the canyon of Pikes Peak Creek and following this northerly course. Gulches 100 to 200 ft deep have been cut into and through this drift since it was laid down. There is a low boundary ridge on the flat about 2½ miles northeast of Pioneer, which may possibly be a pre-Wisconsin terminal moraine, although this is doubtful. Below it the gravelly flat contains fewer large boulders. It is quite possible that closer study of the moraines of the several glaciers farther south between Pioneer and Anaconda would reveal further evidence of this intermediate stage of glaciation.

On the Little Blackfoot River, 20 to 30 miles east of Garrison, pre-Wisconsin glacial drift occurs both east and west of the village of Elliston. The Little Blackfoot glacier which deposited this drift headed at the Continental Divide, on or near Thunderbolt Mountain in what is now part of the Helena National Forest, about 16 miles south of Elliston. The terminal moraine of the last or Wisconsin stage of this glacier extends across the nearly flat bottom of the valley, 1 to 2 miles south of the Northern Pacific Railway. From this moraine a well-defined terrace, underlain by outwash gravel, extends to the foot of the hill north of the railroad and thence westward from the vicinity of the limekiln and quarry down the valley past the village of Elliston for many miles to the vicinity of Avon.

It appears that the branching glacier that occupied the upper valley of Little Blackfoot River and its tributary valleys during either Illinoian or early Wisconsin (Iowan) time was considerably thicker and 4 or 5 miles longer than the later glacier and also that the valley was not so deep during the earlier as during the later stage. This conclusion is based on the presence of glacial drift high above and far outside the Wisconsin terminal moraines, on the sides of the valley to the northeast, north, and northwest.

Heading near the village of Elliston there is a well-defined high terrace extending for some miles westward down the north side of the valley of Little Blackfoot River. This terrace is at the top of a rhyolite cliff and about 300 ft above the low Wisconsin outwash terrace which borders the stream. There is a small erosion remnant of a terrace on the south side of the valley, about a mile west of Elliston. This remnant is in a small reentrant in the lower part of the high south slope and is cut by two or three gulches, but its top is at the same general height as the upper terrace north of the river and is also underlain by rhyolite. It is probable that the plain represented by these terrace tops was once continuous across the valley and formed the valley bottom during Pleistocene time, after the stream had cut through the Tertiary beds and 500 ft or more into the earlier Tertiary rhyolite. The top of the south terrace remnant and the slopes below are sprinkled with pebbles of lava, granite, quartzite, and limestone, some of which show glacial striae.

That this old bottom land was glaciated before the inner 300-ft valley was eroded is indicated by the presence of the striated drift pebbles on the south terrace remnant, and also by the presence of a much more extensive deposit of drift on the north terrace and the absence of a corresponding terminal moraine in the inner valley. From a cemetery about 4 miles west of Elliston a road extends northward up a gulch and onto and across the upper terrace, here 250 to 300 ft above the river. Near the north edge of the terrace a low swell-and-swale north lateral moraine extends westward for about a mile, across the road, and curves around southward toward the crest of the rhyolite bluff as the terminal moraine of a pre-Wisconsin glacier which occupied this old valley bottom, now the upper terrace. The undulating and somewhat eroded surface of the moraine contains numerous boulders of quartzite and granite, many of them 5 to 10 ft in diameter, derived from the hills to the east and southeast.

East of the road the lateral moraine is characterized by two parallel well-defined, though small, bouldery ridges which extend southeastward up the slope in a curving course, showing where the ice margin curved around the hill slope north of Elliston. The limit of the drift is traceable to an altitude of 5,800 ft—that is, nearly 800 ft above the river near the village. A small but fairly distinct marginal ridge of drift, with striated pebbles, curves around the slope and eastward across the upturned quartzite and the Madison limestone at an altitude of about 5,800 ft, high up on the slope above the Northern Pacific Railway near the limekiln at Calcium. This eastward-trending slope is directly opposite the mouth of the upper part of the valley of Little Blackfoot River, so that during the pre-Wisconsin advance of the glacier the ice moved directly toward and up this slope and spread laterally east and west in two short terminal lobes. The west lobe crowded past the quartzite ledges 1 to 2 miles west of the limekiln and thence around the slope onto the old valley bottom, now the upper terrace, for a distance of 2 miles west of Elliston. The shorter, but thick, lobe of the east side advanced northeastward up the valley of Dog Creek toward Mullan Pass for about 1½ miles above the limekiln and there deposited a considerable quantity of glacial till. There are drift pebbles and boulders for several hundred feet above this place on the hill slope south of the railroad. Northeast of this limit the valley of Dog Creek was probably occupied by a temporary lake at about the same altitude as the drift-covered terrace west of Elliston. This lake bottom is not trenched by an inner valley. It is possible that at its highest level this lake spilled eastward through Mullan Pass. Among the scattered pebbles and boulders where the highway crosses the pass (altitude 5,850 ft) a few striated pebbles were noted. They may have been dropped from masses of ice floating eastward from the Little Blackfoot glacier.

In 1931 a highway (US 10) was being graded up a gulch leading to a pass at the head of Walker Creek, nearly due east of the Calcium limekiln. For about 4 miles southeast of the limekiln, 10 to 40 ft of glacial till were exposed in some of the road cuts below an altitude of 5,600 ft. One of these cuts showed fine, laminated glaciolacustrine silt overlain by 20 ft of glacial till and also underlain by till. The silt, obviously deposited in a small temporary lake held in by an ice dam to the west, is folded, overthrust, and faulted, and some till is infolded with it. This deformation resulted from an eastward readvance of glacier ice which overrode the laminated silt. One of the cuts nearer the limekiln also showed somewhat crumpled glaciolacustrine silt overlain and underlain by glacial till.

At the west, near the limekiln, the drift exposed in the highway and railroad cuts merges with a morainal deposit that extends southward nearly 2 miles along the east side of the Little Blackfoot outwash terrace like an older lateral moraine. A similar drift deposit extends westward from the limekiln, like a terminal moraine banked against the lower slope north of the railroad. On a higher slope sharp notches are cut across spurs, suggesting spillways for waters forced to flow along the slope by the forward crowding of a glacier front.

As stated previously (p. 80), there are some slight indications of pre-Wisconsin glaciation on Threemile Creek, 7 or 8 miles north of Avon, in T. 11 N., R. 8 W.

Consideration of the several deposits in this vicinity suggests the possibility that three distinct stages of glaciation are represented here and that the oldest, which is represented by the scattered drift high up on the slopes and by the moraine of the upper terrace west of Elliston, is older than either the early Wisconsin (Iowan) or the Illinoian drift.

DRIFT IN THE BLACKFOOT RIVER BASIN

At intervals for about 2 miles northwest of the bridge over the Blackfoot River, which is northwest of Helmville, low bluffs along the river expose 10 to 50 ft of reddish to buff, clayey till containing scattered striated pebbles of red and green argillite and of quartzite and limestone. Some of the exposures show northeast-dipping, light-buff, semi-indurated Tertiary clay and sandstone underlying the till. The till in these exposures is outside the Wisconsin terminal moraines, which are well defined south of the North Fork of the Blackfoot River, and therefore is thought to be of pre-Wisconsin age. Pardee mapped this drift as present also on the slopes and in gently undulating tracts rising above the broad gravelly flats bordering Nevada Creek near Helmville and extending northwestward along the Blackfoot River to and up Cottonwood Creek, west of Ovando. There is no terminal moraine at the outer limit of this drift. The drift was evidently deposited by a great piedmont glacier whose numerous branches headed in the high mountains to the north and occupied the gorges of Cottonwood, Monture, and Rock Creeks, and of the North Fork of Blackfoot River, and their tributaries after the valleys had been eroded nearly or quite to their present depths. (See topographic maps of Coopers Lake and Ovando quadrangles.)

If there was in pre-Wisconsin time a great piedmont glacier occupying the Nevada Valley as far south as the vicinity of Helmville, there probably was a contemporaneous glacier occupying the upper valley of the Blackfoot River as far west as the head of the narrow gorge 3 to 4 miles west of the present village of Lincoln. Judging from the morainal drift and the extensive outwash gravel deposits, an enormous amount of glacier ice invaded this valley from the mountain gorge heading at the Continental Divide on Alice Creek and Landers Fork, and also from the gorges of Copper, Stonewall, and Beaver Creeks.

A review of Pardee's mapping of the moraines north, west, and south of Lincoln, indicates that there was glaciation of this part of the valley either during the Illinoian stage or when the Iowan drift was deposited. The relations here are somewhat similar to those observed on Dearborn River directly across the Continental Divide to the northeast. The valleys of the creeks tributary to the Blackfoot from the north near Lincoln are relatively short. They face toward the south and their contours, as shown on the map of Coopers Lake quadrangle, do not show the effects of vigorous glaciation. It is probable, therefore, that pre-Wisconsin ice from the valleys of Alice and Copper Creeks and Landers Fork extended down the valley of the Blackfoot River nearly to the head of the narrow gorge 4 miles west of Lincoln. A low moraine borders the north side of the broad gravelly flat that extends westward into sec. 21, T. 14 N., R. 9 W. On the south side of the valley there is a strongly defined moraine that extends westward from a point about 2 miles southeast of Lincoln. Some of the morainal knobs west of Poorman Creek are 100 ft or more high. Evidently the mouth of the valley of Poorman Creek was blocked by ice. Laminated clay (exposed in a road cut) was probably deposited in the temporary lake thus formed and this lake had an outlet westward through the gap now followed by the road between the moraine and the hill slope to the south. The topography east of Poorman Creek is rather peculiar, evidently being due to a combination of moraine, marginal channels, and marginal terraces, partly on bedrock, which occur up to 300 ft or more above the bottom lands. High above the moraine between Poorman Creek and Willow Creek is a remnant of a gravel-strewn terrace 500 ft or more above the bottom land. Some of the pebbles on this bench show faint striae.

Judging from the distribution of the outermost glacial drift, as mapped by Pardee, south of the confluence of the Clearwater River and the Blackfoot River, in the vicinity of Greenough south of Elk Creek, a pre-Wisconsin(?) advance of the Clearwater glacier extended to the north slope of the hills 5 to 8 miles east of the village of Potomac, in T. 13 N., R. 14 W. There is, however, no well-defined terminal moraine marking this limit. Near the bridge where the branch of the Chicago, Milwaukee, St. Paul & Pacific Railroad crosses the Blackfoot River below the mouth of Elk Creek, drift, very largely composed of boulders 1 to 10 ft in diameter, underlies 10 ft of fine laminated silt which was probably deposited in glacial Lake Missoula. The drift seems to indicate that the west front of the pre-Wisconsin glacier extended as far west (or nearly so) as this exposure and terminated at the glacial lake. When this ice front receded or later during the Wisconsin stage of glaciation, the lake water extended eastward over the drift and covered it with the silt. The smooth terrace known as Ninemile Prairie, which borders the river on the north for several miles, is very largely mantled with lacustrine silt, between 3,640 and 3,780 ft above sea level. This is the most easterly place where the silt has been observed by the writer. It is possible, though not certain, that glacial Lake Missoula stood high enough during the Wisconsin stage to have deposited this silt.

DRIFT IN THE FLATHEAD RIVER BASIN

That lobes of the great Flathead glacier extended nearly to, possibly through, the gaps both southeast and west of the hills of the National Bison Range is shown not only by deposits of till but also by well-striated ledges of bedrock that were formerly exposed but later defaced in road grading. One ledge is on the west side of the Flathead River about 5 miles north of Dixon, near the SE¼ sec. 23, T. 19 N., R. 22 W. The striae seen here trended S. 80° to 88° E., where the ice flow was deflected by the adjacent southeast-trending hill slope. About a mile northeast of the Flathead River bridge at Dixon some ledges of the Belt series projecting from beneath silt of glacial Lake Missoula have very smooth surfaces but show no glacial striae. The smoothing here probably was due to wear by the river water. No till was seen nearby on the west side of the stream. One erratic block, on the surface beside the road near the glaciated ledge in sec. 23, measured 12 by 15 by 18 ft. Examination of the surface of the ledge (about 3,400 ft above sea level) and the west slope of the 700-ft rock hill in the midst of the valley 2 miles north of Dixon, showed no evidence that it had been overridden by a glacier. The thin-splitting rock, however, is not of a character to retain glacial striae. The scattered boulders and quartzite pebbles on this hill may perhaps have been dropped from icebergs floating on glacial Lake Missoula, whose shore lines are clearly defined in places on the hills of the National Bison Range to the east as high as 3,800 ft above sea level, or higher. The plain surrounding these hills is mantled with whitish, lacustrine silt, in which pebbles and boulders are embedded, some of them striated and evidently dropped from floating ice.

In August 1931, road cuts about 3 miles southwest of Saint Ignatius (sec. 28, T. 18 N., R. 20 W.) showed 5 to 15 ft of very stony till containing many striated pebbles and exposed a glaciated ledge of bedrock with well-marked striae trending S. 50° E. The southeasterly trend at this place probably was due to deflection of the ice southeastward into a depression between the hills by the steep slope of Red Sleep Mountain in the National Bison Range. In 1936 the glaciated surface of the ledge was found to have been removed by blasting. The surface of the drift both south and north of the highway here has a mild swell-and-swale topography like that of the moraines farther north. In a cut in the gap about 2 miles farther southwest, and half a mile north of Ravalli, a striated rock surface measuring 5 by 8 ft was exposed. This rock, however, may be a boulder embedded in the till rather than a ledge in situ. Farther south and less than 2,800 ft above sea level, only laminated silt of glacial Lake Missoula is exposed in the road cuts. Till-like material containing some striated stones was exposed during grading of the west approach to the bridge west of Ravalli on State Route 3.

Neither C. H. Clapp nor J. T. Pardee found any striated ledges on the hills of the National Bison Range, such as would show that the ice had overridden them. The striated pebbles and boulders scattered on the slopes below an altitude of 3,400 ft were probably dropped from icebergs. The lake shore lines are well marked in places on the grassy slopes up to altitudes of 4,000 ft or more. Similar berg-transported boulders, a few of them 10 to 15 ft in diameter, are scattered over the hills north and east of Ravalli below altitudes of 4,000 ft.

It seems probable from the previous observations of Pardee and from observations made by the present writer that at least one of the successive great glaciers that occupied the Flathead basin extended south into Jocko River valley. When this ice invasion occurred Flathead and Jocko Rivers had already cut their valleys in the vicinity of Dixon nearly to their present depths. This is indicated by data cited above and by the fact that several of the cuts on State Route 3 east of Dixon expose what appears to be glacial till beneath the fine laminated silts of glacial Lake Missoula. A short distance east of the upper bridge near Dixon, Jocko River cuts into the low bluff below the road on the south and exposes about 50 ft of very stony, brown-stained (oxidized) till-like material. There is 20 to 30 ft of finely laminated silt of Lake Missoula exposed in the road cuts almost directly above this deposit. Till is also exposed in the bottom of a pit beside the road just south of the bridge and here there are many striated stones in the coarse unsorted bouldery material.

At some stage the glacier probably extended southward down Mission Valley west of the hills in the National Bison Range. Whether the ice spread eastward from the vicinity of Dixon all the way up Jocko Valley to the site of Ravalli is not known. South of the Dixon schoolhouse and above the glacial Lake Missoula clay terrace, bouldery drift is banked against the slope approximately as high as 500 ft above the valley bottom, 3,050 ft above sea level; in places it encloses small hollows or kettle holes. It is possible, however, that these hollows are due to slumping. Below the slope on which the drift lies, a somewhat dissected terrace slopes from an altitude of about 2,650 ft to the crest of the lower bluff. There the surface drops abruptly to the lower, late Pleistocene terrace, on which the railroad and the village of Dixon are built. Laminated silt of glacial Lake Missoula, in places overlying sand, is exposed in this lower bluff. The lake silt is evidently younger than the till, both on the slope above and in the river bank east of Dixon, and has not been overridden by glacier ice. For about two miles between Dixon and Revais Creek, to the west, the lake terrace has been cut away, perhaps by lateral erosion by a former meander of Flathead River. The river is now cutting at the north side of the flat. West of Revais Creek a belt of low, very bouldery undulating ground extending northward in a curve from the road to the river may be what is left of the terminal moraine of the west lobe of Flathead glacier. The section exposed where the railroad cuts into the bluff above the south bank of the river, 3 to 4 miles west of Dixon, however, shows dune sand and lacustrine silt but no till overlying the rock of the Belt series. The general appearance of the rough rock ledges projecting from the south slope of the valley both east and west of Revais Creek does not suggest glaciation, but the ledges may have been roughened by weathering since glaciation or may have projected above the surface of the thin western end of the ice lobe.

The writer climbed one of the grassy foothills south of Dixon to an altitude of 3,350 ft (barometric), or about 1,300 ft above the upper limit of the drift observed on the slope below to the north. To this height at least the grassy top and slope of this foothill spur are sprinkled with cobblestones and boulders of quartzite and argillite of the Belt series, but no evidence of glaciation was noted at such high levels. The relations of this and adjacent similar spur tops suggest that they are remnants of an old bench, a pre-Pleistocene valley slope or bottom, perhaps of Pliocene age. The presence of the pebbles and boulders is probably due to berg transportation on the waters of glacial Lake Missoula, inasmuch as shore lines are plainly visible on the grassy slopes to the lower edge of the woods—that is, to levels hundreds of feet above the altitude reached in climbing. Such pebbles, some of them striated, are also embedded in the finely laminated, lacustrine silt along the valley, where they were dropped from floating ice. No other evidence of glaciation had been noted by the writer in the valley of the Flathead River between Dixon and Perma.

Below McDonald (about 8 miles west of Dixon) a road cut exposed a considerable deposit of boulders 1 to 3 ft in diameter. Most of the boulders are subrounded and smoothed and polished as though waterworn. No definite indication that the deposit was glacial was noted, although there appeared to be faint striae on one boulder.

Eugene Stebinger describes in his field notes for June 8, 1914, an exposure (not seen by the present writer) near the mouth of Mission Creek, about 4 miles north of Dixon in the south bank of the creek 200 yd above the wagon bridge about as follows:

Deposits on Mission Creek west of Moiese, Mont.

3. Till, light-gray, stony; across creek it appears beneath laminated clays of glacial Lake Missoula. Contact with (2) an erosion surface, is very distinct and in one place there is 3 in. of carbonaceous material on the contact. (3) is clearly much fresher and less weathered than (2).
2. Till, reddish or rusty buff, stony; cobbles of Belt rocks and sandy clay matrix. Rusty tint is due to weathering.
1. Clay, gray, blocky; no bedding planes visible; is clearly not laminated clay of glacial Lake Missoula sediments. May be Tertiary or Cretaceous (?). Erosion contact with till (2) is very plain. Only a small patch visible.

From this exposure it seems probable that the rusty lower till (2) is the same as that observed by the present writer east of Dixon and that the upper and fresher gray till was deposited by the Flathead glacier when the Mission moraine was formed. Evidently the ice at this stage extended 2 miles or more farther southwest (into the gap at Moiese northwest of the National Bison Range) than the border of the Mission moraine, as shown on the map, plate 1.

About 8 miles north of the mouth of Mission Creek the upper smooth sloping terrace, bordering Flathead River on the east, rises to and merges with a small swell-and-swale moraine, probably the outer part of the Mission moraine. This is near the crest of the bluff down which the road extends to the low terrace south of the river bend. The following generalized section is exposed in the opposite bluff, which is about 100 ft high, north of this low terrace.

Deposits along Flathead River, 6 miles north of Moiese, Mont.

4. Gravel, coarse, bouldery.
3. Glacial till (middle? Pleistocene).
2. Gravel, stratified, sand, and silt.
1. Glacial till (early? Pleistocene).

The full section is not exposed where the road descends the south bluff between an intermediate terrace and the low terrace. The moraine top is about 50 ft above this intermediate terrace, and on this moraine top an irrigation ditch conducts water westward across the head of the outwash terrace from a flume built around the slope of the rock hill to the east. There is no glacial Lake Missoula silt on top of this moraine (about 2,600 ft above sea level).

About half a mile northeast of the mouth of Crow Creek a bare face of the north bluff exposes the following section:

Deposits along lower Crow Creek

	Feet
5. Glacial till (middle? Pleistocene)	10
4. Gravel, fine, stratified	2
3. Lake silt, stratified	5
2. Gravel, coarse	1–3
1. Clay, till, light-gray, pebbly, with a thin layer of gravel in lower part (early? Pleistocene)	30
Total thickness	50±

North of Dixon, in other places in Mission Valley, till is exposed on both sides of the river. Eleven miles north of Dixon is the site of the old Sloan ferry and the present bridge (sec. 18, T. 20 N., R. 21 W.). Where the road ascends the 250-ft bluff north of this bridge only till is exposed below a thin deposit of glacial Lake Missoula sediments at the top. At the east side of the big bend about 3 miles west of the bridge the lower half of the inaccessible bluff appears to be till and the upper half lake sediments. A dark band between the two appears to be gravel. At the west side of the bend, about a mile farther west, there is till under 175 ft or more of laminated lake silt. While its valley was blocked by the ice depositing this till the Little Bitterroot River may have cut the small rock gorge, 150 ft deep, across the low mountain spur southwest of Sloan bridge; otherwise this gorge must have been cut while the Little Bitterroot was meandering on the flat after glacial Lake Missoula was drained. No evidence was noted indicating that the glacier extended up Little Bitterroot Valley farther west than sec. 26, where till is exposed beneath the silt. This till may have been deposited either as part of the Mission moraine or at an earlier stage of glaciation.

Drift probably deposited by a pre-Wisconsin Flathead lobe of the Cordilleran ice is widely distributed throughout the southern part of the broad Mission Valley north of Dixon and Ravalli.

South and southwest of Saint Ignatius, drift shows mild morainal swale-and-swell topography. Two miles east of Saint Ignatius the bank of Mission Creek and the adjacent road cut afford two exposures of drift below the level of the big flat north of the creek (sec. 20, T. 18 N., R. 19 W.):

Deposits in road cut 2 miles east of Saint Ignatius

	Feet
3. Soil, gravelly	1
2. Silt, pinkish-gray, laminated, with some embedded berg-dropped pebbles	6–7
1. Till (pre-Wisconsin), coarse, pebbly, partly cemented and with a 1-foot brownish oxidized zone at top	3+

Deposits in creek bank 2 miles east of Saint Ignatius

	Feet
3. Overgrown grassy slope, probably underlain by lacustrine silt, with 1- to 10-ft boulders, berg-dropped, on its surface	10
2. Till (pre-Wisconsin), partly cemented, grayish, with included masses of distorted laminated clay as from overridden lacustrine sediments (possibly of a local lake); oxidized brownish at bottom, about	10
1. Gravel, coarse.	

Evidently deposit 1 of the road cut is the same pre-Wisconsin till as deposit 2 of this nearby creek bank. The silt may perhaps have been deposited in a small lake held in front of the ice as it spread southeastward up Mission Valley during a pre-Wisconsin stage. These exposures are about a mile west of the terminal moraine of Mission Creek glacier, which headed high up in the Mission Range to the east.

North of the gravelly flat that borders Dry and Mission Creeks and between the latter stream and Post Creek, numerous shallow road cuts on the smooth westward-sloping plain, east and north of Saint Ignatius, expose till. This till plain is mostly more than 3,000 ft above sea level and it is not covered by lacustrine silt.

THE MISSION MORAINE

Part of the plain east of Post Creek and southwest of the terminal moraine is characterized by slight swells and swales. North of Post Creek and 100 ft or more above it is an area of similar topography extending southwestward in a broad curve to the railroad near D'Aste, 3 miles east of Moiese. This surface stands but little above the plain to the north but there is a definite slope from its crest down to Post Creek on the south. A similar belt of swells and swales extends from east to west across the plain on the south side of Crow Creek, between 1 and 4 miles north of Charlo. Cut off from this area by Crow Creek, 3 miles south of Ronan, a similar belt of swells and swales extends north-northeast to the east of Ronan and Pablo, where it is cut across by Mud Creek. Here there are imperfectly developed moraines, probably recessional moraines of the pre-Wisconsin Flathead glacier. Between the moraines is Ninepipe Reservoir and considerable irrigable land. In some parts the swell-and-swale topography is so uneven as to preclude irrigation. The land is also very stony in places. Some of the basins hold small ponds or marshes. In the lower tracts bordering Post, Mission, and Crow Creeks, the till is overlapped by uneroded remnants of laminated lacustrine silt. It is significant, however, that this silt does not cover the upper slope and top of the combined morainal belt.

One of the best of these exposures is at the south end of Crow Creek dam (sec. 12, T. 20 N., R. 21 E.), where about 80 ft of compact stony till, including two intercalated layers of gravel, is exposed. The section above the level of the road crossing the dam exposes the upper 15 to 20 ft of till overlain by a thin bed of gravel and 2 ft of fine, stratified sand above which is about 10 ft of beautifully varved lacustrine silt containing many embedded pebbles evidently dropped from ice floating on glacial Lake Missoula. One boulder 6 by 10 ft in diameter lies on top of the till and is covered by the lacustrine deposits (fig. 15).

FIGURE 15.—Laminated silt of glacial Lake Missoula overlying (pre-Wisconsin?) glacial till exposed at the Crow Creek dam near the inner part of the Mission moraine southwest of Ronan.

In 1911 Eugene Stebinger examined much of the Flathead basin and from his unpublished map and notes in the files of the Geological Survey considerable information has been obtained. Stebinger's map shows a crescentic area, 4 to 7 miles wide north of Mission Creek as characterized by morainal topography. Probably it is to this moraine that Elrod (1903, pp. 197–203) applied the name "Mission moraine". The combined moraines extend from positions near the foot of the mountains on the east to the rock hills near Flathead River on the west. The depressions range from 10 to 50 ft or more in depth, some contain ponds. Judging from the material exposed in the cuts on the road and on the railroad east of D'Aste, there is 100 ft or more of till at that place. As stated above, at the mouth of Crow Creek and in the Flathead River bluffs above D'Aste, considerable thicknesses of till are exposed. In the basin east of the rock ridge, which extends about 7 miles northward from Moiese, the bedrock surface beneath the glacial drift is evidently quite uneven for, although Stebinger states that a well being drilled about a mile north of D'Aste in 1911 penetrated 178 ft, mostly of clay with some gravel, yet near Crow Creek, midway between Charlo and Ronan, ledges of the Belt series are exposed at the surface; also between 2 and 7 miles west of Ronan the small buttes of bedrock rise above the plain.

Examination of the east bluff of Flathead River, 6 to 7 miles above the mouth of Little Bitterroot River (sec. 18 or 19, T. 21 N., R. 21 W.) showed the following section:

Deposits 3 miles northwest of Round Butte

	Feet
4. Clay of glacial Lake Missoula, laminated	?
3. Till, light-buff, pebbly	?
2. Clay, laminated, lacustrine	5–10
1. Till, light-buff, pebbly	75–100
Total	250

There is no soil or weathered zone intercalated in this section, but the exposure is at the western edge of the Mission moraine and the lower till may perhaps be early glacial drift corresponding to that on Crow Creek and Mission Creek, at Dixon, and at Midway south of Ravalli. The upper till (3) here may be of Iowan or Illinoian age with lacustrine clay below and on top. The laminated silt, however, does not extend eastward onto the top of the Mission moraine. Lower till is also exposed at places farther north where the bluffs were examined. In secs. 15 and 22, T. 22 N., R. 21 W., there is a buried ridge of upturned rocks of the Belt series. The river has cut through the overlying glacial and lake deposits and has eroded a narrow sinuous gorge in the rock. The river makes sharp angular bends across the strike of the rock beds.

Farther up stream the rock dips below the bed of the river and the following deposits appear to be in the partly overgrown bluff:

Deposits along the Flathead River north of Round Butte (sec. 15, T. 22 N., R. 21 W.)

5. Clay, laminated, whitish, lacustrine.
4. Till, thick, light buff.
3. Grassed slope (on lower lake clay?)
2. Lower till, light buff.
1. Gravel, oxidized.

Total, about 350 feet.

The smooth high terrace on top of the upper lake clay rises gradually northeastward to the front of the Polson moraine, and near the Polson dam site it has an elevation of about 3,200 ft.

At the bend below (west of) the Polson dam site and outside the Polson moraine the following section is exposed in the north bluff, below the 3,200-ft flat (fig. 16):

FIGURE 16.—Glacial till in the gorge of Flathead River. Pre-Wisconsin(?) till, about 175 feet thick, is exposed below the Polson dam site and outside of the Polson moraine of Wisconsin age. It is eroded in buttresses, overlain by whitish silt of glacial Lake Missoula, and underlain by lower till. View east, 5 miles below Polson with the Mission Range in the background.

Deposits west of Polson dam site (sec. 11, T. 22 N., R. 21 W.)

	Feet
5. Clay, laminated, whitish, lacustrine	10±
4. Till, thick; eroded in buttresses	100+
3. Pebble beds, stratified.	
2. Slump.	
1. Till laminated silt, and gravel (to the river in nearby cut).	
Total	500±

The bluff half a mile above (southeast of) the Polson dam site shows the following section (fig. 21):

Deposits southeast of Polson dam site (sec. 13, T. 22 N., R. 21 W.)

[Measurements are approximate.]

	Feet
5. Overgrown upper slope	50
4. Till, buff glacial	300
3. Gravel, coarse	20
2. Till, buff	50
1. Sand, stratified in lower part	5
Total	425

Probably the upper part of this deposit includes some of the Polson morainal drift, but no demarcation is visible in the section.

When the ice retreated to the inner part of the Mission moraine the glacial lake in the Little Bitterroot Valley became confluent with glacial Lake Missoula. Before the removal of the ice dam, water from the former lake escaped through the narrow pass in the crest of the ridge south of Camas and Hot Springs, 3,700 ft above sea level (barometric). It is probable that when the ice front lay along the inner belt of the Mission moraine it crossed the present course of the river a few miles northwest of Round Butte and, farther north, lay along the east face of the mountain ridge to the west. While the ice blocked the valley of Irving Creek or White Clay Creek and held a lake therein, an outlet stream doubtless flowed southward along the edge of the ice to glacial Lake Missoula. It may be that the location of Flathead River between the mouths of the Irving (or White Clay) and Crow Creeks, at the west side of the basin, was determined by the discharge along the west margin of the early Flathead glacier while the ice front lay at the Mission moraine.

One feature, an outer moraine, about 4 miles southwest of the village of Big Arm, is suggestive of that part of the early Flathead glacier. A glacial lobe of the last Flathead glacier evidently extended southwestward from the lake basin to the limit shown by the well-defined morainal loop (northwest part T. 23 N., R. 21 W.). About half a mile west of this, in secs. 1 and 12, T. 23 N., R. 22 W., is a lower and smoother outer moraine, partly eroded. This outer moraine may mark the limit of the earlier ice lobe. Beyond it is a narrow rock gorge through which glacial waters escaped to the valleys of Irving Creek or White Clay Creek.

It is probable also that a lobe of the earlier ice lay in the head of Big Draw west of Elmo and that the remnant of a high gravel terrace, which borders the west front of the moraine about 3,500 ft above sea level, represents this early stage. This terrace is mostly cut away and a lower broad gravelly flat forms the floor of Big Draw westward. The flat is probably the outwash terrace of the later or Wisconsin stage of glaciation. North of the foot of Flathead Lake, inside the later glacial mountains, glacial and lake features of early stages have not been differentiated from those of the Wisconsin stage.

For descriptions of glacial drift of possible pre-Wisconsin age farther north on Flathead, Stillwater, and Tobacco Rivers and near Libby, see pages 137–144.

Crow and Mission Creeks and their tributaries have eroded considerably in their lower courses within 5 or 10 miles of the river. A large part of the plain south of Flathead Lake, however, has been but moderately dissected by erosion and the preservation of the swell-and-swale topography suggests that the advance of the Cordilleran ice, to which the till and outer moraines are due, did not occur earlier than middle Pleistocene. It is probably the correlative of Blackwelder's Bull Lake stage of glaciation in the mountains of Wyoming and of either the Illinoian or the Iowan glaciation of the Missouri and Mississippi basins. If the drift south of the Mission moraine was not deposited before middle Pleistocene time, it seems probable that the Mission moraine is to be regarded as marking a halt in the recession of the ice front from a southern limit in or near Jocko Valley. Perhaps it was at this stage that the ice in the Flathead Valley and the western part of Glacier National Park was of such great thickness that it overrode Apgar Mountains, including Huckleberry Mountain, and made the striae which were found trending southwestward obliquely across the narrow mountain crest. This crest is 3,000 ft above the present channel of the Flathead River. It is also possible that the mountains west of the Flathead Valley in the western part of Kintla Lake quadrangle were almost, or quite, buried beneath ice at this time (Daly, 1912, p. 576, pl. 49).

In the gorges that gash the west flank of the Mission Range there were undoubtedly local mountain glaciers at the times when the great Flathead glacier was depositing the drift of the Mission moraine and also the drift to the south of this moraine. It seems probable, however, that most, if not all, of the Mission Range glaciers south of the Flathead Lake basin were tributary to and merged with the contiguous eastern part of the Flathead glacier, just as those farther north in the Swan Range merged at this time. The several mountain glaciers at the south may perhaps have deposited terminal moraines on the piedmont at times and places when the Flathead glacier was not crowded close against the foot of the Mission Range. If so, these moraines were probably overridden by the readvancing mountain ice when the later Flathead glacier extended only as far as the Polson moraine during the Wisconsin stage.

LITTLE BITTERROOT VALLEY

It would seem probable that, if a lobe of the Cordilleran ice invaded the broad part of the Little Bitterroot Valley near and south of Niarada from the north, the hills would show some definite evidence of that invasion. To gain light on this question, the hilltop, 4 to 5 miles northwest of Niarada, was examined. The slopes and the top, about 3,850 ft above sea level, are strewn with pebbles and boulders, but the ledges of quartzite exposed are angular, showing no evidence of glaciation, and none of the pebbles or boulders, so far as noted, show striae. One was an erratic boulder of granite-gneiss of unknown origin. Shore lines of glacial Lake Missoula are well marked across a small embayment in the north slope. There are numerous striated erratic pebbles scattered on the lower hill slope near Niarada, where rhyolite ledges are exposed. These erratics, however, were probably dropped from icebergs floating out of the Big Draw to the east.

Striated pebbles and boulders are found along the road on the lower slopes on both sides of the ridge between the Irving Creek basin and the Little Bitterroot Valley below the upper levels at which glacial Lake Missoula stood and on the west side of the latter valley. On the lower hill slope northeast of Camas Hot Springs a pit has been opened from which considerable road material has been removed. This gravel appears to be a mixture of slope wash and berg-transported material, reworked and deposited as a wave-washed beach or bar of glacial Lake Missoula. The material consists largely of local chipstone with many intermingled erratics, one of them a greenstone of unknown origin. Many of the erratics are well striated. It does not appear to be glacial till, however, although it is not clean gravel and is poorly bedded in places. O. L. Tweto climbed to the top of the hill, about 3,600 ft above sea level, and found no erratics and no glacial striae on the angular ledges of diorite there exposed. There is a good deal of erratic material and the deposit might possibly be regarded as a remnant and a local glacial deposit of pre-Wisconsin age, perhaps somewhat reworked, yet the writer does not feel sure that it is. Erratics, many of them striated, are also seen along the roads on the grassy slopes to the south between Hot Springs and Rainbow Lake and Markle Pass. One near the pass is a boulder of granite of unknown origin. Numerous striated erratic pebbles and boulders were also found along the roads extending westward from that part of the Little Bitterroot Valley below the mouth of Warm Springs Creek, and up the valleys of Wills Creek and a creek to the south.

There is no doubt that pre-Wisconsin ice of the great Flathead glacier obstructed the mouths of both the White Clay Creek and the Little Bitterroot River. Glacial till is exposed below the silt of glacial Lake Missoula in the bluffs of Flathead River near the big bend 3 or 4 miles west of Sloan bridge, and in its lower part the Little Bitterroot has been shifted over to the south side of its valley where it has cut a small postglacial gorge into bedrock. The obstruction afforded by this rock is one reason why the river has not accomplished more in the way of reexcavating its valley farther west and north. It is not certain, however, that any part of the Little Bitterroot Valley between Niarada and the Flathead River bend west of Sloan bridge has been invaded by a glacier.

CAMAS PRAIRIE BASIN

Careful consideration has been given the question whether or not a pre-Wisconsin lobe of the Cordilleran ice extended southward into the Camas Prairie Basin, even if it occupied the broad Little Bitterroot Valley north of Warm Springs Creek and Markle Pass. In order to do this, it would not have had to extend any farther south than did the great Flathead glacier, between 10 and 30 miles to the east. The latter glacier, however, besides traversing the Rocky Mountain Trench all of the way south from the Canadian boundary, was also copiously augmented by the ice of local glaciers heading in the mountains in, west, and south of Glacier National Park. In contrast, any glacial lobe moving southward through the Little Bitterroot Valley to enter the Camas Prairie Basin not only would have had to overrun the transverse ridge south of the Warm Springs Creek and the hills north of Niarada nearly as far as the Canadian boundary, a distance of more than 70 miles, but in all this distance this Cordilleran ice would not have been augmented by any local tributary mountain glaciers.

In places on the grassy parts of the slopes surrounding the Camas Prairie Basin, shore lines of glacial Lake Missoula are well preserved, and in many places where the lower slopes below the shore lines and above the lake-silt flat have been examined, scattered boulders are found; many of the boulders are striated. One of the largest is a 15-ft block on the slope about 4 miles southwest of the town of Camas Prairie. Among the highest of those observed are two large well-striated blocks of greenish argillite, about 3,900 to 4,000 ft above sea level, on the mountain slopes below the fire lookout station southeast of the head of Wills Creek (T. 21 N., R. 23 W.).

Besides the striated erratics there are other interesting features in the Camas Prairie Basin that appear to be due to the presence of the waters of glacial Lake Missoula. In the small rock gorge at Markle Pass (about 3,400 ft above sea level) are small, undrained, kettlelike hollows among the angular rock ledges; one hollow contains a pond. Heading at the south end of the pass there is a pitted, gravelly bench on the slope that appears to have been built out into the lake by waters traversing the pass when the lake stood at about the same height.

About 3 miles southeast of Markle Pass there is a similar pass, about 3,500 ft above sea level, through which a road extends eastward down to the Little Bitterroot Valley. Although striated pebbles are found along the road, the rock ledges at and near the pass are angular and, so far as examined, show no evidence of glaciation. Here, at the west end of the pass, another gravelly bench is built out on the slope and pitted with well-defined hollows, like kettle holes. A traverse of a small gulch north of this pass showed small lake bars built across the reentrant in the slope at several levels, and small basins behind the bars, the highest about 3,800 ft above sea level.

Two to three miles farther north, Wills Creek heads in a third pass (about 3,300 ft above sea level) that has angular rock ledges, undrained hollows and ponds. Although some striated pebbles and boulders were seen along the road down Wills Creek, none of the rock ledges in the pass, or on the ridge top to the west showed any evidence of glaciation. A broad bench south of the pass is pitted with kettlelike hollows; some are partly drained. This bench may be a delta structure built out into glacial Lake Missoula. Such delta-like structures might have been formed if at any time the Flathead glacier so effectually blocked the mouth of the Little Bitterroot Valley west of the Sloan bridge as to hold the lake in that valley at a higher level than the lake in the Camas Prairie Basin; under such conditions there would have been a strong outflow from the former valley through the three passes to the Camas Prairie Basin. The hollows in the several deltalike benches may have been due to the melting of stranded and partly buried icebergs, or perhaps to the settling of the component material which appears to consist very largely of rather fine chipstone or slope wash.

Between the head of Wills Creek and the Markle Pass road a shallow swale drains south, in or near sec. 31, T. 21 N., R. 23 W. Lying across this swale is a series of five or six small crescentic ridges, or bars, one above the other. They are 5 to 15 ft in height, with small hollows behind them on the upstream side. Each is cut through by a narrow drainage way and the eroded materials are spread out in little fans below each ridge. These ridges are unusual features, and might possibly be regarded as recessional moraines of a small glacial lobe. However, to the writer they seem to be bars formed by waves during the lowering of the lake in the Camas Prairie Basin.

There are other somewhat puzzling features—namely, a multitude of small ridges 5 to 50 ft high that are spread out on the low piedmont slope between the central flat of lacustrine silt and the hills on the east and north. In places, they extend down the gentle slope, and the branching sags between them are followed by the runoff of storm water, so that the hollows might perhaps be regarded as the product of slight erosion of coalescent alluvial fans heading at gulches in the hill slopes. At other places the ridges lie transverse to the general slope, so that they look more like constructional features. Several of the ridges, about 5 ft high, are cut through by the road grade between Markle Pass and the Camas Prairie School. The material constituting the ridges, as exposed in gravel pits, is partly stratified gravel and largely angular to subangular, poorly sorted fragments of local and erratic rocks. Some boulders are still strewn over the surface.

It seems to the writer, judging from the data now in hand, that some of these numerous small ridges are beach ridges or bars formed by the lowering waters of glacial Lake Missoula, and that some ridges, and the intervening depressions, may be due to moderate erosion of coalescent alluvial fans which headed at the gulches cutting the hills to the east and were extended westward as the lake waters lowered. Although there may be more erratic pebbles and boulders than one would expect, as a result of droppings from ice floating on this part of glacial Lake Missoula, yet there seems to be no clear evidence that a glacial lobe of either Wisconsin or pre-Wisconsin age invaded the Camas Prairie Basin. Mr. Pardee has made a more detailed and careful study of the features in and near the Camas Prairie Basin. He presented his interpretation, which is somewhat different from that suggested here, before the Geological Society of Washington (in his address as retiring president) on December 11, 1940. It was published, with illustrations, in 1942 (Pardee, 1942, pp. 1587–1599, and pl. 3). The following is his very brief summary of this paper:

> Failure of the ice dam in the Clark Fork Valley near the Idaho-Montana State line permitted the rapid draining of glacial Lake Missoula estimated to have held 500 cubic miles of water. Rapid falling of the water surface caused huge currents in the narrows between submerged basins. Current-produced features include the unique giant ripple marks of Camas Prairie, a series of gravel ridges having the form, structure and arrangement of ordinary ripple marks but of incomparable size. The flow through Eddy Narrows is estimated to have reached a maximum of nearly 9½ cubic miles an hour. After the outflow the basin again held a lake which drained away slowly.

RAINBOW LAKE AND BOYER CREEK BENCH

Among the most interesting and puzzling features of this region are the Rainbow Lake gorge and the Boyer Creek bench (fig. 13) which were also described by Pardee (1942, pp. 1584–1587 and pl. 4). The rock-walled gorge in which the lake is situated transects the crest of the range of hills about 6 miles northeast of the village of Plains and the road from Plains to Camas and Hot Springs extends through it. The gorge looks as though it were at some time traversed by a river but its open eastern end now hangs hundreds of feet above the floor of the Camas Prairie Basin on the east and above the bottom lands bordering the Little Bitterroot and its tributaries to the northeast. Only a small amount of drainage from the immediately adjacent higher land now reaches the lake, whose altitude is about 3,600 ft above sea level and 1,200 ft above the Clark Fork near Plains.

On the flat floor of the gorge near and below the foot of the lake there is considerable broken stone, angular fragments, and, near the road, numerous blocks that may have fallen from the steep south wall of the gorge.

Between Boyer Creek and the valley of Lynch Creek on the west is a north-trending ridge of rock that terminates north of Plains. High above the road along the northern two-thirds of the east flank of this ridge and covering all but its highest parts is a flat-topped deposit of coarse gravel forming a bench that appears to be an erosion remnant of a great alluvial deposit nearly 4 miles long and heading in Rainbow Lake gorge. For convenience of reference, this smooth, wooded bench is designated the Boyer bench (fig. 17). From an altitude of about 3,650 ft, the little-dissected, flat top slopes gradually about 300 ft to the eroded south end of the gravel cap about 2 miles north of and nearly 900 ft above the river at Plains.

If the Little Bitterroot Valley and the Camas Prairie Basin were not occupied by Pleistocene glacier ice, so as to divert marginal glacier waters southwestward

FIGURE 17.—Boyer Creek bench (Pliocene? or Pleistocene) and terrace of glacial Lake Missoula. Faint shore lines of the lake are visible on the grassy slope between the top of the gravel-covered bench and the terrace on lacustrine silt below. View east in valley of Clark Fork.

through the Rainbow Lake gorge to glacial Lake Missoula in the region of Plains, it seems possible that these basins were still, in Pliocene time, filled with Tertiary deposits to heights corresponding to the altitude of the Rainbow Lake gap—that is, to 3,650 ft or more above sea level. So also the bottoms of the Lynch Creek basin and the valley of Clark Fork at and above Plains may not yet have been cut below levels corresponding to the Boyer bench. If these valleys were filled with Tertiary deposits to correlative heights, 3,000 ft or more above sea level, it would seem that there would be some remnants of valley fill, but none has yet been found in this vicinity. If the valleys were at such heights in Pliocene time, a stream could have flowed southwestward through the Rainbow Lake gorge to join the Clark Fork and could have then formed the Boyer bench as an alluvial fan. Incidentally, it may be noted that poorly consolidated Tertiary sediments are still preserved in the valley of Clark Fork between 30 and 60 miles southeast of Plains, to altitudes of 3,500 to 4,000 ft or more, and also in the Bitterroot Valley to the south.

About 4 miles northeast of Plains a trail slopes upward along the east face of the bluff below the Boyer bench. Most of the material exposed along this trail consists of angular to subangular fragments of quartzite and argillite, resembling talus, with intermingled rounded cobblestones; the upper part is coarse gravel with well-rounded pebbles. No ledges are exposed along this trail, but there are large blocks of diorite and other rock 1 to 8 ft long on the upper slope above the road, as much as 3,500 ft or so above sea level. The crest of the rock ridge, on which the Boyer bench is preserved, rises at the west side somewhat above the bench top as a narrow ridge. A somewhat pitted, narrow remnant of a bench also borders the west side of the ridge crest. This remnant appears to head to the north at a gap in the rock ridge. The main bench heads at the west end of the Rainbow Lake gorge and appears to have been formed as an alluvial fan, partly on top of talus, by a vigorous stream flowing westward through this gorge. The bench may originally have extended eastward to the adjacent mountain ridge. If so, more than half of the original deposit has been removed by erosion of Boyer Creek. The bench remnant is now 900 to 1,200 ft or more above the Clark Fork at Plains. It seems quite possible that this bench is of Pliocene or early Pleistocene age and it has been so mapped on plate 1. It is also possible, however, if a lobe of the Cordilleran ice really occupied the Camas Prairie Basin at a pre-Wisconsin stage of glaciation, that the gravel of Boyer bench may correspond to some of the Lake Missoula gulch fills described on pages 158–160. It might thus have been formed by a marginal glacial stream flowing through the Rainbow Lake gap and sweeping gravel into the somewhat lowered waters of glacial Lake Missoula. In his address before the Geological Society of Washington, and in his published paper, Mr. Pardee attributed the deposition of the gravel of Boyer bench to a strong flow of water through the Rainbow Lake gap, due to the failure of the dam of glacier ice near the Montana-Idaho State line and the rapid lowering of glacial Lake Missoula at some stage in its history.

No evidence of glaciation has been noted along the road from Plains north to the Thompson River. Examination of the high gravelly fan terrace transected by the lower gorge of Bear Creek (northwestern part of T. 23 N., R. 26 W.) shows that it heads at the mouth of the mountain gorge about 3,600 ft above sea level and slopes thence west about a mile to the crest of the lower bluff, 3,400 ft above sea level or 500 ft above the river at the bridge (B. M. 2,903 ft above sea level). There are other bench remnants of similar height farther north. One examined is near Big Rock Creek, 3 miles south of the Big Bend ranger station. On it are angular fragments of argillite and limestone and some rounded pebbles, 3,550 ft above sea level. These terrace remnants have about the same altitude as the Boyer bench. It is possible that some of these high-level benches are alluvial-fan terraces of Pliocene or early Pleistocene age, and since that time the Thompson River gorge has been deepened, or reexcavated, as much as 500 to 600 ft.

WISCONSIN STAGE OF GLACIATION WEST OF THE CONTINENTAL DIVIDE

The local differences in altitude between the Wisconsin terminal moraines and both the higher drift-covered spurs and the gravel-covered second terrace remnants east and west of the Continental Divide show that there were fairly long periods of valley deepening between early, middle, and late Pleistocene time. The writer believes this valley deepening resulted partly from an increase in gradient of the streams due to a definite uplift or series of small uplifts accompanied by differential movements along many of the faults bordering the steeper mountain fronts. The fact that many of the Wisconsin terminal moraines are in the valleys, 100 to several hundred feet below the smooth, gravelly tops of the terraced benchlands (second terraces) indicates that the deepening of the valleys continued into late Pleistocene time until interrupted by the deposition of the coarse gravelly outwash from the mountain glaciers. Outside of, but near, some of the well-defined terminal moraines of the Wisconsin glaciers there are worn-down moraines, perhaps of either Iowan or Illinoian age. The relations of these deposits to the Wisconsin moraines are described below.

GLACIERS OF EAST FORK AND BITTERROOT RIVER

The valley of the East Fork of Bitterroot River heads on the west flanks of the Anaconda Range and the Sapphire Range near their junction at Pintlar Peak. A glacier heading near Pintlar Peak extended westward (in T. 2 N., Rs. 16 and 17 W.), 9 or 10 miles down to an altitude of 5,400 ft at a point about 2 miles above the East Fork ranger station near the junction with Moose Creek. A sharp, narrow, bouldery ridge about 25 ft high on the valley bottom between the steep, wooded slopes appears to be the terminal moraine of the glacier during the Wisconsin stage. Above this is a swamp flat due either to obstruction by this deposit, to beaver dams, or to both. About a mile farther downstream is a smooth bouldery ridge that may be the worn-down terminal moraine of an older glacier. There may have been several other glaciers at the heads of Moose and other creeks.

Small glaciers may have formed at the heads of some of the southern tributaries of the East Fork. No evidence of glaciation was seen along U. S. Highway 93, which extends southward up Camp Creek for about 6 miles on the valley bottom. South of Gallogly Hot Springs the well-graded road climbs along the steep, wooded east side of the valley to the narrow divide at Gibbons Pass (6,800 to 6,900 ft above sea level), in T. 1 S., R. 19 W. On Saddle Mountain to the west are several small cirques near Hughes Point a few miles to the southwest on the Idaho side of the Divide.

GLACIERS OF THE BITTERROOT RANGE

As shown on plate 1, the Bitterroot Range was thoroughly glaciated during Wisconsin time as far south as T. 1 N., R. 22 W.; farther south there is evidence of successive stages of valley deepening but no evidence of glaciation. There may have been a few small glaciers at the heads of the north branches of Nez Perce Fork, but the topography as seen from Nez Perce Pass and vicinity (T. 1 S., R. 23 W.) and the narrow wooded gorge of Nez Perce Fork itself, cut mostly in granite, are typical of unglaciated country. Similarly, from the pass about 7,600 ft above sea level, at the head of Woods Creek (T. 4 S., R. 23 W.) the country to the southeast and southwest appears unglaciated. The road from this pass descends deep narrow gorges between steep, craggy walls of granite, pre-Cambrian sedimentary rocks and Tertiary rhyolite, along Woods Creek and the Bitterroot River. At the mouth of Woods Creek a well-defined bench borders an inner gorge about 150 ft deep, and on the lower east slope near Overwhich Creek a sloping bench top is strewn with well-rounded quartzite cobblestones above ledges of rhyolite. Also, at the mouth of Blue Joint Creek, opposite the Slate Creek ranger station, there is a well-preserved, rock-cut terrace about 100 ft above the stream. These benches suggest that the canyon cutting was interrupted by one or more intervals of valley broadening. Picturesque, craggy cliffs of granite tower south of Nez Perce Fork, gray to buff colored and in places bright yellow, probably from lichens.

BOULDER CREEK

The canyon of Boulder Creek was evidently occupied in Pleistocene time by a glacier which extended 5 or 6 miles nearly due east from the divide north of Bare Peak, past the south foot of Trapper Peak, and thence followed the gorge south by east for 4 or 5 miles farther, to the channel of the river a mile east of the West Fork ranger station. The lower 2 to 3 miles of the glaciated trough, where traversed by the writer, is flanked by two narrow-crested, sloping spurs, 100 to 600 ft in height. These spurs, which join the higher mountain slopes about 5,200 to 5,300 ft above sea level, apparently have cores of granite covered with very bouldery drift of lateral moraine. The narrow crests are strewn with boulders, mostly of granite porphyry and gneiss, many of which are 5 to 15 ft or more in diameter; one measured 20 by 35 by 35 ft. They are little weathered and are not simply boulders of disintegration. Extending across the bottom of the glaciated trough, 1 to 2 miles above the lower end, are granite ledges with smoothly rounded surfaces like roches moutonnées; also many boulders. Faint striae were seen on one 15-ft boulder of argillite. For some distance below the ledges there is a smooth gravelly flat with a few or no big boulders. Beyond this to the southeast is a great bouldery terminal moraine between the lower ends of the big, sloping, lateral ridges that extend nearly to the highway on the river bank. Cuts both north and south of the Boulder Creek moraine expose bedrock. It appears that the sloping spurs beneath the drift are interstream remnants of a broad, deeply dissected and wooded piedmont bench or foothill belt, one to several miles wide, which was originally continuous northward for 15 miles or more on the west side of the river to the vicinity of Darby. This old erosion surface may have been at or near the broad valley bottom in late Tertiary (Pliocene) or early Pleistocene time.

What may be a remnant of a pre-Wisconsin south lateral moraine was seen on the ridge just north of the North Fork station. For some distance just outside the south lateral moraine described above, nearly parallel to it and separated from it by a narrow sag or drainage trough, there is a smoother and perhaps more worn-down ridge crest strewn with small boulders. On the slope north of the ranger station below this outer moraine there are some weathered ledges of limestone overlain by rounded quartzite gravel.

TRAPPER CREEK

The next great glaciated trough to the north is that of Trapper Creek. The lower end of this trough, midway between Darby and Boulder Creek, is flanked on both east and west sides by narrow-crested spurs. These spurs also are evidently interstream remnants of the old dissected bench or foothill belt. Unlike the Boulder Creek trough, however, there are no morainal deposits or big boulders for about a mile below the junction of Little Trapper Creek with Trapper Creek; instead, there are craggy rock ledges exposed below the benched slope on the west side. Evidently a glacier nearly 10 miles long headed in the high-level cirques at and west of Trapper Peak. This glacier, however, did not quite reach the junction of Little Trapper Creek with Trapper Creek, as only small boulders and cobblestone gravel were seen below that junction, about 4,200 ft above sea level. Above it boulders become more numerous and larger, and a morainal deposit has been traced from the valley floor obliquely up the steep slope to the narrow crest of the spur on the east side. At and north of the forest boundary 1- to 10-ft boulders are abundant on this spur top. Farther northwest, above an altitude of 4,700 ft, the narrow crest of the northeast spur rises above the upper limit of numerous big boulders which form the lateral moraine. To an altitude of about 5,200 or 5,300 ft, as far as this crest was traversed by the writer and O. L. Tweto, there are a few scattered boulders much more weathered than those that are so abundant along the lateral moraine 100 to 200 ft below. These upper granite boulders may be either residual or of older, pre-Wisconsin glacial drift. From this ridge top there is a fine view up the glaciated trough to Trapper Peak and adjacent crests. On the steep side slope to the creek, 5 or 6 miles above the terminal moraine, the thickness of the glacier at the Wisconsin stage, as indicated by the position of the very bouldery lateral moraine, must have been about 550 ft. One recessional moraine that was crossed in descending the valley contains abundant large granite boulders.

CHAFFIN CREEK

A large glacier appears to have extended 6 or 7 miles down the gorge of Chaffin Creek from the mountains west of Sugarloaf Peak to within a mile of the forest boundary. There is no bulky terminal moraine loop, but above the smooth gravelly flat (about 4,500 ft above sea level) formed by glacial outwash, there are abundant big granite boulders forming a lateral moraine that extends westward and gradually upward along the steep side of the big rock spur on the north. There are also scattered granite boulders on the slope and crest above the lateral moraine. Perhaps these upper boulders were deposited by a pre-Wisconsin glacier before the gorge was as deep as now. The glacier probably did not extend as far east as the high quartzite hill near the forest boundary. Judging from the relations of the terminal moraines on Chaffin, Trapper, and Boulder Creeks, it is quite evident that the valley of the West Fork was almost as deep in late Pleistocene time as now. There has been little subsequent stream erosion.

From the junction of the east and west forks of the Bitterroot Valley northward to Darby there are remnants of an upper terrace or intermediate gravelly bench. The remnants are underlain by disintegrating granite or gneiss that is exposed in places in the lower marginal bluffs. Apparently the broad uneven bench or foothill belt had been worn down to a smooth gravelly valley bottom by middle Pleistocene time as far south as the forks near Conner. North of Tin Cup Creek the only remnants of the higher foothills are the drift-covered spurs that flank Tin Cup, Rock, and Lost Horse Creeks for 1 to 3 miles east of the portals of the glaciated mountain gorges. They were considered on pages 49, 50.

TIN CUP CREEK

Three to four miles west of Darby, Tin Cup Creek issues from the mouth of its glaciated canyon and flows down a broadly curving trough which is flanked on the south by the foothills and on the north by a long, curved, wooded ridge or spur (pls. 4 *D*, 5). This spur has a smooth, narrow top which joins the steep front of the mountain north of the portal of the canyon, 5,100 to 5,200 ft above sea level—800 ft above the stream. From this altitude the narrow spur slopes east-southeast in about 3 miles to an altitude of about 4,400 ft near its lower end 1¾ miles southwest of Darby. The south side of this curved ridge is very abrupt, being the north wall of the glaciated trough. The north side is somewhat dissected and is cut off from the foothills to the north by gulches drained by Bunkhouse Creek. The northeast side is steep and regular, sloping from a height of 700 to 200 ft above the upper or back part of the great dissected second piedmont terrace.

An incomplete traverse of the long, curved spur and of the glaciated trough on the south was made. Many large and small boulders of granite and gneiss lie on the crest and south side of this spur and an excavation at the lower southeast extremity exposes stratified arkosic sand and rounded granite boulders.

When Tin Cup and the neighboring creeks deepened their canyons following the first glacial stage, they cut deeply into the rocks underlying the piedmont and, where it was not protected by bouldery drift, the old terrace was mostly destroyed. Deep gorges were cut by the main creeks and the second terrace was developed along Bitterroot Valley. Later, in early or middle Pleistocene time, there came two or more advances of the glaciers, which scoured out troughs east of the canyon mouths. One advance reached the outer moraines, of which only remnants remain. After another and shorter interval of deglaciation, the glaciers of the Wisconsin stage advanced and melted away in their turn, leaving the great bouldery lateral moraines and terminal loops. The earlier advance of Tin Cup glacier (Illinoian or Iowan) seems to have reached a short distance beyond the end of the long curved ridge on the northeast and to have laid its terminal moraine east of the road about 2 miles southwest of Darby, in the NW¼ sec. 27, T. 3 N., R. 21 W., about 4,000 ft above sea level. Tin Cup glacier at this stage was about 15 miles long. A somewhat later moraine extends diagonally down the steep slope of the big spur in the N½ sec. 21, to an altitude of about 4,100 ft. What may be the terminal moraine of the Wisconsin stage lies across the floor of the trough (about 4,200 ft above sea level), just below the sharp bend of Tin Cup Creek, in sec. 17. Very bouldery lateral deposits extend diagonally upward along the steep south face of a great ridge on the north, partly as minor ridges and partly scattered. The two outer moraines are partly eroded and the lower gravelly flat or outwash terrace extends through the eroded gaps to the river bank, 1 to 2 miles south of Darby, 100 ft or more below the bordering remnants of the transected second terrace.

ROCK CREEK

The glaciated trough containing Lake Como (T. 4 N., R. 21 W.) lies between two spur remnants of a high piedmont terrace. (See pls. 4 *D* and 5). Here the shorter spur is on the north or inner side of the curve of the valley; the south spur is 2 to 3 miles long. It is bisected by the head of Waddell Creek, and an unnamed drainage line partly cuts off a third short crest. These smooth, wooded, spur crests are about 4,700 ft above sea level at their outer ends and join the steep mountain front at altitudes of 5,100 to 5,200 ft—1,000 to 1,200 ft above the mud flat on which Rock Creek is meandering. On the outer ends of the longer spur and of the shorter branch spur to the south, there are badly weathered boulders of gneiss 5 to 15 ft in diameter; one measured 15 by 18 by 30 ft. The size of these boulders and their positions make it probable that they were transported by an early Pleistocene glacier. The exposures of gray and rusty red arkosic sands in the slopes suggest that the spurs may be very largely erosion remnants composed of Tertiary sediments.

The outermost and uppermost of the south lateral moraines of the Wisconsin stage of glaciation is at an altitude of 5,175 to about 5,200 ft, where it lies along the steep slope at the south side of the canyon mouth. From this height, nearly 1,000 ft above the creek on the flat, the outer south lateral moraine and the next lower inner moraine gradually slope northeastward to the terminal moraine of the Wisconsin stage, through which Rock Creek has cut below Lake Como. A boulder ridge about 1½ miles below Lake Como is an erosion remnant of an outer and older moraine probably of Illinoian or Iowan (?) age. It lies in the valley, 3,900 to 4,000 ft above sea level, between the outer ends of the south and north spurs. Rock Creek glacier at its maximum was about 15 miles long. The outer moraine and the glacial outwash terrace are 100 ft or more below the bordering remnants of the gravelly second terrace, which clearly is of pre-Wisconsin age.

LOST HORSE CREEK

High above the upper western parts of the great sloping second terrace, two curved ridges or spurs jut out from the steep mountain front at either side of the glaciated trough along Lost Horse Creek (pls. 4 *D* and 5). The spur on the southeast side of the trough is about 3 miles long (fig. 11), and its narrow, wooded crest joins the steep mountain front about 5,100 ft above sea level. The crest is nearly 900 ft above the stream on the north and 600 ft above Lick Creek on the south. At intervals along this crest are big boulders of disintegrating gneiss and granite, one of them measuring 10 by 15 by 20 ft. This spur is an erosion remnant of a high piedmont terrace, probably of Pliocene age, and capped with early Pleistocene glacial drift. The top of the ridge is divided by longitudinal sags into two or three narrow crests that merge into one crest extending westward to the steep mountain front. Along the lower part of the north face of the ridge are several bouldery lateral moraines, one below another. The lower ones mark recessional stages of the last glacier. About 2½ miles below the canyon mouth the terminal loop that joins the ends of the main lateral moraines of the Wisconsin stage is cut through by Lost Horse Creek, 3,900 ft above sea level. Extending about half to three-quarters of a mile east of this terminal moraine are remnants of a somewhat older, partly eroded moraine, on which are weathered boulders. From these moraine remnants an outwash terrace extends about 1½ miles down the valley transecting the upper second terrace to a depth of 100 ft below its gravelly top. The valley is clearly of pre-Wisconsin age.

There are, therefore, as was suggested to the writer by Pardee, what appear to be remnants of two older sets of moraines outside of the well-defined Wisconsin moraines. The oldest is probably of early Pleistocene age, lying on erosion remnants of a late Tertiary (?) piedmont terrace. At its maximum the Lost Horse Creek glacier was 16 to 17 miles long.

At its highest stage (about 4,200 ft above sea level), the water of glacial Lake Missoula must have extended up the canyon of Lost Horse Creek to a point about 4½ miles above the outer front of the Wisconsin terminal moraine, unless this part of the trough was then occupied by the glacier.

ROARING LION CREEK AND SAWTOOTH CREEK

West of Grantsdale a bouldery gravel fan spreads out from the canyon mouths of Sawtooth and Roaring Lion Creeks. Heading at an outer moraine in front of the canyon mouths, about 4,000 ft above sea level, this fan slopes to an altitude of less than 3,700 ft in less than 2 miles and in part merges with, or is covered by, the lower terrace. The outer moraine, which is loaded with granite boulders ranging from 1 to 20 ft in diameter, appears to be partly cut away, as though of pre-Wisconsin age. Behind it is an inner, bouldery moraine probably of the Wisconsin stage. As seen from the north, there appear to be one or more remnants of a high piedmont terrace similar to those seen farther south, but shorter.

The bouldery fan was probably submerged by the waters of glacial Lake Missoula during its highest stage, but no specific lacustrine features were observed. From the vicinity of the bridges west of Grantsdale southward to Charlos Heights the railroad and the highway are on a broad, flat, gravel terrace below the margin of the bouldery fan terrace and 20 to about 50 ft above the river. This lower terrace is probably of Wisconsin age.

Sawtooth Creek glacier was 11 miles long and its terminal moraine is about half a mile outside the canyon mouth. Possibly the waters of glacial Lake Missoula during its maximum stage may have bordered the glacier front. Well-rounded granite boulders are so abundant in the first mile below the abrupt front of the moraine that they have been gathered and piled in walls to clear the land at an old ranch (fig. 18). The moraine, which has not been cleared, is thickly strewn with large granite boulders, is crescentic, and the north end is cut through by the creek near the mountain. As seen from the highway near the river, the combined bouldery fans of Sawtooth Creek and Roaring Lion Creek would probably be regarded as part of the great second terrace.

FIGURE 18.—The very bouldery terminal moraine at the canyon mouth of Sawtooth Creek, viewed from the outwash terrace to the east.

BLODGETT, CANYON, AND MILL CREEKS

At the south side of the canyon mouth of Blodgett Creek, 3 to 4 miles northwest of Hamilton, there is a spurlike ridge 400 to 500 ft high and about a mile long similar to those seen at the mountain front farther south. On the crest of this ridge below an altitude of 4,550 ft is a lateral moraine on which are many granite boulders 1 to 10 ft in diameter. The badly weathered condition of boulders on the upper western part of the ridge suggests that the moraine is of pre-Wisconsin age. From the lower end of this spur a broad remnant of the second terrace extends southeast for a mile or more to the crest of an abrupt marginal bluff, 50 to 100 ft high with a lower gravel terrace spreading below. The lateral moraine merges into a terminal moraine trending northward away from the eroded second terrace across a broad sag at the head of the lower terrace and forming a terminal loop of the Wisconsin stage, 3,800 to 3,900 ft above sea level. Blodgett Creek glacier was 14 miles in maximum length.

Blodgett Creek does not flow directly eastward through the terminal moraine. Within the outer loop are inner moraines and the relations seem to indicate that one of them was so high that when the ice melted, it diverted the outflowing water through a sag in the north lateral moraine close to the foot of the mountain, whence the creek now flows to the northeast. It is possible that the creek may have located here when the waters of glacial Lake Missoula receded from its highest levels.

Canyon Creek glacier was relatively small and only 6 or 7 miles long. There may also have been some little glaciers in the cirquelike scallops, high on the front slope of the mountain to the south.

The glacier that occupied the deep canyon of Mill Creek west of Woodside was about 10 miles long during the Wisconsin stage and extended about a mile outside the canyon mouth. There it laid its symmetrical terminal moraine loop on the head of the second terrace at an altitude of 3,900 ft. South of the narrow postglacial cut made by the creek, the moraine recurves west to northwest. On the moraine are many granite boulders 5 to 10 ft in diameter. From the moraine front an outwash terrace slopes eastward for 2 miles, somewhat more steeply than the second terrace, and southwest of Woodside it merges with the terraces at the foot of the bluff below the upper terrace. From the south side of the canyon mouth a high, sloping rock spur extends eastward about half a mile. The south lateral moraine, in part double-crested, lies along the steep north face of this spur and curves around its east end, showing that the ice spread as soon as the end of the confining rock spur was passed. The outer terminal moraine of this glacier appears to be of Wisconsin age. Here also the waters of glacial Lake Missoula at its high levels may have reached the glacier front.

FRED BURR CREEK AND BEAR CREEK

The glacier that occupied the gorge of Fred Burr Creek, northwest of Corvallis, was 12 miles long, extending about a mile beyond the mountain front in a trough cut several hundred feet below the tops of narrow spurs that flank the canyon portal.

At a pre-Wisconsin stage of glaciation (probably not the earliest) the Fred Burr glacier seems to have extended out onto the head of the second terrace and to have deposited a great accumulation of cobblestones and boulders mostly in the form of a bouldery fan. These boulders may perhaps have been dropped into the high-level waters of glacial Lake Missoula either directly from the glacier front or from icebergs floating out from it. From an altitude of 4,000 ft, in sec. 27, T. 7 N., R. 21 W., the surface of this fan slopes 250 to 300 ft in a mile to a lower and flatter gravelly bench. Later, when the ice melted and perhaps when glacial Lake Missoula dropped to an altitude of 3,500 ft or less, Fred Burr Creek swung over to the north side of this deposit and washed away part of the material, making a new valley 100 ft or more deep. When the glacier readvanced during the Wisconsin stage, a narrow terminal lobe of ice extended into the inner valley and deposited a well-defined terminal moraine below the upper bench. From the moraine an outwash gravel train extends eastward down to the lower terrace, on which is the highway west of the river.

Bear Creek glacier, which had a total length of about 11 miles, extended out between two rock spurs that project from the foot of the main mountain front, the loop of its terminal moraine being about 3,900 ft above sea level where cut through by the creek. The glacier thus ended below the level of the highest stage of glacial Lake Missoula. The terminal moraine was seen by the writer from points on the narrow, wooded, and very bouldery crest of the south lateral moraine. This lateral moraine joins the mountain front about 4,500 ft above sea level and extends thence eastward from the sloping crest of what appears to be an erosion remnant of the high piedmont terrace of the Pliocene(?) age, composed of disintegrated granitic material, arkosic sand, gravel, and some boulders. Below these remnants a broad, bouldery fan or terrace, known as Poverty Flat, slopes eastward to an eroded margin not far west of the Park to Park Highway (U S 93).

BIG CREEK AND KOOTENAI CREEK

Four or five miles southwest of Stevensville, Big Creek emerges from the mouth of its deep canyon between two short rock spur remnants of the Tertiary piedmont slope about 4,000 ft above sea level, or 400 to 500 ft above the creek. The trail up the canyon was traversed for 3 or 4 miles above its mouth. Along its walls great projecting ledges rise above the irrigation flume and one 50-ft pinnacle stands on the valley bottom. Evidently this lower part of the gorge was never glaciated. Near the forest boundary, about 2 miles upstream, there are abundant granite boulders at about 4,000 ft above sea level, suggesting a glacial moraine, and to the west the bottom is smoother and flatter. Between altitudes of 4,200 and 4,300 ft the trail crosses a great ledge of massive granite gneiss, and for miles the great gorge has a scoured-out appearance as though glaciated. No striae were seen near the trail on this ledge and not a single striated pebble or boulder was noted farther east. According to contour lines on the topographic map of the Hamilton quadrangle, the lower two miles or so of the valley is below the highest levels attained by glacial Lake Missoula. Possibly it is for this reason that no well-defined terminal moraine was formed, although, judging from the general appearance of the topography, the Big Creek glacier extended into this part of the gorge.

The mouth of the gorge of Kootenai Creek west of Stevensville is in cross section a rather broad valley (Pliocene?) in the bottom of which the narrow later gorge has been eroded to a depth of 1,000 ft or more between craggy, precipitous walls of jointed gneiss and schist. The terminal moraine of Kootenai Creek glacier lies a mile or so above the canyon mouth, where the canyon broadens out somewhat in granite, 3,900 to 4,000 ft above sea level. Here the stream plunges over a great accumulation of rounded granite boulders. West of the moraine the canyon seems to have been heavily glaciated.

The smooth gravelly flat that merges with the lower terrace west of the river slopes gradually westward for 2 miles to an altitude of 3,500 ft. Across the lower slope the creek flows southeastward to the river.

BASS, ONE HORSE, AND CARLTON CREEKS

A traverse of the Bass Creek trail for about 3 miles above the mouth of the deep gorge revealed no definite evidence of glaciation. Near the forest boundary, at an altitude of 4,400 to 4,500 ft (barometric), there is quite a large accumulation of bouldery material which may possibly be a terminal moraine. At altitudes of 5,300 to 5,500 ft the stream plunges from a hanging part of the gorge in a series of cascades over great ledges of massive granite and banded gneiss. Judging from conditions observed in the gorge of Kootenai Creek to the south, the canyon above these cascades has probably been glaciated. Several miles farther west Bass Lake lies in a higher hanging cirque at the head of the canyon. Tremendous towering cliffs rise above the heavily wooded lower slopes. About a mile south of Bass Creek the piedmont slope drops from the upper bouldery fan terrace about 100 ft to a broad terrace which extends southward to lower Kootenai Creek.

There are abundant 1- to 4-ft boulders on the fan below the canyon mouth of One Horse Creek and some of the granite boulders near the mountain front are 5 to 20 ft long. No evidence was noted to show that the last glacier extended outside the portal of the canyon. No granite boulders were seen above the level of the highest remnants of the old piedmont terrace. There are small remnants, 4,100 ft above sea level, composed of disintegrated granitic material, or arkose, either resting in situ, or redeposited as Tertiary beds.

About 3 miles northwest of Florence at the mouth of the steep canyon of Carlton Creek there is an enormous dump of granite boulders 4,000 to 4,200 ft above sea level. It is probably the terminal moraine of Carlton Creek glacier. From it a steep bouldery gravel fan slopes 700 to 800 ft in 2 miles or less, merging with the lower terrace. Just outside the canyon mouth the creek shifts to the left and flows across the northern part of this fan. Many boulders have been gathered from the stony surface of the fan and piled in walls to clear some fields. The gorges of Carlton Creek and Sweeney Creek have not been examined by the writer. Judging from the contours shown on the topographic map of the Missoula quadrangle, the upper parts of both gorges were glaciated. The same is true of the South Fork of Lolo Creek; there may have been a small glacier heading in a cirque high up on the north flank of Lolo Peak in T. 11 N., R. 21 W.

GLACIERS OF THE ANACONDA RANGE AND SAPPHIRE MOUNTAINS

The topographic map of the Philipsburg quadrangle shows that part of the rugged Anaconda Range was heavily glaciated on both its north and south flanks (pl. 1). (See pp. 167–169.) In the southwestern part of the quadrangle glaciers of the Wisconsin stage occupied the branching gorges of the forks of Rock Creek. The lower parts of these gorges had already been cut down several hundred feet below the well-defined, gravel-capped remnants of the piedmont terraces when the glaciers of the Wisconsin stage reached their lower limits. The terminal moraine of the East Fork glacier, in the NE¼ sec. 36, T. 5 N., R. 15 W., 4 miles southwest of Georgetown Lake, lies on the inner gorge about 5,800 ft above sea level. So thick was the ice, however, as shown by the strong west lateral moraine in this vicinity, that a small lobe crowded into a sag in the ridge crest on the west and spilled over into the Meadow Creek basin (Calkins and Emmons, 1915, p. 11 and map).

The glacier of Middle Fork was nearly 20 miles in length, and its terminal moraine is strongly marked in the vicinity of the ponds known as the Potato Lakes. The moraine extends down the valley to an altitude of 5,500 ft in sec. 20, T. 5 N., R. 15 W. The ice evidently crowded up nearly to the top of the bordering terrace (5,600 to 6,000 ft above sea level), and one little marginal lobe spilled over a small sag into the valley of the East Fork in sec. 22, as shown by the distribution of the drift. When the ice front retreated the channel of the Middle Fork was reestablished, and in so doing the Middle Fork cut westward into the Sapphire quadrangle behind a small rock ridge 200 to 300 ft high in sec. 20. The moraine is little eroded where the road crosses it in the sag east of the rock ridge. Remnants of what appears to be a somewhat older moraine lie a short distance north of the strongly defined moraine of the Wisconsin stage. Even when that earlier moraine was deposited the valley of the Middle Fork was nearly as deep as now. Detailed examination of the lower valley of the Ross Fork of Rock Creek, immediately to the west, has not been made, but the presence of low knolls and ponds in the eastern part of sec. 18 suggests that the Ross Fork glacier, heading on the east flank of the Sapphire Mountains, may have extended that far down the valley at either the earlier or the later stage; the swell-and-swale topography, however, may be due to a landslide.

The valley of the West Fork of Rock Creek shows no evidence of glaciation more than 6 miles below Skalkaho Pass. Above Sand Basin there is an accumulation of large granite and quartzite boulders which may be a moraine, though they lie on and around granite ledges. There are morainal knolls near Mud Lake, and some till containing well-striated quartzite boulders is exposed in road cuts. Some of this till may be of pre-Wisconsin age, but the till, as seen along the road, does not show these relations clearly. There is some suggestion that the drift in the upper 6 miles of the valley is pre-Wisconsin and is related to an older upland topography, below which the narrow lower gorge is cut. No drift was observed west of the pass along the road down Skalkaho Creek.

It is evident from the topographic map of the Sapphire quadrangle that a glacier occupying the valleys of the upper branches of Stony Creek headed in cirques on the Sapphire Mountains. There is coarse bouldery gravel in the lower part of Stony Creek gorge, but no moraine or other evidence of glaciation was seen within 1½ miles of the junction with Rock Creek. The pebbles and boulders are mostly of Belt rocks, though some are of porphyry; none of granite was noted. No evidence of glaciation was seen in a traverse of Rock Creek gorge to the Clark Fork.

East of Georgetown Lake there was extensive glaciation during the Wisconsin stage. Several large glaciers heading on the north flank of the Anaconda Range joined with two or three that headed to the north on the Flint Creek Range. The trunk glacier extended eastward down the valley of Warm Springs Creek to a point about 7 miles west of Anaconda, 5,700 ft above sea level. In sec. 27, T. 5 N., R. 12 W., from the mouth of Olson Gulch about 1½ miles west of the quarry at Browns, westward to Silver Lake there is much bouldery drift. The relations of this drift and of that deposited by the several glaciers of the Anaconda Range in and east of Lime Kiln Gulch are described (Calkins and Emmons, 1915, p. 11) as follows:

> East of Georgetown Lake lies an extensive complex of moraines, deposited by the Warm Spring glacier system, which was by far the largest sheet of ice in the quadrangle. The distribution of its moraines shows that the glaciers forming it overflowed the divides at many places and surrounded such isolated heights as Silver Hill, the ridge east of Cable Creek, and the hill south of Browns. The moraines of this area were in large part deposited during a recession of the ice that continued until the branch glaciers had one by one shrunk away from the trunk stream and finally vanished. The intermittency of the retreat is strikingly indicated by the succession of rudely parallel moraine loops just west of Big Gulch, where the deposits are stripped of timber. This barrenness of the landscape makes it easy for the observer looking southeastward from Warm Spring Creek to Mount Haggin to obtain an instructive view of the excavation and the deposits made by the ice that occupied Gray's Gulch. At the mouth of the gulch the front of the moraine rises abruptly to a rudely semicircular crest behind which chaotic heaps and ridges of bowlders extend for several miles to a large amphitheater cut into the base of the mountain, from which most of this material was derived. The correlation between cirque and moraine is here peculiarly striking.

GLACIERS OF THE FLINT CREEK RANGE

LOST CREEK, RACETRACK CREEK, AND DEMPSEY CREEK

The contour lines on the topographic map of the Philipsburg quadrange show that the deep gorges gashing the eastern flank of the Flint Creek Range north of Anaconda were heavily scoured by glaciers.

About 10 miles northwest of Anaconda, Lost Creek heads on the granitic rocks high on the east flank of the Flint Creek Range. It flows southeastward through a steep-walled gorge cut to depths of 1,000 to 2,000 ft through upturned Paleozoic and pre-Cambrian rocks. This gorge was evidently well scoured by a glacier which deposited a terminal moraine about 5,800 ft above sea level in the lower part of the gorge about 4 miles north of Anaconda. On this moraine and on the floor and lower side walls to the northwest are abundant boulders, mostly of granite and gneiss 1 to 20 ft in diameter. The probable thickness of the ice is indicated by the upper limit of these boulders which rises upstream along the walls of the gorge to heights of 700 ft or so above the creek. For about a mile outside the main terminal moraine of the Wisconsin stage there are low boulder-strewn knolls which may be remnants of a somewhat older terminal moraine, and beyond is the head of the smooth gravelly outwash plain. This glaciofluvial fan below the mouth of the gorge merges with the great alluvial flat across which Warm Springs Creek flows northeast of Anaconda to join Clark Fork in the Deer Lodge Valley.

Racetrack Creek glacier (8 to 10 miles north of Anaconda) was about 15 miles long and was evidently of considerable size, as shown by the morainal field. Below the mouth of the narrow gorge the ice spread out as a piedmont lobe 2 miles wide, which extended to a well-defined, bouldery, terminal moraine loop 5,200 to 5,300 ft above sea level. From this moraine broad trains of outwash gravel extend down Modesty Creek and Racetrack Creek to the south and north of an isolated remnant of the higher or second terrace. The glaciated gorge at the mountain front is about 1,500 ft below the bordering benched spurs on which remnants of pre-Wisconsin drift were found (pp. 65, 66).

Dempsey Creek glacier, the next to the north, occupied a much smaller and shallower gulch. Its terminal moraine appears to be about 5,300 ft above sea level. The ice nearly overtopped the high benched spur of the south lateral moraine, which is covered with the pre-Wisconsin drift, and it crowded a small lobe into a sag in the crest of the lateral moraine.

TINCUP JOE CREEK AND ROCK CREEK

About 5 miles west of Deer Lodge, at about 5,200 ft above sea level, is the great bouldery terminal moraine of Tincup Joe glacier. This moraine, which is 100 ft or more high, lies in a broad flat-bottomed valley, down which a gravelly outwash plain extends between bluffs topped by two remnants of the gravel-capped pre-Wisconsin second terrace. The outwash merges with the broad lower third terrace west of the river and south of Deer Lodge.

Eight miles northwest of Deer Lodge the Rock Creek glacier extended down a gorge that transects the piedmont benchland. The maximum length of this glacier, which headed in several large cirques on the flanks of Goat Mountain near the Powell-Granite County line, was about 15 miles. For several miles beyond the mountains the gorge is very narrow and cuts the high bench remnants; on the southernmost remnant the old pre-Wisconsin glacial drift was found. (See page 65.) Pardee found the older drift also capping the north spur outside of the very bouldery north lateral moraine. Where the narrow, smooth, and less bouldery top of the north spur (5,800 to 6,000 ft above sea level) slopes east of the national forest boundary, north lateral moraine trends to the left (northeastward) to Mill Creek, near the point where the road to Pioneer crosses, showing that the piedmont lobe was about 1½ miles wide. The glacier extended eastward down this broader part of the valley nearly to the head of the narrow rocky gorge through which Rock Creek flows north to join the Clark Fork at Garrison. There is laid its terminal moraine, about 4,800 ft above sea level, in the valley 200 ft or more below the benchland on the south. As viewed from the upper bench, the morainal field is a wilderness of boulder-strewn knolls, ridges, and hollows, some containing ponds. The pebbles and boulders consist very largely of gray coarse-grained porphyritic granite, schist, and white quartzite. In places the outermost north lateral ridges are somewhat smoother and less stony, as though somewhat older.

PIKES PEAK CREEK AND GOLD CREEK

A glacier about 8 miles long extended northeastward out of the upper canyon of Pikes Peak Creek and down the narrow gorge that transects the piedmont benchland nearly to the Pioneer road, about 5,000 ft above sea level. There is some indication that in pre-Wisconsin time the Pikes Peak glacier, or a lobe of it, extended northward into Squaw Gulch south of the village of Pioneer and deposited the old glacial drift exposed at the placer pits about 500 ft below the oldest or Pioneer drift on Ballard Hill. During the Wisconsin stage of glaciation, however, Pikes Peak glacier barely overtopped the gravel-capped bench 2 miles south of Pioneer and extended a small lobe northward for about a mile through a shallow sag in the crest of the high bench just inside the boundary of the national forest.

The mountain gorge of Gold Creek, west of Pioneer Gulch, contained a glacier 8 miles long which headed in large cirques on the flanks of Mount Princeton and Rose Mountain, in the northeastern part of the Philipsburg quadrangle. The Gold Creek glacier extended northeastward for 1 to 2 miles beyond the mouth of the canyon and laid its terminal moraine in the valley between two gravel-capped remnants of the upper or second terrace 1 mile northwest of Pioneer, and about 4,800 ft above sea level. The front of the moraine, at the edge of the woods, is about 50 ft high. From it a flat terrace underlain by coarse bouldery gravel extends down the valley beyond the junction with Pioneer Gulch. Both this lower terrace and the moraine contain numerous boulders of fresh gray granite. No granite boulders were seen on the remnant of the upper terrace, 100 ft above the flat. The pebbles and boulders noted on this upper terrace are mostly angular fragments of gray and white quartzite with some of dense dark crystalline rocks. On the east lateral moraine, along the narrow crest of the spur west of Pioneer Gulch, are abundant boulders of unweathered gray granite 1 to 10 ft in diameter. The abundance of this granite on the moraines of the Wisconsin stage of glaciation is in marked contrast to the scarcity or absence of granite in the early Pleistocene drift just across the gulch to the east on Ballard Hill. It is possible that in early Pleistocene time none of the branches of Gold Creek glacier had excavated headward appreciably into the granite southeast of Mount Princeton. So far had glacial and interglacial erosion progressed by late Pleistocene time, however, that the head of the south branch of Gold Creek glacier, just west of Rose Mountain, had quarried nearly 2 miles into the granite; in consequence a great quantity of this granite was transported down the canyon by the last Gold Creek glacier and deposited in the valley that transects the piedmont area. It has not be determined whether the bouldery gravel along Gold Creek and along lower Pioneer Gulch is wholly or in part a glacial outwash deposit of Wisconsin or late pre-Wisconsin age or a post-Wisconsin torrential deposit.

BOULDER CREEK AND FRED BURR CREEK

Apparently the Boulder Creek glacier during the Wisconsin stage terminated about 5,400 ft above sea level at the moraine a short distance above the old village of Princeton, but during the earlier stage the glacier was joined by one or more tributaries and extended about 8 miles farther along the Flint Creek Valley to a level about 1,000 ft lower, north of Maxville. The relations of the deposits formed by the Boulder Creek glacier north of Philipsburg during the earlier and later stages of glaciation are described on page 86.

Three to four miles south of Philipsburg the great terminal moraine of Fred Burr Creek glacier forms a broad semicircular dam at the mouth of the gorge. The glacier, which headed on the smooth upland near Fred Burr Lake (7,700 ft above sea level), was 8 to 9 miles in length; the abrupt front of its terminal moraine, 200 to 300 ft high, is 5,300 to 5,600 ft above sea level. The partly wooded surface of the moraine, where seen by the writer, is very uneven and is strewn with many granite boulders. Just outside the foot of this moraine is what appears to be a worn-down moraine. The granite boulders on this deposit are considerably weathered with denser parts projecting 1 to several inches. This outer moraine is somewhat older, but perhaps not greatly older, than the big moraine of Wisconsin age. The absence of boulders on the hill slope north of the big moraine is in striking contrast to their abundance on the moraines. From the big moraine a smooth flat slopes to Flint Creek.

GLACIERS OF LITTLE BLACKFOOT RIVER AND THREEMILE CREEK

The upper parts of the valley of the Little Blackfoot River and its tributary, Telegraph Creek, heading at the Continental Divide near Thunderbolt Mountain and Bison Mountain east of Deer Lodge and south of Elliston, were occupied by a large glacier during the Wisconsin stage of glaciation and also at least once during pre-Wisconsin time. The glacier that headed on the opposite side of the Divide and extended down the valley of Thunderbolt Creek southward to Boulder River was only 6 miles long and its terminal moraine, 7 miles west of Bernice, is 6,045 ft above sea level. The last glacier of Little Blackfoot River was 20 miles long and extended northward to within 2 miles of Elliston, at an altitude of about 5,200 ft. The position is marked by two terminal moraines. They are of low relief but have characteristic swell-and-swale topography, and each is bordered by an outwash gravel terrace. It is possible that the outer moraine is of either early Wisconsin or pre-Wisconsin age. The inner one is certainly of Wisconsin age. About a mile north of the outer moraine the river turns to the west at the foot of a transverse mountain slope and flows past Elliston. The earliest glacier in this valley was 4 or 5 miles longer than the later one. (See p. 87.) Evidently after the earlier ice disappeared the Little Blackfoot River deepened its valley 250 ft or more prior to the later ice advance. It has cut a shallow terraced inner valley through the two later moraines since the last glacier ice disappeared. The bouldery gravel of the terrace, the site of the south part of Elliston, is 50 to 60 ft above the stream and is probably outwash from the outer Wisconsin moraine. The lower gravel terrace, the site of the railroad station (5,061 ft above sea level) and the main street north of the stream, is 20 ft above stream level and was probably formed while the ice front stood at and receded from the inner moraine.

The basin of Threemile Creek contained a branching glacier that headed on the flanks of Black Mountain at the Continental Divide. Its terminal moraine, 7 or 8 miles north of Avon is in T. 11 N., R. 8 W. about 5,400 ft above sea level, heads a gravelly flat bordering the creek. There are here two well-defined concentric bouldery terminal moraines, both of which may be of Wisconsin age. Through each terminal ridge the creek has cut a narrow gap. Between these moraines is a smooth grassy sag. The outer front of the inner moraine is very abrupt and about 50 ft high. The outer moraine may possibly be of pre-Wisconsin age, inasmuch as it is lower and less abrupt. The drift is composed of quartzite, granite, and limestone. Boulders of limestone on the surface, especially of the outer moraine, are somewhat etched by solution.

BLACKFOOT RIVER BASIN

The Rocky Mountains between Glacier National Park on the north and the Clark Fork and the Blackfoot River on the south were in general heavily glaciated. The writer has seen little more than the borders of this great area. Several glaciers extended southward into the Blackfoot Valley and left moraines on or near which are automobile roads. The first of these moraines is near the crossroad 12 miles above Lincoln on the Helena road. The glacier that formed this moraine headed to the north in the mountains near Lewis and Clark Pass and extended southward down Alice Creek so far across the Blackfoot Valley that the river was crowded against the south bluff where it has cut a narrow gorge 150 ft deep across a rock spur. Probably a temporary lake was held in the upper part of the valley while this gorge was being cut. For a mile or more north of the crossroad there is a great deposit of morainal drift about 100 ft high completely blocking the main valley (secs. 26, 34, and 35, T. 15 N., R. 7 W.). This deposit also extends westward across the mouth of the valley of Alice Creek. Glacial ice occupied the next valley to the west and extended about a mile down Blackfoot Valley into secs. 4 and 5, T. 14 N., R. 7 W. Here also Blackfoot River was crowded to the south side of its valley and cut a small gorge in the rock. Two to three miles farther west a glacier in the valley of Copper Creek joined one in the valley of Landers Fork and the combined flow reached Blackfoot Valley. This branching glacier was 18 to 25 miles long and had a considerable gathering ground in the mountains to the north. There is a moraine at the mouth of the valley from which a partly eroded, gravel terrace extends for miles down the Blackfoot. This moraine may mark the terminus of the glacier at the last or Wisconsin stage of glaciation, but there are indications that a glacier extended about 10 miles farther down the Blackfoot Valley either during this or an earlier stage of glaciation.

Below the mouth of the gorge (sec. 25, T. 14, N., R. 11 W.), Blackfoot River flows in a sinuous course for 25 miles or more through the southern part of a valley or basin 8 to 10 miles wide. (See Ovando and Drummond quadrangles.) Two or more glaciers, 20 to 30 miles long, extended southward from the mountains on the north and deposited their moraines in great loops on the floor of the basin. The glacial drift south of these moraines may be of Illinoian or Iowan age. The present course of Blackfoot River westward to its junction with Clearwater River was evidently determined, in general, by the outlet available past the southern ends of the great glaciers of the Wisconsin stage.

The glacier of the Blackfoot North Fork headed at the pass near Donaher Mountain and in cirques near the Continental Divide, Scapegoat Mountain, and Evans Peak. Its volume was evidently so great as to override the hills west of Coopers Lake and crowd through the short valley in which this lake lies. The transverse ridge, 200 to 325 ft high, just south of the lake is not wholly a moraine; its narrow part consists of upturned rocks of the Belt series. Smoothed and striated ledges show that the top of this bedrock ridge was much glaciated. Kleinschmidt Creek flows from the lake through a narrow gorge cut at the west end of this rock ridge.

Small tributary glaciers evidently occupied by U-shaped gulches and cirques that hang high up on the flanks of the magnificent mountains to the east. Doubtless these gulches were also occupied by ice during one or more earlier stages of glaciation. The road north from the mouth of the Blackfoot gorge continues for 2 to 3 miles, partly on a terrace 40 ft above the river. It then crosses an outer lateral moraine, a narrow depression, and a wooded inner moraine which extends for miles southwestward along the southeast border of Kleinschmidt Flat. This smooth, gently sloping flat is underlain by gravel. Farther west these moraines subdivide somewhat and extend westward in concentric curves to gaps cut by the North Fork of Blackfoot River. In places there is a strongly defined knob-and-kettle topography, but the more southerly belts are not so rough. These moraines seem clearly of Wisconsin age, although there are in places only a few boulders upon them. The boulders consist of quartzite, red and green argillite, diorite, and limestone of the Belt series rocks which do not generally make large boulders. North of the gaps cut by the North Fork of the Blackfoot the bulky lateral moraines trend northeastward and coalesce near the mountains. The abrupt northwest margin of the outer moraine ridge is bordered by a smooth flat terrace formed by outwash from this moraine and the moraine of Monture glacier on the northwest.

At and near this junction west of the North Fork moraines, the Blackfoot River and the North Fork have cut through the outer and older drift and 100 to 200 ft into Tertiary "lake beds." It may be that prior to the last glacial invasion of the basin the Blackfoot flowed more directly northwestward from the foot of the canyon north of Helmville past the site of Ovando and there swung westward to join Clearwater River.

As mapped by Pardee, the moraines in T. 15 N., Rs. 12 and 13 W., outline the piedmont lobe (about 40 sq mi in extent) of a great glacier that occupied the mountain gorges of Monture Creek and its tributaries, north of Ovando and nearly blocked the Blackfoot Valley. In places these moraines also have strongly defined knob-and-kettle topography. This is particularly true 1 to 3 miles northwest of Ovando and also 5 to 6 miles west of the village, where the moraines are bordered on the west by an outwash plain. The streams have cut gaps through the moraines and these drainageways are occupied by gravel terraces. This part of the Blackfoot drainage basin appears to have been occupied by a still larger glacier at an earlier time, probably corresponding to the Illinoian or Iowan glaciation.

Judging from the relations of glacial deposits mapped by Pardee in the northwestern part of the Drummond quadrangle and the southwestern part of the Ovando quadrangle, there was vigorous glaciation of the valley of Clearwater River southward to and beyond the junction with Blackfoot Valley (in T. 14 N., R. 14 W.).

Nothing indicating the direction of ice movement across the divide between the heads of Clearwater and Swan valleys was noted near the road. The great west wall of Swan Range, 3,000 ft or more high, continues south-southeastward past the lower divide ridge and foothills into the Ovando quadrangle. Rainy, Alva, Inez, and Seeley Lakes in the Clearwater valley are surrounded by glacial drift; Salmon Lake in this valley occupies a rock basin in a narrow gorge. A wide, gravelly, low terrace extends down the valley from the vicinity of Lake Inez to Seeley Lake, where it is 4,000 ft above sea level, or near the upper level of glacial Lake Missoula. At Morrell's bridge are remnants of two gravel terraces 25 and 50 ft, respectively, above the broad flat. There are also kettle holes in drift banked against rock hills to the south.

About a mile northwest of the head of Salmon Lake a road cut showed coarse, morainal gravel jammed against fine, stratified sand which dips south as though washed into standing water at about 4,000 ft above sea level at the ice front during a recessional stage. A little farther south gravel caps a small outwash terrace remnant and overlies 15 ft of fine, rippled, lacustrine sand and silt, possibly of glacial Lake Missoula. East of Salmon Lake a pitted morainal deposit borders a broad gravelly flat or outwash terrace to Woodworth (4,200 ft above sea level). The outwash forming the terrace may have been swept into the waters of glacial Lake Missoula. The terrace extends southward along Cottonwood Creek, in T. 15 N., R. 13 W., bordering the west front of the well-defined moraine of the Monture glacier to the Blackfoot River.

Apparently the ice traversing the narrow rock gorge in which lies beautiful Salmon Lake (Tps. 15 and 16 N., R. 14 W.) was so thick that its top was high above the abrupt side walls of the canyon. It was 1,000 ft or more thick. The upland slope 1 to 4 miles southeast of the foot of Salmon Lake, and 300 to 700 ft above the river, is marked by gentle swells and swales and is strewn with scattered large erratic blocks of rock to an altitude of 5,000 ft or so. The rock hills in the angle above the junction of the Clearwater with the Blackfoot were overridden and mantled with drift. The ice appears to have extended 3 to 4 miles farther south onto the ridge north of Sunset School and to have formed its terminal moraine at the eastern part of Ninemile Prairie (T. 14 N., R. 14 W.).

West of the junction of the Clearwater River with the Blackfoot River there are slopes that show shore lines of glacial Lake Missoula as high as 4,000 ft above sea level. Still higher these slopes are strewn with boulders and on top are kettle holes, signifying a morainal deposit of the Clearwater glacier; a similar moraine is present on the east side of the Clearwater River. From the river a broad smooth gravelly terrace, Ninemile Pairie, slopes westward. This terrace is coated with a thin deposit of Lake Missoula silt, except where erosion channels formed after the lake lowered. A lower terrace borders the Blackfoot River and on it are abundant boulders. There are also well-preserved terraces above the road east of the Blackfoot, at and below an altitude of 4,000 ft. Near the old railroad bridge, very stony drift, composed largely of boulders 1 to 10 ft in diameter, underlies 10 ft of the silt. This seems to indicate that the west front of the pre-Wisconsin glacier extended nearly or quite as far west as this exposure and terminated in the glacial lake. When the last ice front receded the lake water extended eastward over the drift and covered it with the silt. This is the most easterly place at which this silt has been observed.

The remarkable upper gravel terrace along Clearwater River, 1 to 6 miles north of the Blackfoot, is pitted with large kettle holes in T. 15 N., R. 14 W., showing that great blocks of ice were buried in gravel as the ice front receded up the valley. These buried ice blocks appear not to have melted until after the outwash of gravel ceased and the stream was cutting down to lower levels. Evidently this pitted terrace was not overridden by a later advance of the ice and is therefore believed to be of Wisconsin age.

What appears to be a correlative of this pitted gravel terrace farther south is the terrace, 100 to 200 ft above the Blackfoot River and the road, extending southward for 2 miles from the mouth of the Clearwater on the east side of the river. This terrace, however, may be underlain by Tertiary deposits, as volcanic ash is exposed where the road slopes to the terrace level, and volcanic porphyry is exposed in the bluff to the west.

The relations of the morainal deposits about Placid Lake, a few miles west of Salmon Lake, have not been studied thoroughly, but the valley has evidently been glaciated by ice tributary to the Clearwater glacier.

The remarkable series of four or five lower terraces 2 to 3 miles south of Salmon Lake may be the result of meandering of Clearwater River at lower and lower levels corresponding to the lowering of glacial Lake Missoula during successive stages when the Wisconsin ice front was receding. The abundant boulders on the lower terrace south and southwest of the mouth of Clearwater River are either residual from erosion of the drift, or were dropped from icebergs floating down the valley. So far as the writer has observed, there is no evidence of the presence of glacier ice in the Blackfoot Valley west of Ninemile Prairie. Banks of bouldery gravel in places along the railroad appear to be torrential deposits. It has been suggested that there was a glacial moraine near the west line of sec. 18, T. 13 N., R. 17 W. The accumulation of big blocks of rock around which the road curves at this place appears to have fallen from the high cliff that towers above it on the south.

Evidently there were local glaciers in the hills or mountains north of the lower Blackfoot River. The ranger station on Gold Creek is on a low, wooded, boulder-strewn terminal moraine near the junction of the north and west forks, about 4,100 ft above sea level. Some of the pebbles and boulders show glacial striae. The glacier terminating at this moraine evidently headed in the mountains east of the McLeod Peak and was about 8 to 10 miles long.

GLACIER OF RATTLESNAKE CREEK

Unfortunately, the topography of the Mission Range and of the rugged mountains about the head of the Jocko River basin and north of latitude 47° N. in the region north of Missoula and Bonner has not yet been mapped. Much of this area has evidently been heavily glaciated. Only on Rattlesnake Creek, which joins the Clark Fork at Missoula, has the lower limit of glaciation been determined by the writer. Heading in several glacial cirques on the flanks of McLeod Peak and Stuart Peak, Rattlesnake Creek flows southward to southwestward in a narrow gorge between rugged mountain walls 2,000 to 3,000 ft high, in the northwestern part of the Bonner quadrangle. Where the gorge curves southward 7 to 8 miles north of Missoula, the stream has swung to the south side and cut a gap through a narrow, transverse ridge of bouldery gravel 100 to 200 ft high. This is evidently the terminal moraine of the Rattlesnake Creek glacier.

No other frontal moraine was seen by the writer in a traverse 8 or 9 miles farther up the valley. As seen from an altitude of 4,500 ft, on the trail a mile or so north of the Franklin ranger station (sec. 2, T. 14 N., R. 18 W.), High Falls Creek appears to be cascading from the lip of a high hanging valley to join Rattlesnake Creek.

The top of the terminal moraine of the Rattlesnake Creek glacier is 3,900 to 4,000 ft above sea level, or nearly on a level with the upper shore lines of glacial Lake Missoula, which show very plainly on the west flanks of the mountains a few miles farther south. It is also about 800 ft above the flat on which the State University and the city of Missoula are built.

From the abrupt west front of the moraine a boulder-strewn outwash-gravel terrace extends down the valley to the Clark Fork and there merges with the upper terrace on which most of the city is built. One of the lower terraces and the upper, or outwash, terrace continue southward through Hutchins Park; the outwash terrace appears to merge with the broad gravel terrace on which the Northern Pacific Railway extends for more than 4 miles northwest of Rattlesnake Creek.

For some distance below the moraine the stream has cut two narrow terraces below the outwash terrace. The outwash terrace heads about 50 ft above the creek or 3,800 ft above sea level. The cobbles and the boulders, many 1 to 4 ft in diameter, consist mostly of red and greenish argillite of the Belt series, and in part of diorite. So abundant are the boulders that great quantities of them have been gathered from yards, fields, and orchards and built into walls. The stones are partly angular, partly subangular; many are smoothly rounded. The average gradient of the outwash terrace between the terminal moraine and the Clark Fork is 80 to 85 ft per mile, judging from the topographic map. Either the transporting water was torrential, or many of the larger stones must have been dropped from ice from the glacier front.

The features along Rattlesnake Creek and in the Missoula Valley seem to have the following relations:

The finely laminated silt underlying the upper terrace west of Missoula was deposited in glacial Lake Missoula, during either pre-Wisconsin or early Wisconsin time. As, or after, the lake lowered, the gradients of the streams entering the Missoula Valley were increased, the streams became torrents and swept coarse bouldery gravel, some of it glacial outwash, down their valleys. After the lake level fell below an altitude of 3,100 or 3,200 ft, the Clark Fork and its tributaries below Hell Gate Canyon meandered widely over the lacustrine plain, and much of the silt where unprotected was washed away, leaving a lower flat below the crenulate margin of the upper silt terrace. Onto this lower flat the coarse, bouldery gravel was swept and spread out widely by the shifting streams. A large amount of coarse, bouldery material appears to have been washed down the Blackfoot River to Bonner by floods from the vast melting ice fields that extended as far east as the divide above Lincoln. Much of this material was swept along westward by the Clark Fork through the gorge to the Missoula Valley. The gravel and boulders that came down the Rattlesnake Creek from the terminal moraine appear to be of Wisconsin age. Some came down Grant Creek and some may have been brought in by the Bitterroot River from the south.

The preservation of such extensive remnants of the upper Lake Missoula silt terrace west of Missoula appears to be due to the protection from meandering streams that was afforded by the coarse, bouldery gravel and conglomerate in the hill 4 to 5 miles west of the city (in secs. 22 and 23, T. 13 N., R. 20 W.), and to the limestone and coarse gravel in the bluff salient 6 miles farther northwest (in sec. 30, T. 14 N., R. 20 W.). Well-preserved gravel terraces continue westward down the valley of Clark Fork to Saint Regis, but the relations of these terraces to the moraines formed by glaciers in the bordering mountain ranges have not been investigated.

GLACIERS OF JOCKO RIVER BASIN

It is not known that there were any glaciers on the west flank of the mountains near Evaro, although there were glaciers a little farther north. There is a great sloping bench several square miles in extent and heading at the mouths (4,000 to 4,200 ft above sea level) of gulches which cut this mountain slope. This smooth bench slopes radially westward to the crest of the 100-ft bluff east of the Northern Pacific Railway. The bench is transected by sharp narrow gulches on whose sides coarse cobblestone gravel composed of Belt rocks is exposed. Boulders 3 to 5 ft in diameter are exposed on the surface, but no glacial drift was noted. It is possible that this piedmont bench gravel either was deposited in the waters of an early stage of glacial Lake Missoula, or it is of late Tertiary age.

A few miles farther north, about a mile east of Schley, the irrigation canal extends along the slope near the base of a steep bluff below what appears to be a remnant of a similar piedmont terrace. The top of this bench, between altitudes of 4,200 and 4,400 ft, is uneven like a moraine and contains many angular blocks of red and green rocks of the Belt series, some of them 10 ft in diameter, on its surface. Here there may be a combination of an old terrace remnant and early and late glacial moraines.

Above the canal at the canyon mouth of Agency Creek (3,800 ft above sea level) there is a big terminal moraine at which heads the great gravel fan which is crossed by the roads.

At the mouth of the mountain valley of Jocko River 4 to 5 miles east of Arlee (in sec. 10, T. 16 N., R. 19 W.), a rock ridge, 100 to about 200 ft high, projects about halfway across the valley mouth like a remnant of a terrace or an old valley floor. It is directly in front of the gorge of Big Knife Creek. The creek bends abruptly to the north, behind the ridge, in order to join the Jocko, which swings to the north to pass the end of the ridge. Not only is the present stream diverted to the north but disposition of the terminal moraine loop indicates that the last of the Big Knife glaciers also was diverted by the rock ridge. Striated pebbles found on the hills east of Arlee and north of the Jocko River, 575 ft above stream level, may have been transported by icebergs in glacial Lake Missoula. No drift pebbles or boulders were noted above an altitude of 4,000 ft on the eastern part of these hills.

Farther up the valley are remnants of a terrace 300 ft or so above the broad, gravelly flat. On one remnant about 400 ft above the river, striated argillite pebbles were found. These pebbles may have been dropped from icebergs. No evidence that a glacier extended out of the mouth of the gorge of the South Fork of the Jocko River was noted. About a mile farther east the main broad terrace, underlain by bouldery outwash gravel, heads at the outer front of a terminal moraine 4,100 to 4,200 ft above sea level. This is 1 to 2 miles below the irrigation dam. It looks as though the till, from the dam northwestward along the slope to Twin Lakes, may be correlated with this moraine, although it may perhaps be of pre-Wisconsin age. The road down the Jocko Valley extends much of the way on the broad outwash gravel terrace—the second terrace above the stream.

Near the junction of South and Middle Forks are four terraces 20 to 30 ft apart, and remnants of a fifth about 50 ft above the road. Beyond the constriction at the rock hill near Big Knife Creek the outwash terrace merges with the great smooth gravelly plain that extends westward past Arlee as the second terrace above the stream. At the narrows, in the bluff below this terrace, coarse cobblestone gravel is exposed overlying rock. North of Arlee the grade of the gently sloping gravelly plain descends to the upper limit of the Lake Missoula silt; thence northwestward, what is left of that whitish silt forms a dissected bench or terrace bordering the north and south sides of the flat. It seems probable that the gravel underlying the main broad terrace is mostly glacial outwash of Wisconsin age and that before its deposition the Lake Missoula clay had been exposed to erosion by lowering of the lake. It also seems probable that the reflooding of the lake during the Wisconsin stage was not up to a level much more than 3,000 ft above sea level and may not have extended as far up the valley as Arlee (3,094 ft above sea level). This interpretation is in harmony with the relations of deposits just west of Missoula.

Traverse of the Jocko Valley for 10 miles east of Arlee, and thence southeast about 17 miles farther up the narrow wooded canyon of the South Fork to the pass leading eastward to the head of Boles Creek, revealed no evidence of a South Fork glacier, although there may have been one or more small glaciers heading farther west in the region of McLeod Peak. About 2 miles east of the junction of an east branch with the South Fork there is a conspicuous gap in the mountain ridge on the north, and through this the canal from the Upper and Lower Jocko Lakes extends northwestward to the reservoir on the Middle Fork of the Jocko River. In this gap there is a great deposit of bouldery glacial drift, apparently an extension of the great deposit of till in which the canal west of the reservoir dam is excavated. The distribution of this till suggests that a small lobe of a great glacier to the north advanced southward into the gap. C. H. Clapp (1932, pl. 1) has mapped a continuation of the Mission fault as extending in a southeasterly direction from Saint Marys Lake through this gap and thence up the east branch to the Upper and Lower Jocko Lakes and beyond. From this gap eastward past the lakes to the pass, 4,650 to 4,700 ft above sea level, the writer saw no evidence of glaciation. Between 3 and 4 miles east of the gap a great deal of angular rock fragments appear to have fallen or slid down from a high cliff or scarp on the north. The small Upper and Lower Jocko Lakes appear to be due to obstruction of the stream channel by this great dump of fallen rock, which consists largely of limestone and red, greenish, and gray argillite of the Belt series. Outflow from the lower lake is by seepage through this loose mass of rock fragments. A canal was constructed to divert water westward from streams east of the divide through the pass to the Upper and Lower Jocko Lakes, and thence westward to the Flathead basin for irrigation.

Two miles northwest of Arlee near the railroad and highway bridges, the Jocko River flows through a narrow, shallow inner gorge cut across a nearly buried ridge of reddish quartzite of the Belt series. The low cut-off rock hill on the north, which is thinly covered with Lake Missoula silt, has restrained the meandering of the river and has protected the broad upper gravel terrace to the north and east from erosion. To the northwest the upper terrace has been cut down by the streams, leaving a broad, lower gravelly flat about 3,000 ft above sea level. No clear evidence was found that the valley between this place and the canyon mouth east of Arlee has been glaciated. North of the highway bridge a smooth surface on the quartzite closely resembles a glaciated ledge. Fine lines simulate glacial striae, but close examination shows them to be thin seams in the rock and not glacial scratches. The smoothing is probably the result of waterwear, or possibly wind action, rather than ice abrasion.

The river has cut into old oxidized glacial till near the mouth of Valley Creek, 1 to 2 miles south of Ravalli (see pp. 67, 68). This till, overlain by Lake Missoula silt, is probably of pre-Wisconsin age. It may have been deposited by a glacier that headed on the mountains to the southwest. There is also some fresher-looking unoxidized gray till in places farther south. No terminal moraine has been seen in the part of the mountain gorge that has been examined.

There are many scattered erratic boulders on the broad, undulating plain bordering lower Valley Creek in T. 17 N, Rs. 20 and 21 W.; on the short bench spurs in or near sec. 33 at T. 17 N., R. 20 W., at altitudes between 3,750 and 4,000 ft (barometric); and on the hills east and southeast of Ravalli less than 4,000 ft above sea level. Many of the smaller erratics in these places show glacial striae. Several large erratic blocks are 10 to 15 ft in diameter. Some striated boulders were also seen near the highway between Evaro and Schley. Evidently most of these erratics were dropped from icebergs floating on glacial Lake Missoula. In places, for example Ravalli and Dixon, striated pebbles are found in the midst of the finely laminated silt. In many places the old lake shore lines are well preserved, though they are faint on grassy slopes such as those on the hill south of Arlee.

GLACIERS OF THE MISSION RANGE

From Saint Marys Lake (Tabor Reservoir) in T. 17 N., R. 18 W. in the valley of Dry Creek, southeast of Saint Ignatius, northward to the mouth of Swan River near the town of Bigfork, a distance of more than 50 miles, the western flank of the Mission Range overlooks the Flathead basin. In most of the northern half of this extent the western flank of the range rises abruptly from the eastern shore of Flathead Lake. During the Wisconsin stage of glaciation the great southward-moving Flathead glacier occupied the lake basin and crowded up along the mountain wall to heights decreasing southward from something like 2,000 ft to a few hundred feet in T. 22 N. Here the Polson terminal moraine diverges from the mountain front and extends southwestward to the river below Polson. The Polson moraine appears to mark the southern limit of the advance of ice in the Rocky Mountain Trench during the Wisconsin stage of glaciation. North of this limit small glaciers on the upper west flank of the Mission Range probably merged with the marginal ice of the great trunk glacier. South of the Polson moraine large, separate mountain glaciers occupied ten or more of the deep gorges that gash the west flank of the range, and they deposited noteworthy terminal moraine loops at the foot of the range. None of these terminal morainal deposits has been differentiated as of pre-Wisconsin age, and it therefore seems that the mountain glaciers were fully as long at the maximum of the last advance as at any earlier stage. The glacial features are described in order, beginning at the north, as of Wisconsin age.

MUD CREEK

East of Pablo in Lake County, in the southeastern part of T. 22 N., R. 19 W., there are several narrow rock spurs extending for about a mile in a northwesterly direction from the steep higher mountain slope at their heads. They are interstream ridges between branches of Mud Creek and may be erosion remnants of a former piedmont terrace, as are some others farther south. Lying on these rock spurs, and continuing northwestward down the piedmont slope, are sharp, narrow, bouldery lateral moraines of two or more glaciers. Where not cut away these laterals merge into terminal moraines.

The writer traversed the crests of two of these combined moraine and rock spurs from the vicinity of the Pablo feeder canal, about 3,200 ft above sea level, to the junctions with the steep mountain front, 4,800 to about 5,000 ft above sea level. The southern spur is bordered on the south by a lower smooth, partly farmed bench sloping from the foot of the mountain, about 4,000 ft above sea level, to an abrupt margin along which the canal extends, about 3,200 ft above sea level. The canal is dug in gray, stony, clay till, probably of pre-Wisconsin age. This high, narrow, rocky spur trends northwestward—that is, obliquely athwart the east-west trend of the glaciated mountain gulch above it on the east. The northwesterly trend of these spurs is in marked contrast to the southwesterly trend of similar spurs farther south. As stated above, evidently the northwesterly trend of the moraines is not a result of deflection by the east margin of the southward-moving Flathead glacier as it advanced to or beyond the Mission moraine, but the direction of the ice movement was controlled by the rock spurs. The moraines are probably to be correlated with the Polson moraine as of Wisconsin age. There are slight transverse sags or short steplike drops in the narrow crestline of the northernmost spurs, at altitudes of about 3,800, 4,200, and 4,800 ft. A similar sag in the crest of the southern spur was noted at an altitude of about 4,400 ft. These sags could be results of Recent faulting, but may be simply effects of erosion.

Farther south there is a rather marked tendency for the combined moraine and rock spurs and the intervening gulches to be deflected somewhat south of an easterly trend. It has been suggested that the deflection may have been due to southward movement in the contiguous part of the great Flathead glacier when it extended to or beyond the Mission moraine in pre-Wisconsin time. However, instead of the direction of deflection being evidence of the contemporaneity of these piedmont moraines with the pre-Wisconsin moraines of the Flathead glacier, it seems to be the reverse, for the moraines of at least three of the ten mountain glaciers show an equally striking northwesterly trend, as though the protrusion of the last of the piedmont glacial tongues occurred when the Flathead glacier stood at the Polson moraine and did not directly affect these mountain glaciers.

What seems really to have controlled the trend of these piedmont ice tongues and that of the related lateral moraines was the trend of the twin spurs that flanked the canyon mouths. It is as though the spurs were erosion remnants of fan-shaped rock pediments, each heading at canyon mouths. When conditions came about that favored down cutting or dissection, some of the streams were flowing directly out of the canyon mouths and others were flowing down the radial slope either to the right or to the left and there began their down cutting. The troughs between the spurs thus had various trends when the last of the several ice tongues reached their maximum extension between the spurs and laid their bordering moraines.

CROW CREEK

Crow Creek, southeast of Pablo, flows southwestward from its canyon mouth between short rock spurs 300 ft or more high. Lateral moraines lie along the spurs to their outer and lower ends, beyond which the north moraine curves southward and the two laterals join in a loop laid around the lower end of the Crow Creek glacier.

The combined rock spur and south lateral moraine of another of the Crow Creek glaciers and the north lateral of a third, east of Ronan was traversed. The lower ends of these moraines are on the piedmont slope a short distance above the Pablo feeder canal. The crest of the northern of these two sharp, high spurs is not broken by steps or sags but rises smoothly to join the steep mountain front at an altitude of about 4,800 ft. A lower rocky morainal ridge branching from the south side of the main moraine may be either a somewhat older moraine or the north lateral of a shorter glacier. The main moraines curve toward the southwest near their lower ends. The narrow crest of the north lateral of the moraine spurs due east of Ronan is marked by transverse sags at altitudes of 4,200 and 4,400 ft; it also joins the steep mountain front at an altitude of about 4,800 ft. Views north and south over these numerous spurs show a general uniformity in height and suggest that the rock spurs are erosion remnants of a piedmont terrace of either early Pleistocene or late Tertiary age.

The mountain gorge of the South Crow Creek has been greatly glaciated and what appears to be the back of the high-level cirque (fig. 19) is cut by a great notch.

FIGURE 19.—Glaciated gorge of South Crow Creek in the Mission Range.

The floor of the canyon descends by series of steps over which the creek cascades to lower levels.

From the north side of the mouth of the gorge (sec. 15, T. 20 N., R. 19 W.) a great steep-sided spur, probably with a rock core like those to the north and south, projects obliquely (S. 20° W.) from the steep foot of the mountain for half a mile and ends abruptly. At its junction with the mountain front the top of the spur is about 4,500 ft above sea level. A short distance below the mountain front there is a rather steep drop in the crestline from 4,450 to about 4,375 ft. There is no bare scarp at this place, but the drop suggests the possibility of faulting. Below this drop the narrow crest has a fairly uniform slope to about 3,975 ft at the top of the abrupt lower end. The southeast or ice-contact face of the spur is very steep and near the mountain front shows some ledges of rock. It is overgrown and was not examined in enough detail to determine how far out the spur has a rock core. From the abrupt lower end a great, boulder-laden moraine, about 300 ft high, extends westward, curving gradually southward for about a mile to join a similar south lateral moraine in a terminal loop. There is also a companion spur, nearly 500 ft high, to which the south lateral is joined. It may have a rock core mantled with drift. It has a more westerly trend than the north spur and joins the mountain front 4,100 ft above sea level. There is no break in the sloping spur crest between this point and its outer end, where there is a 50- to 75-ft drop to the top of what is evidently the south lateral moraine, about 3,600 ft above sea level.

It may be that the high spurs do not have more than short rock cores and that they are actually remnants of pre-Wisconsin moraines formed when the Flathead glacier extended to the southern part of the basin and when its east margin was not far from the foot of the Mission Range. Such an interpretation may account for the remarkable S. 20° W. trend of the north spur obliquely across the trend of the mountain gorge. About a mile north of the South Crow Creek canyon are what appear to be two short stubs of rock spurs with which no moraines are connected.

The terminal morainal loop was probably developed during the Wisconsin stage when the front of the Flathead glacier was at the Polson moraine. Within this loop are some lower morainal ridges.

POST CREEK

Features similar to those on the branches of Crow Creek were seen farther south on Mohlman Creek, the most northerly tributary of Post Creek. The back wall of the high cirque is deeply notched, a much-glaciated canyon descends in several rounded steps, and a narrow spur extends southwestward from the mountain front at the north side of the canyon mouth (sec. 22, T. 20 N., R. 19 W.). The top of the spur is about 4,500 ft above sea level where it joins the mountain slope. The slope of its crest is rather steep and there is a sharp drop, possibly due to faulting, between altitudes of 4,450 and 4,425 ft. The crest of the spur is very narrow and on it are many boulders of quartzite, argillite, and diorite.

There is an abrupt drop from 4,100 ft at the end of the spur to 3,800 ft above sea level. A bouldery slope extends from the foot of the spur to an irrigation ditch, 3,550 ft above sea level, just above the fields. Part of this bouldery slope is a morainal deposit, but there are no well-defined lateral and terminal ridges extending below the spur as there are farther north. The wooded sides of the big spur were not examined for ledges indicative of a rock core.

Within the next mile farther south there are three short, wooded rock spurs, apparently remnants of a piedmont terrace, that do not head at glaciated gorges and do not join moraines. The top of the one traversed is about 4,500 ft above sea level at its junction with the steeper mountain front. Small, angular chips of limestone and argillite, and some big blocks or ledges of diorite were the only rock materials noted. The presence of such rock spurs at the mouths of non-glaciated canyons supports the idea that the moraine-covered spurs to the north and south may have rock cores and may be remnants of an ancient piedmont terrace.

In the lower mile of Post Creek canyon, 9 miles east of Charlo, is McDonald Lake, a reservoir which is held by an artificial dam. On the north and south sides of the canyon mouth, flanking the lower end of the lake, short spurs project from the foot of the mountain. Between these spurs and extending beyond their outer ends is a great bouldery morainal deposit disposed in a symmetrical terminal loop extending 2 miles below the lake. Across it runs the Pablo feeder canal. Apparently this moraine is younger than the drift on the plain to the west, which extends southward to Saint Ignatius between Post Creek and Mission Creek. On the western face of the moraine are faint but clearly marked shore lines of glacial Lake Missoula.

A short distance below the mountain slope there is a well-defined sag in the steep, sloping, narrow crest of the spur at the north side of Post Creek. This depression does not have the location and appearance of a normal erosion gulch but suggests the scarp of a Recent fault of small amplitude parallel to the mountain front. The spur, whose sloping top near the steeper mountain front is 600 ft or more above the lake, is perhaps an erosion remnant of a former and higher piedmont terrace, like those on Crow Creek. The canyon at and above the lake has very steep sides and has been much glaciated, and there are now small glaciers on McDonald Peak and adjacent peaks.

The north lateral morainal spur of Ashley Creek glacier has a marked southwesterly curving trend, and is longer and more bulky than the opposite moraine on the inner side of the bend. The Pablo feeder canal extends along the outer west slope of the north moraine and on the slope above the canal are well-marked shore lines of glacial Lake Missoula. This great moraine, like the others, is loaded with many large rocks of the Belt series, some 15 to 20 ft in diameter. It has a broad top at the terminal end, but farther up the crest is as sharp and narrow as a single-track railway grade. The spur joins the steep mountain front at an altitude of about 5,000 ft (barometric). No evidence of Recent faulting was noted (fig. 9).

MISSION CREEK

The writer traversed both the north and south lateral moraines and the terminal moraine loop that extends out onto the piedmont for about a mile from the rock spurs that flank the portal of the Mission canyon east of Saint Ignatius. The inner slopes of these combined moraine spurs are very steep (30° to 45°). The great, wooded north lateral moraine behind the broad terminal ridge has a narrow, sinuous crest (fig. 20 *B*) on which are many rocks of the Belt series, some 15 to 20 ft long. Between 4,000 and about 4,250 ft above sea level the crest broadens a little and appears to join the rock spur whose narrow crest slopes somewhat more steeply to join the steep mountain front 4,700 or 4,800 ft above sea level (fig. 20 *A*). The view overlooking the top of the combined south spur and moraine in figure 20 *A* shows a shallow notch in the crest with a wooded gulch extending down the slope between the second and third bare or brushy patches. This feature was not closely examined, but it suggests the possibility of Recent faulting, as do similar features farther north. The north moraine slopes westward and bends southwestward in a broad curve to merge with the terminal loop, which is cut through by the creek at the irrigation dam (fig. 20 *C*). On the outer base of the moraine are well-marked shore lines of glacial Lake Missoula. The south lateral moraine bends also but, being on the inside of the curve, is shorter. It is somewhat broader on top and has three parallel crests, which merge eastward toward the mountain.

A noteworthy feature of Mission canyon, several miles above its mouth, is an abrupt drop of about 2,200 ft in the floor of the U-shaped trough from the upper to the lower part of the glaciated canyon. Here Mission Creek plunges down in a series of cascades locally known as Elizabeth Falls (fig. 20 *C*). Although many of the shorter glaciated gulches hang high up on the west flank of the mountain, the lip of the hanging valley at Elizabeth Falls is several miles up the canyon. There are very similar features above Saint Marys Lake (Tabor Reservoir) at the south end of the Mission Range. Such abrupt breaks in the canyon profiles constitute the steps of the so-called glacial staircase. Many such features are shown on the topographic maps of the glaciated parts of the Rocky Mountains north and east of this place and elsewhere. No full discussion of

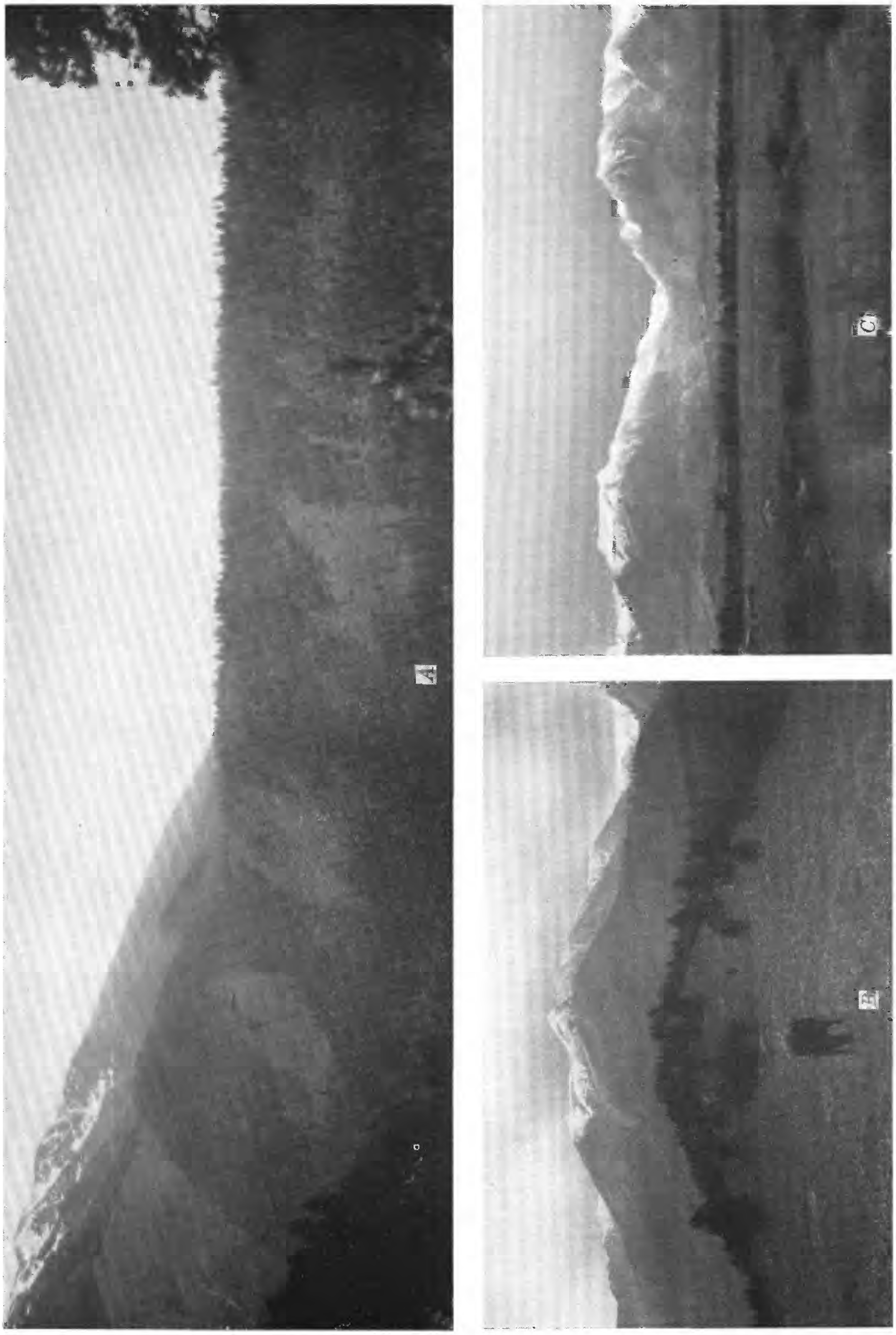

FIGURE 20.—Glacial features of the Mission Range. *A*, Drift-covered spur (Pliocene or early Pleistocene?) at the south side of the canyon mouth of Mission Creek. *B*, Drift-covered, benched spur east of the north lateral moraine of Mission Creek glacier. *C*, Terminal and lateral moraines of glaciated canyon of Mission Creek east of Saint Ignatius.

the origin of such features is presented here, but it may be stated that the writer regards the hanging upper parts of such gorges as genetically related to, and resulting from, earlier stages in development of the gorges when the streams that first cut the canyons were working at horizons or levels corresponding approximately to the relative positions of the bottoms of these hanging parts of the present gorges, and to the tops of such remnants of higher piedmont terraces as may be preserved. They are therefore significant of early stages in the physiographic history of the region.

There is what appears to be a remnant of a corresponding high bench directly across from the mouth of Mission canyon, 5 to 6 miles to the southwest, projecting from the hill slope south of Saint Ignatius (sec. 36 (?), T. 18 N., R. 20 W.) about 1,000 ft above Mission Creek.

From the south side of the south lateral moraine on Mission Creek, two or three ridges diverge southwestward. They are either older (pre-Wisconsin) moraine or erosion remnants of an old piedmont terrace.

Between Mission Creek on the north and Dry Creek on the south, the Mission Range has a more southeasterly trend and is bordered by partly wooded foothills rising high above the gravel terrace along Dry Creek. This terrace heads in a narrow gorge which is blocked, about 10 miles southeast of Saint Ignatius, by a morainal dam retaining Saint Marys Lake about 4,000 ft above sea level. South of the head of the lake is a pass leading southward to Jocko Valley.

There appear to be remnants of one or more terraces on the foothills between Mission Creek and Dry Creek, the upper one being 600 or 700 ft above the gravel flat bordering the channel of Dry Creek. These terraces are the beveled edges of upturned Belt rocks, which are exposed in places on the slopes and in the small gorge cut by the predecessor of Dry Creek below the lower terrace.

The presence of shore lines of the lake on the grassy front slopes of the terminal moraines of some of these Mission Range glaciers and also on the south front of the Polson moraine shows that the southern part of the Flathead basin, and also the valleys of the Jocko River and the Clark Fork were flooded by the waters of glacial Lake Missoula during the Wisconsin stage of glaciation to an altitude of 3,400 ft or more above sea level.

THE FLATHEAD GLACIER

THE GLACIAL ADVANCE

During the Wisconsin stage and earlier stages, an enormous glacier advanced southeastward down the Kootenai River valley across the present international boundary (pl. 1 and fig. 14). Near Rexford, Mont., where it is joined by the Tobacco River from the southeast, the Kootenai River leaves the Rocky Mountain Trench and diverges to a more southerly course; part of the ice followed the present river valley. A large part of the ice, what was perhaps the main axial flow, crossed the so-called Tobacco Plains east of the river and continued southeastward along the part of the Rocky Mountain Trench that is now drained by the small Tobacco River. Crossing the low divide near Stryker, this great glacier, known as the Flathead glacier, advanced southeastward down the part of the continuous Rocky Mountain Trench that is now drained by Stillwater River. Forty to fifty miles south of the boundary, it entered the broad Flathead basin south of Whitefish and Columbia Falls, in what is now Flathead Lake. The Flathead glacier, both north and south of the boundary, was joined by numerous tributary glaciers heading in the Galton and Whitefish Ranges on the east.

Daly (1912, p. 585) has estimated that the maximum(?) thickness of the ice in the vicinity of the boundary was about 5,000 ft. Although its axial flow was along the Rocky Mountain Trench, which is nearly 12 miles wide at the boundary, the total volume of moving ice appears to have been so enormous that, about as far south as the latitude of Kalispell, it probably spread laterally far out over the hills west of the Tobacco and Stillwater Rivers (fig. 14, and p. 57). Only short traverses were made into the Salish Mountains, a rough wooded region which is designated on some maps as the Flathead Mountains, and for which Clapp suggested the name Selish Range.

These traverses were in the valleys of Swamp Creek and Good Creek, the middle fork of the Stillwater. One proof that the ice entered this region is the presence of a glaciated ledge observed on Sheppard Creek, 5 or 6 miles west of Tally Lake (E½ sec. 8, T. 30 N., R. 24 W.). This ledge showed clearly marked glacial striae trending S. 15° to 20° W. It is not known, however, that all the hill and mountain tops in this area were covered with ice of the Flathead glacier. Evidently the axial flow of the glacier was controlled by the Rocky Mountain Trench and the great mountain wall on the east.

Drumlins and drumloidal flutings (elongated low ridges with drumlin trend), the product of the advance of the ice over the Tobacco Plains (see Stryker topographic map), and the region farther south near Kalispell, are described on pages 126, 127. Glacial striae were observed at numerous places southeast of the divide. East of Stryker, in sec. 25, T. 34 N., R. 25 W., the branch road to Stryker Lake ascends over smooth glaciated ledges of maroon argillite showing striae trending southeastward; about a mile farther southeast (in sec. 31, T. 34 N., R. 25 W.) the vertical face of a ledge beside the U. S. Highway No. 93 is remarkably smoothed and striated. On a ledge north of Olney striae trend S. 25° E. At, north, and east of the point where the Great Northern Railway rounds the spur of the hill, 1½ to 2½ miles west of the head of Whitefish Lake, a number of ledges show striae trending S. 10° to 20° E.

The ice of the tributary Whitefish River glacier may have been crowded over and forced to traverse Whitefish Lake basin before it completely merged with the trunk glacier. About a mile east of the head of the lake striae seen beside the railroad trend S. 70° E. At many places along the railroad, where it follows the west shore of the lake between this point and the town of Whitefish, there are glaciated ledges of limestone. In some places striae cross one another, and some striae trend obliquely up smoothed vertical rock faces. The trends of the striae range locally from S. 10° E. to S. 50° W., showing how the ice crowded closely against the hill slope, rounding each salient and crowding into each embayment, while the axial flow of the Whitefish River glacier continued southeastward along the lake basin. It is not known whether or not the hills west of the lake were completely overridden by ice; probably they were at the maximum stages.

Great glaciated gorges (shown by contours on the topographic maps of the Stryker, Kintla Lake, Nyack, and Marias Pass quadrangles and of Glacier National Park) gash the east flank of the Galton and Whitefish Ranges west of the north fork of Flathead River and also the west flanks of the Livingston Range and all the other mountains of Glacier National Park west of the Continental Divide. At the maximum of the Wisconsin and earlier stages most of these tributary glaciers united in great branch glaciers. One moved southward along the Flathead Valley. Much ice crowded through the deep narrow gorge west of the Apgar Mountains, now traversed by the Flathead River. Some of the ice crowded through the Mud Lake gap west of Demers Ridge between Coal Creek and Big Creek. In 1913 the writer observed striae trending southward across the crest of one of the spurs at the west side of this gap (in or near the SE¼ sec. 2, T. 33 N., R. 21 W.). One and a half miles south of the highway bridge over Big Creek a well-glaciated ledge with striae trending southeastward was observed. That the ice was at some time thick enough to completely override the Apgar Mountains is shown by striae (observed in 1913 by E. M. Parks) trending S. 10° E. across the top of Huckleberry Mountain (6,580 ft above sea level) and by striae (observed by the writer in the same year) trending S. 37° to 84° W. across the crest of Apgar Mountains about 3 miles southeast of Huckleberry Mountain (in or near sec. 1, T. 32 N, R. 19 W.). The ledges are 2,500 to 3,000 ft or so above the present channel of Flathead River to the west. Transverse striae were observed by C. S. Corbett on the crest of Demers Ridge. Some of the ice that topped this ridge probably moved southwestward to join the Flathead glacier beyond the hills west of Coram and followed the route past Spoon Lake and Bailey Lake to the vicinity of Columbia Falls, the route now followed by the highway. There is much glacial drift along this route.

As shown by contours on the topographic maps of the Nyack and Marias Pass quadrangles, the flanks of the mountains both west and east of the South and Middle Forks of the Flathead River are gashed by many gorges which, like others of the Glacier Park region, were occupied by local mountain glaciers. These mountain glaciers were tributary to the great branch glaciers in the valleys of the Middle Fork and South Fork respectively. Both valleys contained much glacial till, but neither has been studied in detail by the writer. On the South Fork near the mouth of Spotted Bear River, two glaciated ledges of maroon argillite and red quartzite were observed beside the road. One is at the horseshoe bend about 6 miles north of Spotted Bear River; the other, 3 miles farther south, is well striated with edges of the beds smoothly rounded on the south side, showing that the ice of the South Fork Flathead glacier moved down the valley from southeast to northwest.

In 1911 the writer traversed the Great Northern Railway on foot between the summit at Marias Pass and the junction of Bear Creek with the valley of Middle Fork at Java. The character of some of the striated ledges seen on the Jurassic(?) and Cretaceous rocks less than 3 miles southwest of Summit seemed to indicate that that far west of the Continental Divide the ice had moved northeastward through the pass to join the great Two Medicine glacier. Farther southwest where striated ledges were observed in several places, the ice appears to have moved southwestward and been tributary to the glacier of the Middle Fork of Flathead River. Along the Theodore Roosevelt Highway (US 2) in the valley of Middle Fork below Java, traversed by the writer in company with C. L. Gazin, glaciated ledges showing striae trending from southeast to northwest down the valley were seen about 2 miles southeast of Nyack (NE¼ sec. 28, T. 31 N., R. 17 W.) and also about 4 miles east of West Glacier (Belton). Beyond West Glacier the valley of Middle Fork curves southwestward. Here the Middle Fork glacier was joined by the glacier of McDonald Creek coming from the north-northeast. Striae, observed by the writer on ledges between the railroad and the river west of Lake Five, trend S. 22° to 55° W. The valley here and to the south is 4 to 5 miles wide. Two miles south of Coram the river swings to the west, is joined by the South Fork, and flows westward through Bad Rock Canyon, a deep constricted gorge, about a mile long. This gorge is barely wide enough for the passage of the river, the Great Northern Railway, and the U. S. Highway 2. West of the gorge is the great Kalispell Valley, 14 to

15 miles wide. There is considerable glacial till in the valleys of each of the three forks of the Flathead River.

Ice, probably from the combined Flathead, Middle, and South Fork glaciers, crowded westward through Bad Rock Canyon to form the great trunk of the Flathead glacier. Some indication of this movement can be seen along the highway south of the river, though no glacial striae were observed on smoothed parts of rock ledges there. North of the river, a quarter of a mile west of the junction of the South Fork with the main Flathead River, east-dipping ledges of greenish argillite are grooved and striated, and the rounding of projecting corners shows that the ice was moving from east to west. The maximum thickness of the ice crowding through this narrow canyon was probably more than 3,000 ft.

From a width of at least 16 miles in the latitude of Columbia Falls and Whitefish the main trunk of the Flathead glacier gradually narrowed southward to about 8 miles at the present head of Flathead Lake.

For about 10 miles, from Bad Rock Canyon, to the vicinity of Lake Blaine, the eastern margin of the ice crowded closely against the abrupt western front of the Swan Range. South of Lake Blaine the west face of this range has a more southeasterly trend and the Kalispell Valley merges with the broad, flat-bottomed, northern part of the valley of Swan River.

North of Lake Blaine the ends of the spurs between the lower **V**-shaped gulches are sharply truncated by triangular facets as described by W. M. Davis (1920, pp. 89–90). These facets have declivities as high as 45°; above them the angle of slope may be 30° to 35°. The heads of some of the gulches are **U**-shaped and were evidently occupied by small glaciers, some of which may have been confluent with the great Flathead glacier.

East of Lake Blaine and not far south of the point where the northern front of the Swan Range changes from a southerly to a southeasterly trend, a projecting spur ends in a triangular facet. The Swan Range and the Mission Range stand en échelon and between them for 50 to 60 miles south-southeast is the valley that Swan River drains northward through Swan Lake and thence westward to Flathead Lake, through a gap in the hills near the town of Bigfork. Judging from available nontopographic maps and from distant views at intervals from the road near the river, much of the eastern flank of the Mission Range, like its western flank, especially the southern half, is gashed by canyons that have been heavily scoured by mountain glaciers. Apparently the west flank of the Swan Range also was glaciated, although less severely. Presumably the glaciers in these several gorges were tributary to a great branch glacier that moved northward and joined the Flathead glacier almost head-on between Bigfork and Lake Blaine. However, though there is much glacial till along State Route 31 in the valley of Swan River, no striated ledges or other evidences were noted to show that the Swan River glacier moved northward. About a mile south of the village of Bigfork, ledges exposed beside the road show striae made by the Flathead glacier moving southward.

From the rock hills north of the gap through which Swan River flows, a belt of mild morainal topography extends northward to Echo Lake and Lake Blaine. The relations of this moraine are not entirely clear but they suggest that it may be a lateral moraine of the Flathead glacier and in part a terminal deposit formed during the closing stages by the Swan River glacier. It is almost directly in line with the west flank of the Swan Range north of Lake Blaine. Features of the ground moraine that show the effects of the southward-moving ice are drumlins and drumloidal flutings, like those on the Tobacco Plains to the north, which are well developed in places between Whitefish and Kalispell. There are also a few of these ridges between the Flathead River and Lake Blaine.

At the earlier stages of glaciation, the Flathead glacier extended farther south, but it seems probable that the southern limit at the Wisconsin stage is marked by the Polson moraine, 1 to 4 miles south of the south end of Flathead Lake. Striae on glaciated ledges along the road (U S 93) between Somers and Dayton, and also 9 to 10 miles north-northwest of Polson, trend nearly due south, and striae observed on ledges beside the river above the Little Falls and about 3 miles below Polson trend S. 40° W. The ice flow here was radiating toward the nearby terminal moraine that changes in trend from eastward to southward.

Glaciated ledges observed by Stebinger (unpublished notes) in 1911 on the lake shore 1 to 2 miles east of the village of Big Arm and on the north shore of Wildhorse Island trend southwest where the ice was crowding into the western bay, or Big Arm, of the lake basin. One of the limestone ledges near the road 2 miles east of Big Arm shows crescentic chatter marks. So also, glaciated ledges, 3½ miles northwest of Dayton, near the road to Lake Mary Ronan, show striae trending N. 37° W., where a small marginal ice lobe diverged up the valley of Dayton Creek toward the terminal moraine that blocks a tributary valley and shuts in Lake Mary Ronan. Striae trending N. 59° W. were observed north of the home of A. E. Hurlbutt 2 miles east of Dayton, and striae trending S. 45° W. were seen about 1,300 ft above the lake on the steep southeast slope of the rock hill northeast of Hurlbutt's house. The wooded moraine at Lake Mary Ronan has an abrupt east face and the lake is said to be 300 ft deep at one place near its west shore. The grassed slope north of Dayton has the appearance of having been fluted east to west by the ice rounding this slope to enter the valley of Dayton

Creek. The lines are not horizontal and parallel, as are the shore lines of glacial Lake Missoula.

About 2 miles southwest of Kalispell striae trending S. 35° E. were seen by the writer on ledges where the ice crowded up onto the hills east of Island Lake or Foy Lake, and striae trending S. 16° to 40° E. were observed on the lower rocky slope of the same group of hills beside Patrick Creek, 4 miles south of Kalispell.

One of the remarkable features of the Flathead glacier was the sinuous branching lobe that diverged from the west side of the trunk glacier, 3 to 4 miles west of Kalispell, and advanced southwestward for a distance of 18 to 20 miles up the valley of Ashley Creek and westward at least to the divide in the gap between the mountains near Marion. This divide is on top of a great deposit of bouldery terminal morainal drift. Bordering it on the west is a smooth-surfaced deposit of coarse bouldery outwash gravel, about 1,000 ft higher than Kalispell (2,955 ft above sea level). This deposit appears to constitute the dam that holds Little Bitterroot Lake in a recess in the hills at the head of the Little Bitterroot Valley. From the moraine near Marion the flat-topped outwash deposit extends southward for 5 or 6 miles along Little Bitterroot River, through a gap between the rocky hills, to the head of the sharp inner gorge near the Prairie Pine dude ranch (sec. 8, T. 26 N., R. 24 W.). When the ice front stood at the moraine near Marion the glacial waters flowed southward over this outwash terrace to a branch of glacial Lake Missoula in the Little Bitterroot Valley. Laminated lacustrine silt was observed in one road cut a short distance east of the Prairie Pine ranch. The presence of some low knolls, and kettle holes pitting the terrace, several miles southwest of the moraine is an indication that the ice may have extended that far beyond the moraine.

That the Ashley Creek glacial lobe actually advanced up the valley from the vicinity of Kalispell is shown by the character of the glaciated ledges exposed in places along the railroad and the highway (US 2) between the villages of Kila and Marion. Protruding edges of the glaciated rocks are generally smoothly rounded on their eastern or downstream sides. Striae observed near Kila trend S, 35° to 40° W., and farther west where the valley curves the striae trend nearly due west. Almost directly south of these striae a glaciated ledge in the mouth of the valley of Mount Creek, 3,125 ft above sea level (sec. 25, T. 27 N., R. 23 W.) shows, by striae trending nearly due south, that a small branch of the glacier diverged and extended southward up this valley. For 5 or 6 miles along the creek and road there is much glacial till exposed in places in the woods, and in secs. 13 and 14, T. 26 N., R. 23 W., the creek cuts through a bulky terminal moraine about 3,900 ft above sea level. South of the moraine are meadows in a flat-bottomed basin which probably contained a temporary lake 2 or 3 miles long. When the ice stood at the moraine the water may have been ponded high enough (about 4,200 ft above sea level) to spill over the divide southward to an arm of glacial Lake Missoula in the valley of Sullivan Creek, a tributary of the Little Bitterroot Valley. Striated pebbles, probably dropped from floating ice, are found near the road in places farther south.

The valley of Porter Creek to the west shows that an ice lobe extended southwestward up that valley and deposited a terminal moraine which forms the dam holding Lake Rogers, 3,700 ft above sea level, about 3 miles southeast of Marion. There is also an outer moraine, probably of pre-Wisconsin age, bordered by an outwash gravel terrace at a ranch in the through valley 2 to 3 miles southwest of the lake. These outer deposits were partly cut away during the Wisconsin stage by the glacial water that escaped to the Little Bitterroot Valley through this spillway when the ice front stood at the moraine at Lake Rogers. The valley of Truman Creek to the east, which has not been examined by the writer, may have contained a similar ice lobe.

It seems probable, also, from the general relations described above, that one branch of the Ashley Creek glacier diverged 4 to 5 miles east of Marion and crowded northward into the upper valley of Ashley Creek and there deposited the great fill of drift that holds Ashley Lake, about 3,900 ft above sea level. It is not known that glacier ice invaded the lake basin from the north or east. The ice from the south, however, may have extended as far north as the lake. For nearly 5 miles below the lake the fill in the valley is flat and about a mile wide, with no evidence of a moraine, as far as noted from the road. There is a low morainelike crest just north of Monroe Lake, about 3,650 ft above sea level. The road from the main highway to this crest is graded all the way on glacial till.

The Ashley Creek ice lobe and its branches are here considered as of Wisconsin age. However, similar lobes may have occupied the branching valley at least once during pre-Wisconsin time.

The maximum thickness of the ice at the site of Kalispell during the Wisconsin stage was probably at least 2,500 ft. If the surface of the ice there was about 5,500 ft above sea level, the average down slope westward for 20 miles to the top of the moraine near Marion would be about 75 ft per mile, a slope quite adequate to cause the ice to advance up the several valleys, as described above.

With 5,000 ft of ice in the valley of the Kootenai River at the international boundary, as estimated by Daly, the surface of the glacier there would be about 7,300 ft above sea level. With 3,000 ft of ice at Bad Rock Canyon and Columbia Falls, the surface there would be about 6,100 ft above sea level and probably about the same level near Whitefish. The average slope of the surface of the trunk glacier as far as Whitefish, nearly 60 miles southeast of Gateway, Mont., where the international boundary crosses the Kootenai River, would thus be about 20 ft per mile; from Whitefish to Kalispell, 15 miles, the slope would be about 40 ft per mile; from Whitefish and Columbia Falls to the terminal moraine (3,100 to 3,500 ft above sea level) near the foot of Flathead Lake south of Polson, a distance of 50 to 55 miles, the slope, including the steeper front slope, would average about 50 ft per mile. At the north end of the lake the surface of the ice was probably about 2,200 ft above the present lake level, which varies between 2,885 and about 2,930 ft above sea level; at the south end, 27 miles farther south, the ice surface was 850 to 1,000 ft above lake level, or 250 to 500 ft higher than the crest of the Polson moraine 1 to 2 miles farther south. The thickness of ice indicated was competent to do considerable scouring of the rocky basin but not to wear away the rock masses that form the islands and parts of the peninsulas in the southern half of the basin. As shown by soundings, the depth of the lake itself ranges from a few feet to 329 ft (Clapp, 1929, pp. 4 and 5).

THE POLSON MORAINE AND ASSOCIATED DEPOSITS

There are traces of a terminal moraine, here named the Polson moraine, encircling the relatively low hills and the flat 3 to 5 miles west of the south end of Flathead Lake. South of the gorge of Flathead River the terminal moraine is better defined and extends eastward, as a bulky ridge of drift, to the foot of the Mission Range. The higher parts of the moraine crest south of Polson are 3,400 to 3,500 ft above sea level, or about 500 to 600 ft above the lake. Shallow cuts on some of the roads crossing the ridge and cuts on the railroad expose very stony till and coarse waterworn gravel. The writer has no data indicating whether or not there is a rock core buried in the ridge southeast of Polson. Rock is exposed at lower levels where Flathead River has cut through the moraine, and the sides of the gorge afford very interesting exposures of the rock and of drift older than the moraine.

At the Polson dam site in SW 1/4 sec. 12, T. 22 N., R. 21 W., the gorge is about 500 ft deep and very narrow (fig. 21). For 2 to 3 miles farther upstream the bluff on the south (left) side is about the same height, but as the stream cut down it shifted southward, so that the north side is a more gradual, though steep, slope, dropping to two terraces, one about 50 and the other 100 ft or so above the stream. Rock is exposed at intervals on this north slope, and for 3½ miles the narrow inner gorge below the terraces is largely cut in rock. The stream plunges in places as rapids and low cascades. The surface of the rock, as exposed in the bluffs, is very uneven, ranging from several hundred feet above to an unknown depth below the stream. The uneven surface of the rock is overlain by deposits of glacial drift having a maximum thickness of 500 ft or more. Deposits exposed in the bluffs above and below the Polson dam site in secs. 13, 11, and 15, T. 22 N., R. 21 W., are described on page 93. They include two sheets of pre-Wisconsin till separated by stratified deposits; the upper deposit is overlain by whitish, laminated, lake silt of Wisconsin age. Part of these deposits are close to, but outside of, the Polson moraine.

Just below the Polson dam the narrow inner gorge makes a right-angle bend from northwest to southwest, its direction evidently being controlled by the joints that cut the northeast-dipping Belt rocks. The relations suggest that within a mile south of the dam the gorge cuts across an older drift-filled valley, for the rock surface as exposed declines southeastward and passes below the present stream level. Here the entire 500-ft bluff is composed of glacial till and gravel (fig. 21).

About 3 miles southwest of Polson, in sec. 20, a road cut through the outer crest of the moraine exposes fine, rippled sand, partly crumpled and interbedded with coarse gravel. Much gravel has been taken from pits not far west of this place. The surface of the moraine is in general fairly smooth and is not marked by knobs and kettle holes. It is probable that the valleys of the Clark Fork and the Flathead River were flooded by the waters of glacial Lake Missoula while the Polson moraine was being formed, for not only are lake shore lines plainly marked on smooth parts of the grassy hill slopes south and west of the basin, south of the moraine, and on the smaller hills east of the river within the Flathead basin, but there are also shore lines in places on the south slope of the Polson moraine itself. The lake waters may even have laved the front of the glacier, and the moraine may have been deposited in the lake. The maximum height of the glacial lake at this time is not known. The high terrace west of the moraine on both the north and south sides of the river gorge at the Polson dam is capped with 5 to 10 ft of laminated lacustrine silt at 3,200 ft above sea level overlying till (fig. 18). This silt, however, does not necessarily indicate the upper limit of the water at the time it was deposited. Similar silt overlies till in places between the Polson moraine and Crow Creek inside (north of) the Mission moraine. As indicated above, however, the lacustrine silt does not, so far as the writer has observed, cover the top of the Mission moraine, even where it is less than 3,000 ft above sea level. It is not clear why the silt does not cover the moraine if it was deposited while the lake level was so high as to overtop it by several hundred feet. At the south foot of the Polson moraine, north and east of Pablo Reservoir, there is a terrace underlain by coarse gravel, as though the moraine was there bordered either by streams or by shal-

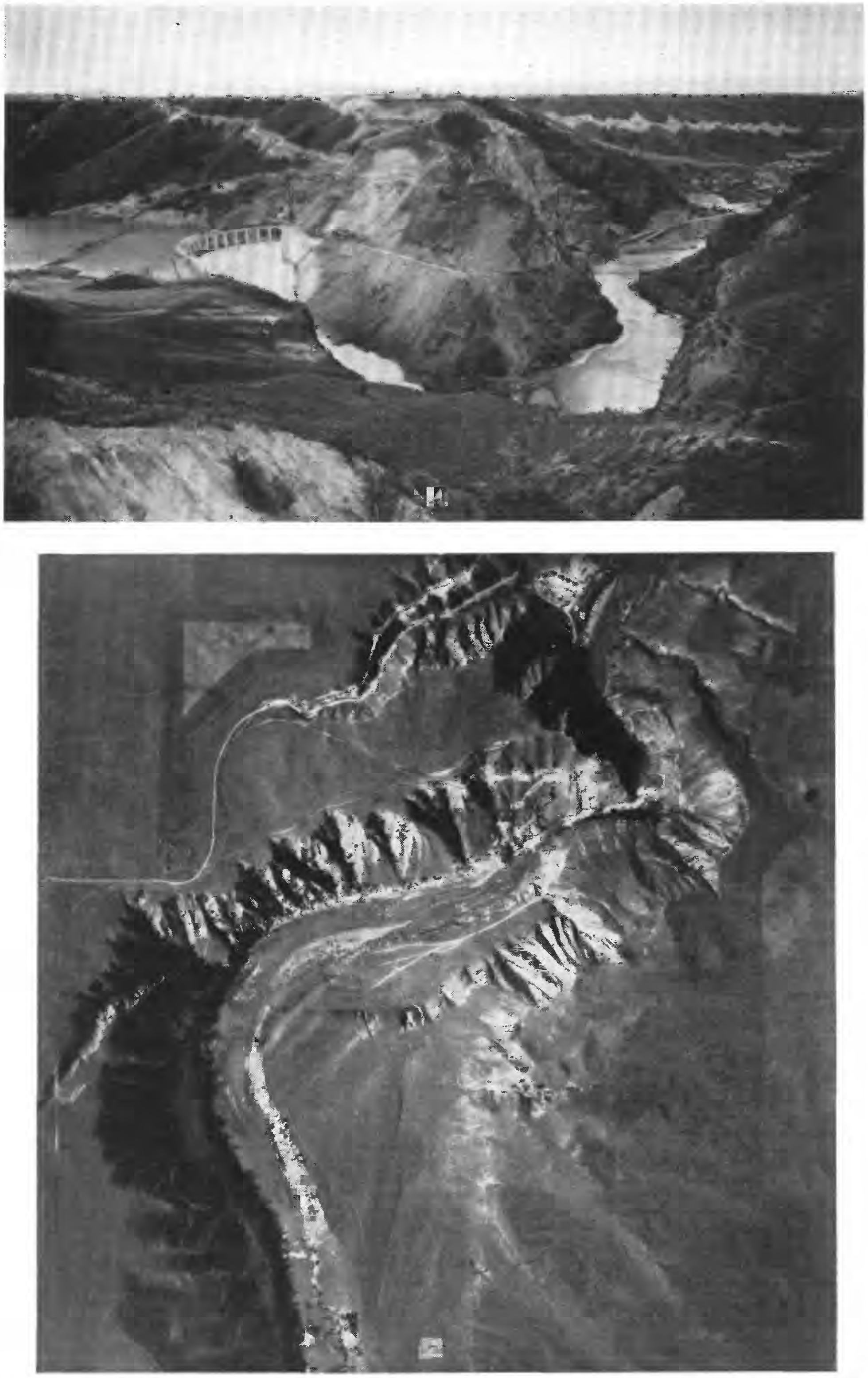

FIGURE 21.—Postglacial gorge of the Flathead River below Polson. *A*, Cut through drift-covered rock of the Belt series at site of Montana Power Co. dam. Photograph by McRay Art Co. *B*, Vertical photograph of the gorge before construction of the dam showing the river cutting in rock at the dam site near the sharp bend and the rapids above the bend at the left. Between these bends no rock is exposed, suggesting the presence of a preglacial valley filled with several hundred feet of drift. Photograph by courtesy of F. F. Henshaw of the Federal Power Commission.

low rather than deep lake water. Some of the fine sandy silt has been blown into low swells or dunes south and north of the village of Pablo, and some has been blown up on top of the coarse gravel of the terrace.

The Polson moraine curves northeastward to northward as it approaches the Mission Range. Five or six miles east of Polson an abrupt slope rises 100 ft or so to a narrow dissected terrace on which is the Allard irrigation ditch; above this terrace are two other steps separated by risers 100 ft to several hundred feet high. Stebinger states in his field notes (1911) that, as seen from the lake, there appear to be three lateral morainal ridges, with southward slope, in the woods within a height of 400 or 500 ft above the lake.

The present writer went up the steep slope just north of Big Creek and up over two or three benchlike steps on the upper surface to the top of this foothill tract about 600 ft above the lake. The surface is obscured by woods and brush but appears to be underlain by drift. Rock is exposed in the bluff just above the road 1 to 2 miles north of Big Creek so the great benchland tract evidently is due only in part to glacial deposits.

As seen from the rock hill near the north extremity of the peninsula the wooded bench above the lower slope east of the lake appears quite extensive. Several glaciated gulches hang above it, and perhaps moraines of one or more local glaciers lie upon it. This bench appears to extend northward to a point about opposite the north end of the peninsula. The relations suggest that this bench remnant corresponds to those remnants farther south that are thought to be parts of a Pliocene or Pleistocene piedmont terrace at the west foot of the Mission Range. Thence northward there is a succession of glaciated gulches hanging high above the lake and at a fairly uniform height, probably several hundred feet above the shore. For several miles south of Swan River there is quite definite benching on the flank of the Mission Range. Doubtless there was a good deal of scouring along this flank by the southward-moving Flathead glacier. Figure 22, reproduced from W. M. Davis' paper (Davis, 1920, fig. 5, p. 93; 1916, pp. 267–288) shows diagrammatically the relations of the Polson moraine to small glaciated gulches on the northern part of the Mission Range.

While the ice front was at the Polson moraine one arm of glacial Lake Missoula extended up the valley of Irving Creek 10 to 13 miles west of Polson. Through a narrow gap leading to this arm were glacial waters discharged from the minor ice lobe that extended to a terminal moraine 4 miles southwest of the village of Big Arm. The valley is floored with whitish lacustrine silt. No evidence indicating that any glacier invaded this valley was found, although the Flathead glacier may have blocked the mouth of the basin 6 to 10 miles southwest of Polson during a pre-Wisconsin stage. Striated pebbles and boulders scattered on the slopes above the clay flat were probably dropped from icebergs floating on the glacial lake. The lake shore lines are plainly marked on the smooth grassy slopes at the east side of the basin.

Another and much longer arm of glacial Lake Missoula extended up the Little Bitterroot Valley past Niarada to the Hubbart Reservoir site in Tps. 25 and 26 N., R. 24 W. To this arm came silt-bearing waters from several small sublobes of the Ashley Creek glacial lobe while they stood at the moraines near and southeast of Marion.

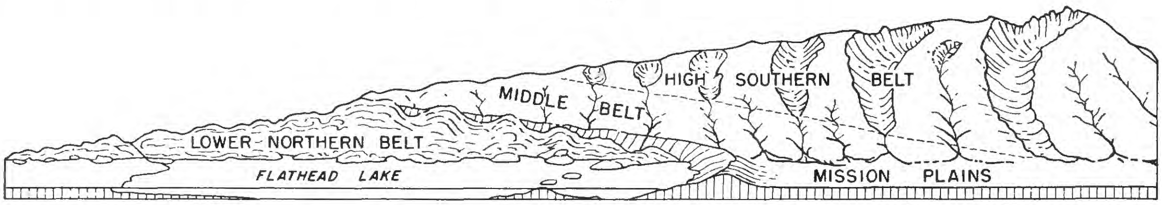

FIGURE 22.—Diagram of Mission Range, looking east. (After W. M. Davis.)

When the ice of the Big Arm sublobe crowded westward, the Big Draw (fig. 23) was completely blocked, as it was probably blocked during earlier stages of glaciation. Part of the great morainal deposit west of Elmo (fig. 24) is probably, therefore, of pre-Wisconsin

FIGURE 23.—Big Draw, an abandoned outlet (Tertiary?) of Flathead basin now blocked by a terminal moraine (not in photo) west of the Big Arm of Flathead Lake. A filling of outwash gravel extends westward from the moraine to the valley of Sullivan Creek (foreground) where there is a whitish silt deposit of glacial Lake Missoula. Lake shore lines are well marked on the grassy hillslopes for hundreds of feet above the bottom land. View east from the hill north of Niarada.

FIGURE 24.—Terminal moraine of the Big Arm sublobe of the Flathead glacier. View east from bordering outwash gravel plain in the Big Draw.

age. The uneven top of the moraine in places is about 600 ft above the level of Flathead Lake, that is, 3,400 to 3,500 ft above sea level. O. E. Meinzer (1917, p. 16) states that a well 560 ft deep in the Big Draw at the Floyd Frye ranch (NE¼ sec. 22, T. 24 N., R. 22 W.), which is on the moraine, passed through bouldery unconsolidated deposits to a level considerably below Flathead Lake without reaching bedrock. Wells near the lower end of the Big Draw in the vicinity of Niarada, 200 ft or so in depth did not reach bedrock but were in sand or gravel at the bottom.

The higher stands of the glacial lake in the valleys of Little Bitterroot and Flathead River, which made the upper shore lines that are so well marked on the grassy hills up to altitudes of 3,800 ft or more, may have occurred during pre-Wisconsin stages of glaciation, perhaps when the Flathead glacier extended to or beyond the Mission moraine and blocked the mouth of the Little Bitterroot Valley west of Sloan.

It is significant that, so far as the writer has observed, the higher shore lines of Lake Missoula—that is, those more than 3,200 ft above sea level—are not present anywhere in the Flathead basin north of T. 24 N., in which is the Big Draw. This is in accordance with the suggestion that the higher stages of glacial Lake Missoula, those between 3,200 and 4,200 ft above sea level, occurred before (and some of them a relatively long time before) the front of the Flathead glacier was melted back northward from the Polson moraine.

Extensive deposits of laminated white silt have been observed as far north as a point 5 miles northwest of Niarada. The same white silt extends several miles up the valley of Sullivan Creek north of Niarada (fig. 23). These silt deposits are mostly, if not all, below an altitude of 3,200 ft, although the lake shore lines are plainly marked on the surrounding grassy hill slopes up to altitudes several hundred feet higher. A lobe of the Flathead glacier extended westward up the Big Arm embayment, crowded into the head of the Big Draw, and deposited a great crescentic terminal moraine in this outlet between 1 and 3 miles west of Elmo. From the west front of this moraine (fig. 24), about 3,300 ft above sea level, a valley train of coarse bouldery outwash gravel extends down the Big Draw to the white clay flat in the valley of Sullivan Creek north of Niarada (fig. 23).

It would seem that the Little Bitterroot arm of glacial Lake Missoula could not have been standing much higher than 3,100 ft above sea level at the time this coarse gravel was being swept westward through the Big Draw during the Wisconsin stage. The white laminated lacustrine silt does not extend eastward into the Big Draw nor much above an altitude of 3,000 ft.

O. E. Meinzer (1917, p. 16) states:

> The bouldery gravel bed thins out downstream, and near the mouth of the draw (NE¼ sec. 20, T. 24 N., R. 23 W.), it gives way abruptly to typical fine-grained lake beds, under which it apparently passes. In the well of P. E. Poe (N½ sec. 27, T. 24 N., R. 23 W.), the bouldery deposits are only 8 feet thick and are underlain by about 50 feet of fine, dry, mealy sand, below which lies 1 foot of sticky blue clay, 2 feet of moist quicksand, and next water-bearing sand and gravel resting on clay. These conditions indicate a somewhat complicated glacial history.

Certain other features in the vicinity of Dayton and Elmo are of interest in this connection. On the steep hill slope back of A. E. Hurlbutt's house, about 2 miles east of Dayton, there is a distinct narrow bench. It is not horizontal but slopes gently northwestward from an altitude of about 4,200 ft (barometric), or 1,300 ft above the Flathead Lake. It is apparently a marginal terrace formed when the sublobe of the glacier crowded around the rocky point to the east and extended northwest up the valley of Dayton Creek. It lies across the mouths of gulches and is marked by small, poorly drained basins, or hollows. Glacier drainage traversing this terrace may have joined water impounded by the ice lobe in the upper valley of Dayton Creek and have escaped thence by way of a temporary spillway past Sheep Rock, 3 miles west of Dayton. A narrow V-shaped gap is cut in the crest of the rock ridge below a bench at the base of the Sheep Rock cliff. From this gap a spillway extends southwestward toward a notch at the north end of the terminal moraine in the Big Draw west of Elmo. Great masses of rock obstruct this spillway, as though they were undercut and either slumped down from Sheep Rock, or were displaced by push of the glacier ice.

Striated pebbles and boulders of Belt rocks scattered on the slopes bordering the upper courses of Sullivan Creek and the Little Bitterroot River and on the hill slopes northwest of Niarada, high above the lacustrine clay flats, were probably dropped from floating ice that came either from the glaciers to the north or from the ice front at the moraine in Big Draw. This may be the source of the boulders found on the slopes of the Little Bitterroot Valley northeast and southeast of Camas Hot Springs. Boulders of granitic rock, 3 ft in diameter, beside the road about 6 miles southeast of Hot Springs are erratics of doubtful source. They are less than 100 ft below the pass to the south, or 3,300 to 3,350 ft above sea level. Associated with them were striated quartzite cobblestones. Any or all of the erratics noted in the Little Bitterroot Valley may have been dropped from floating ice during a pre-Wisconsin stage of glaciation. Some of them may lie too high to be correlated with the Wisconsin stage of the lake.

When the fronts of Ashley Creek glacier west of Kalispell and its several sublobes melted back down the valley from their terminal moraines there was doubtless considerable water ponded locally in the valleys, which was drawn down to the level of the lake in the Kalispell Valley as soon as outlets were available. One indication of this ponding is the laminated lacustrine silt that overlies till and stratified gravel at an excavation about 3 miles north of Smith Lake. This silt may have been deposited when the Ashley Creek lobe had become so shortened that it extended only a mile or two into the mouth of the valley west of Kalispell and was building the knolled moraine that forms the foothills to the north and also surrounds the basin of Foy Lake to the south. Just where the south end of the Flathead glacier was at that time is not known. Probably it was somewhere in the basin now occupied by Flathead Lake. There is some basis for the suggestion that the ice front, after melting back from the Polson moraine, stood for a time at the Allard peninsula in the southeastern part of the basin; it may have extended northwestward near the islands and thence northward along the hills to the moraine at Foy Lake. A rather smooth, pitted-topped, and wooded ridge of gravelly drift extends northwestward along the Allard peninsula to the rock hills at the north end. Probably the lake south of the ice front at first overtopped the smooth ridge and later, as the outlet near Polson was cut down, the water level dropped to the terrace on the south side of the peninsula, which is capped with beach gravel along the road 50 to 60 ft above the present lake. Probably the east margin of the Flathead glacier stood at the moraine that extends from the rock hills near the village of Bigfork northward to Lake Blaine, and the bordering lake was still high enough for the laminated silts at the top of the bluff south of Bigfork to be deposited about 3,000 ft above sea level. Not until later was Swan River reestablished and its valley cut down as the lake dropped by stages, forming the well-defined terraces at Bigfork about 2,975, 2,950, and 2,900 ft above sea level.

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KALISPELL MORAINE AND TERRACES

On the plain west of Stillwater River there is a belt of kettle holes and ponds, swells and swales, and gravel knolls, which has been traced for 8 miles to Kalispell. This is evidently a lateral moraine, here named the Kalispell moraine, formed when the ice had melted out of the Flathead Lake basin and the glacier front had receded to the site of Kalispell. East of Kalispell the corresponding terminal moraine has been very largely cut away by the three rivers, leaving only dissevered remnants; one is the ridge on which the golf links are laid out, north of town. Stillwater River is cutting at the northeast end of the moraine, having already cut entirely through the ridge and into the head of the Kalispell terrace on the south, at the bend where it swings eastward.

East of this gap and the road (US 93) is another ridge with a big gravel pit in its west end and an old water tower and triangulation station on it farther east near the railroad. On top of this hill near the tower are kettle holes. The top of the ridge is 50 ft or so above the big upper terrace to the north between Stillwater River and Whitefish River, and it is high above the Kalispell terrace to the south. This latter terrace is underlain by chocolate-colored, laminated silt which is well exposed in the railroad cut half a mile south of the old tower and at the adjacent slope and brickyard. Coarse gravel is exposed on the steep hill slope just south of the tower, and overlapping it at the foot is the same laminated silt. East of the tower there is an erosion gap through which the railroad extends southwestward from the lower to the higher terrace. East of this gap there is another morainal hill (about 3,050 ft above sea level) and a bit of the bordering terrace is the site of Conrad Memorial Cemetery, 60 to 70 ft above the lower flat. East of the mesalike remnant is a gap 1½ miles wide through which Stillwater and Flathead Rivers flow. On both sides of this gap the upper terrace has been cut away over a width of several miles and the streams are meandering over a plain 50 to 100 ft below it. Cuts at the upper terrace east of the bridge on U. S. Highway 2 expose coarse gravel and boulders. Just east of the old bridge and south of the newer one, Flathead River is now cutting into a ridge about a mile long, which appears to be another remnant of the Kalispell moraine. Beds of loose sand and gravel dipping downstream and partly overlain by laminated silt are exposed in the bluff. For more than a mile to the south and for 3 miles east of the river the broad upper terrace has been cut away and lower plains have been developed. At one time the river apparently meandered over this tract. Farther east and southeast a great area of the smooth flat upper terrace is preserved between the lower flat and the older lateral moraine on the east, south of Lake Blaine.

Farther north meanders of the river have cut deep reentrant scallops into the west edge of the terrace, and the east lateral of the Kalispell moraine has been very largely obliterated. There are, however, a few isolated morainal hills at salients between the scallops of the upper terrace east of the river. The surface of one, 4 miles west of Lake Blaine, is somewhat uneven, contains boulders, and is underlain by till. There is a similar hill about a mile farther north, and about 4 miles south of Columbia Falls the main north-south highway crosses another such hill. The uneven surface is bouldery and a road cut exposes 10 ft of glacial till. To the north and east a belt of low swells gives an appearance of morainal topography, but some of these swells are low sand dunes on the broad upper terrace. A cut in one hill slope exposes till below a thin coating of dune sand. A pitted tract bordering the foot of the Swan Range for a few miles south of the mouth of Bad Rock Canyon may be the northward continuation of either this inner moraine or the outer morainal belt. The morainal hills and terrace remnants indicate that for a time the narrowed south end of Flathead glacier stood near the site of Kalispell and was bordered on the south and east by a lake. This lake may have been the northward extension of glacial Lake Missoula, but later, after glacial Lake Missoula was lowered, it probably became a separate lake dammed by the Polson moraine, first at an altitude of about 3,200 ft and later at successively lower levels. The terrace remnants marking these lower levels are between 2,900 and 3,000 ft above sea level. In this lake the laminated silt underlying the upper terrace was deposited.

While the ice stood at the Kalispell moraine, water from the upper Flathead drainage basin issued from Bad Rock Canyon and flowed southward between the east margin of the ice and base of the Swan Range into the lake. The coating of dune sand was not deposited until after the ice had melted away, the lake had been lowered, and the drainage had shifted farther west.

East of Goodrich Bayou, about 7 miles northeast of Kalispell (in the SE¼ sec. 14, T. 29 N., R. 21 W.), there is a small flat-topped butte, locally known as Bernard Butte, standing 75 to 100 ft above the west bank of the Flathead River at an altitude of 3,000 ft. It is apparently an erosion remnant cut off by the river from the broad plain above the bluff on the east. Thirty feet of compact gray till is exposed in a bare scarp above the talus at the northeast corner of the butte. This till is overlain by about 25 ft of fine stratified sand with interbedded thin layers of clay. Some till is present in the lower part of the west side of the butte. The till apparently slopes southward and is below river level beneath the bare scarp at the southern end of the east side of the butte. At this place brownish laminated clay is exposed 1 to 5 ft above the surface of the water and apparently extends back under a thick deposit of fine sand, which is so loose that it is continually sliding down the face of the bluff into the river. No boulders were seen on top of the butte. Apparently the fine sand and silt were deposited in the lake, which was extended northward as the margin of the glacier melted back from the Kalispell moraine.

About a mile farther north on the west side of the river (in SW¼ sec. 11, T. 29 N., R. 21 W.) there is another hill, a cut-off remnant of the Kalispell moraine or the upland to the east. It displays no clean scarps, but glacial till is exposed on its southeast slope near the top, 50 to 75 ft above Goodrich Bayou. Its west slope is coated with sand. On north end of the flat is a boulder 10 ft in diameter. About 3 miles farther north a similar hill (in sec. 27, T. 30 N., R. 21 W.) has been cut off from the bluff on the west of Whitefish River.

West of the mouth of Bad Rock Canyon is a northwest-trending ridge of drift standing high above the adjacent gravel terrace. This ridge is probably part of a lateral moraine extending northwestward beyond Columbia Falls and on toward Whitefish Lake. The ice may have stood along this northwesterly moraine while the Kalispell moraine was being formed.

At the river bend about half way between Columbia Falls and the mouth of Bad Rock Canyon the north bluff below the gravel terrace exposes the following section:

Bluff section northeast of Columbia Falls

	Feet
4. Gravel, coarse cobble stones partly stratified	40±
3. Glacial till	15±
2. Sand stratified; cross-bedding dips east to southeast	20±
1. Glacial till and talus	25±
Total, about	100

Of these, deposit 1 is probably pre-Wisconsin till; deposit 2, a glacial delta formed in a pre-Wisconsin marginal lake during recession of the early Flathead glacier; deposit 3, Wisconsin till corresponding to the Polson and Kalispell moraines; deposit 4, alluvial gravel deposited by the Flathead River as it issued from Bad Rock Canyon following recession of the ice from the Kalispell moraine and the lowering of the glacial lake. At the slumping west end of the cut an exposure of greenish argillite measuring 15 by 30 ft protudes from the gravel; a big block of similar argillite has fallen below. The pebbles in all four deposits are red and green argillites, quartzites and limestones of the Belt series, and lava and diorite, such as compose the mountains in and near Glacier National Park. The big rock masses were either dropped directly by the glacier or were carried out on floating ice with a rush of water suddenly released in or above the canyon.

As the ice front receded, gravel was washed westward and formed the uppermost of three terraces on which the town of Columbia Falls is built. In a road cut at the eroded edge of this terrace 1½ miles west of town fine stratified gravel and sand was exposed, but farther south, cuts showed coarse gravel.

In the bluff about a quarter of a mile southwest of the old bridge south of Columbia Falls 15 to 20 ft of coarse gravel and about 5 ft of bouldery gravel are exposed, overlying glacial till whose top is about 25 ft above the river. West of this exposure the bluff curves to the southwest and south, and between it and the river are two lower terraces that curve southeastward. North of the main line of the Great Northern Railway, near the town, a broad abandoned channel transects the terrace and extends westward to the end of the lower terrace, as though the river started cutting there when the lake began to lower and later was shifted to its present course south and east of town.

EARLY STAGE OF FLATHEAD LAKE

From Kalispell the lacustrine terrace slopes gradually southeastward nearly to the level of Flathead Lake, and in places, as at Demersville Cemetery and about a mile northeast of there, low hills of drift rise above the surrounding terrace. When the outlet through the Polson moraine was being cut down from an altitude of 3,200 ft, first to one of about 3,000 ft and later to the present lake level about 2,885 ft above sea level, the Flathead River and its tributaries swung from side to side and cut away the silt underlying the great terrace east of the Somers branch of the Great Northern Railway. As the last stage of lowering involved the slow process of cutting a gorge 115 ft deep in Belt rocks, the rivers north of the lake had ample opportunity to broaden their valleys. From a gently sloping plain the terrace was cut down to a lower flat plain, and as the river shifted eastward its meanders cut great scallops in the marginal bluff of the original glacial-like terrace. In one of these scallops lies the abandoned ox bow known as Eagle Slough; the encircling bluff, which is 2 to 3 miles west of Creston, exposes 40 to 60 ft or so of laminated silt below the lake terrace. The slough at the head of the ox bow is about 90 ft below the upper lake terrace, whose altitude is about 2,960 ft in the SW¼ sec. 18, T. 28 N., R. 20 W. From a point half a mile south of Creston toward Holt ferry, northwest of Bigfork, the lake terrace has been so thoroughly cut away that the lower flat now extends eastward to the low rock hills north of Swan River and nearly to the east lateral moraine which extends from these hills northward to Lake Blaine.

Examination of an unpublished detailed topographic map leads to the tentative conclusion that the silt terrace south of the Kalispell moraine originally sloped gently southeastward to an altitude of about 2,920 ft above sea level along a line extending southwestward from the vicinity of Mill Creek southeast of Creston to a point about a mile north of Somers. If this was so, when the water stood at the 2.920-ft level the head of Flathead Lake was 6 or 7 miles north of its present location and near the present south edge of the upper silt terrace south of Creston.

For a time the reestablished upper Flathead River may have flowed southward from Bad Rock Canyon, east of Columbia Falls, near the foot of Swan Range and past Lake Blaine, entering Flathead Lake by the present valley of Lang Creek east of Creston. At the time of the recession of the ice front from the Kalispell moraine, however, the river shifted to approximately its present course south of Columbia Falls and cut through the Kalispell moraine at the gap 1½ to 2½ miles east of the Kalispell bridge. There is, in adjacent parts of secs. 11, 12, 13, and 14, T. 28 N., R. 21 W., a terrace remnant of the old channel of this stage about 2,925 ft above sea level. The meandering of the stream during this stage started cutting the great scallops at the western side of the eastern prong of the Kalispell moraine and of the emerging upper silt terrace. Stillwater River probably cut through the moraine at the gap between the railroad and the hill to the east, on which is Conrad Memorial Cemetery. When Whitefish River was formed by water from the melting ice, the two streams joined to flow through the gap east of this hill. Flathead River continued to flow through the gap east of the new bridge until the lake lowered to an altitude of about 2,910 ft. A large remnant of the valley bottom of this 2,910-ft stage remains in adjacent parts of secs. 1, 2, 11, and 12 of T. 28 N., R. 21 W., and extends eastward to the low curving bluff bounding the upper terrace in the western parts of secs. 6 and 7 of T. 27 N., R. 20 W. As the arm of the lake that had extended up the valley of Ashley Creek was drained, Ashley Creek extended its course and entered the lake about a mile north of Somers. The abandoned part of this course remains south of Demersville; Ashley Creek now joins the Flathead at a point 4 miles farther north.

The present flat northwest of the 2,910-ft shore line between Mill Creek and Somers appears to be the result of extensive meandering and lateral erosion by the several tributary streams as they shifted their channels from side to side. Egan, Church, Half Moon, and other crescentic sloughs lie in some of these abandoned ox-bow channels related to this shore line. The silt derived by this erosion, with that which continued to come from the melting glacier, was swept southeastward and eastward and redeposited in the head of the lowering lake, building a succession of deltas, as shown by the detailed topographic map. It eventually filled the north end of the lake to its present shore line. Some of the hollows in this part of the flat are places left unfilled between the arms of these deltas; some are unfilled portions of the abandoned channels. The old 2,910-ft shore line extended northeastward from the rock hills at Somers to the river bank about a mile below Therriault ferry.

The Flathead River swung eastward to the head of the lake when it was 1 to 2 miles south of Creston and, as the lake lowered, its course was diverted by the hills of drift and rock on the east and extended southward to become well established between the hills of rock north of Holt ferry. Feenan Slough is an abandoned ox bow cut off by the present more direct channel north of one of these rock hills.

MORAINE AND TERRACES NEAR WHITEFISH

In the vicinity of Whitefish and to the west along the U. S. Highway 93 in Stillwater valley a well-formed recessional moraine dams Whitefish Lake. Evidently the ice front remained at the south end of the basin of Whitefish Lake long enough to form this moraine and the bordering outwash terrace, 3,000 to 3,100 ft above sea level (barometric), on which the higher parts of the town, east and west of the river, are built. The material exposed in a big gravel pit west of the river and north of the cemetery is coarse, cross-bedded gravel containing boulders 1 to 5 ft in diameter. The rock fragments are mostly of the Belt series: maroon and green argillite, quartzite, and some limestone. In the northern part of the pit thinly laminated lake silt overlies the coarse gravel. The moraine is banked against the rock hills on the southwest and west. A broad gap has been cut through the moraine; the lower terrace that borders the river on the west and on which the lower part of the town is built, extends northward through the gap to the south shore of Whitefish Lake.

About 5 miles west of Whitefish the U. S. Highway 93, at an altitude of about 3,150 ft, crosses what is probably part of the same moraine just west of the rock hills. The Stillwater River appears to have cut its inner valley here through a great fill of glacial drift. Near the highway this drift is pitted with kettle holes, and remnants of an outwash terrace remain above the lower flat. The outwash from this part of the moraine was swept southward into the lake that was held in Stillwater valley for a time behind the Kalispell moraine.

From the Roosevelt Highway, 4 to 7 miles west of Columbia Falls, southward to the mouth of Stillwater River near Kalispell, Whitefish River is bordered on the west by the upper terrace described above. Like the terrace east of Flathead River, this western terrace is partly coated with dune sand mostly in the form of low swells or ridges. After the ice front had receded to the Whitefish moraine and the cutting of the outlets through the Kalispell and Polson moraines had lowered early Flathead Lake, the Flathead and Whitefish Rivers began trenching the plain. By meandering to and fro as the lake waters receded southward, the streams cut out nearly 100 ft of deposits over a width of 3 to 5 miles and developed the gravelly lower plain now traversed by the railroad most of the way between Columbia Falls and Kalispell.

The upper terrace on the west extends northward, but near the Great Northern Railway, west of Half Moon, a gently undulating ground moraine rises above it and extends northward to the foot of the mountains. There are some indications that Flathead Lake during its early stage was not lowered below an altitude of 3,050 ft before the retreating front of the Flathead glacier had reached the foot of the basin of Whitefish Lake and deposited the moraine there, for laminated lake silt is exposed at Whitefish near the railroad shops, and similar silt overlapping till is exposed near the stock yards east of town.

Where the highway cuts the edge of this terrace (SE¼ sec. 11), about 3 miles west of Columbia Falls, the dune sand is underlain by laminated lacustrine silt. A road cut in the NW¼ sec. 27 shows crumpled, laminated silt underlain by coarse, poorly sorted gravel. Near the middle of the W½ sec. 34, T. 30 N., R. 21 W, a road cut in the upper terrace exposes about 20 ft of finely laminated, lacustrine silt overlying 15 ft or so of very stony glacial till. Laminated silt is also exposed 5 to 6 miles father south-southwest in a cut east of Stillwater River in the NW¼ sec. 30, T. 29 N., R. 21 W., and laminated silt overlying gravel is exposed at the south end of this upper terrace, just north of the Stillwater River bridge north of Kalispell (SW¼ sec. 5, T. 28 N., R. 21 W.). There is 2 to 3 ft of silt overlying gravel on the lower terrace east of this cut.

An undulating ground moraine rises above the flat terrace west of the U. S. Highway 93 on the upper terrace between 6 and 12 miles north of Kalispell and on this upland a remarkable series of drumlins and drumloidal flutings (elongate ridges with drumlin trend) trends south-southeastward. There are a few similar drumlins in the gently undulating ground moraine area west (outside) of the Kalispell moraine in Tps. 28 and 29 N., R. 22 W. The beautiful "stream-lined" contours of these hills, the result of overriding by the moving ice, are mostly unbroken by subsequent gullying (figs. 25

FIGURE 25.—Transverse profile of drumlin four miles southwest of Kalispell, Mont.

and 26). Inasmuch as there are a few drumlins south as well as north of the U-shaped Kalispell moraine, but

FIGURE 26.—Longitudinal profile of drumlin southwest of Kalispell, Mont. View looking east.

none south of the Polson moraine, it seems probable that the drumlins were developed as features of the ground moraine when the Flathead glacier was advancing to the Polson moraine during the Wisconsin stage.

A pitted morainal deposit dams the valley of Logan Creek at the foot of Tally Lake, which is said to be 200 ft or more in depth. When the ice front stood at this moraine the lake was probably high enough to extend southeastward, spill over a pass into Lost Creek, and thence flow to Flathead Lake.

In the hilly tract 4 to 5 miles wide east of Lower Stillwater Lake, the Flathead glacier of the Wisconsin stage was probably joined by a large glacier which occupied the upper Whitefish River valley between Stryker Ridge on the west and Whitefish Range on the east. This trough is 2,000 to 3,000 ft deep. Some ice may have come over the divide through two great notched passes at the heads of the east and west forks. It is probable, however, that these great notches were most severely scoured when pre-Wisconsin ice overwhelmed the whole range.

Between the moraine west of Whitefish and the point 4 miles farther north, where the Great Northern Railway turns west from Whitefish Lake through the gap between the hills, laminated silt is exposed in cuts on the highway and underlies a broad terrace. It is possible this silt was deposited after the ice front receded from the Whitefish moraine.

MORAINES NEAR STRYKER AND GRAVE CREEK

The next recessional end moraine of the Flathead glacier appears to have been between Stryker and Dickey Lake, at the divide (3,300 to 3,400 ft above sea level) between waters now flowing northwest to Kootenai River and those flowing southeast via Stillwater River. The great Flathead glacier had another eastern tributary, the upper Stillwater glacier, which occupied the branching mountain gorge now drained by the headwaters of the Stillwater River. When the ice front receded to the vicinity of Stryker this glacier became separated and ended at the canyon mouth. It formed a moraine of its own at the north ends of the rock-bound basins of Stryker Lake and Bull Lake. For a time the water from this glacier probably escaped southward through a gap in the hills. Finally the front of the Flathead glacier receded to the present divide north of Stryker and deposited a large moraine. Stillwater River then established its present course northeast of Stryker and cut a narrow lower gorge across the glaciated ledges of argillite. Most of the cuts in U. S. Highway 93 exposed compact stony till with a maximum thickness of nearly 50 ft. Some, which was so hard as to require blasting before a steam shovel could move it when the new grade was under construction, may be of pre-Wisconsin age.

Evidently water began to be ponded between the ice and the divide as soon as the glacial front receded from the moraine. Cuts near the head of Dickey Lake expose stratified lacustrine sand and silt, in places overlying coarse morainal gravel and in places crumpled. One cut beside the lake shows interbedded till and stratified gravel overlain by the silt. Silt overlaps the till slope near the north bay of the lake.

One of the best exposures of the lacustrine silt seen is about half a mile northwest of Murphy Lake, in or near the SE¼ sec. 6, T. 35 N., R. 25 W. (fig. 27). This cut, which is 5 to 8 ft in depth, showed very clearly what appear to be seasonal layers of typical varved clay overlying the uneven surface of stony glacial till, which was only slightly exposed in the bottom of the

FIGURE 27.—Glaciolacustrine silt overlying till deposited in the Rocky Mountain Trench in front of the retreating margin of Flathead (or East Kootenai) glacial lobe. The exposure is in a road cut northwest of Stryker near Murphy Lake.

cut. No pebbles were seen in the silt except in the lowest foot immediately above the till. The light-grayish layers deposited in summer range in thickness from 10 to 16 in. They split readily into quite definite layers, but are not distinctly laminated. Between the layers deposited in summer are 2-in. layers of denser and darker-colored silt that were deposited in winter. The lowest silt layer undulates gently over the uneven surface of the till and at the northwest (left in fig. 27) end of the cut, the ends of the strata are turned up and broken as though by the push of an ice front close by. The overflow of ponded water escaped southward through the narrow gap now traversed by the highway and the railroad north of Stryker. Probably a lake, which was retained by the receding front of a lobe of the Flathead glacier, extended far up the valley of Swamp Creek, as indicated by the presence of lacustrine silt overlying till in this valley. The laminated silts exposed farther south near the Olney railroad station are probably of pre-Wisconsin age, if not of pre-Pleistocene age. Fragments of fossil leaves and needles were found in them.

Still other glaciers tributary to the Flathead glacier headed in the Whitefish and Galton Ranges farther north than Dickey Lake. The largest occupied the branching canyon of Grave Creek. In the mouth of the canyon, 4 to 5 miles north of Fortine, there is a well-defined terminal moraine at an altitude of 3,200 to 3,400 ft. Through it Grave Creek has cut a narrow inner gorge nearly 300 ft deep. Remnants of an outwash terrace extend from this moraine westward on the north side of the creek and high above it. From the mouth of the inner gorge that cut through the moraine and outwash terrace, a lower broad gravelly flat extends southwestward to Tobacco River. Evidently the moraine and the upper terrace were formed after the front of the Flathead glacier had receded northward past the mouth of this canyon. The inner gorge and the lower terrace could not have been developed until the valley of the Tobacco River was wholly cleared of ice so that ponded waters found outlet to the Kootenai River.

There are deep, scoured notches in the divides at the head of three of the branches of Grave Creek. Through these notches, at some stage, glacier ice may have entered the canyon from the heads of the gorges of Wigwam River and Weasel and Yakinikak Creeks to the north and east. The notch at the head of the Yakinikak is more than 1,000 ft deep, though barely a mile wide at the top. As shown by the topographic maps of the Stryker and Kintla Lakes quadrangles, most of the gorges that gash the flanks of the Whitefish and Galton Ranges were tremendously scoured by the many branching glaciers tributary to the great Flathead glacier. Probably, as indicated above, the Salish Mountains to the west were mostly overridden by the Cordilleran ice, which at its maximum extended nearly as far south as Ashley and Little Bitterroot Lakes west of Kalispell. It is not known whether any local glaciers headed on this range.

The contours of the floor of the broad Rocky Mountain Trench between Dickey Lake and the vicinity of Glen Lake, as shown on the Stryker topographic map, suggest the presence of many small drumlins, but sufficient examination of this partly wooded tract was not made to determine how many of these small hills are strike ridges of rock shaped into drumloid form by the overriding Flathead glacier.

Recessional moraine deposits have been recognized near Black Lake and adjacent ponds along the hills west of Eureka; morainal deposits have been recognized also on the Tobacco Plains between Gateway and Phillips Creek to the east and between this creek and the Tobacco River to the south. Evidently the receding front of the Flathead glacier stood for a time about 3 miles north of Eureka and there deposited moraines. A peculiar feature of some of these deposits is that they were laid down upon and around drumlins that had been formed during the advancing phase of the glacier. Near Indian Creek (sec. 31, T. 37 N., R. 27 W.), there are well-defined knobs and kettle holes between drumlins, and almost directly to the west some drumloidal ridges have a peculiar knobby appearance owing to the deposition of morainal material upon them. Between 2 and 3 miles farther northwest the basins of Irene and Sophie Lakes, 2,505 ft above sea level, have resulted from the melting of ice blocks buried in morainal and outwash deposits. There are also numerous other large and small ice-block holes in the vicinity. As the front of the glacier narrowed, water flowed southward along the east side, as shown by gravel terraces and by abandoned channels leading to the Tobacco River. In the main channel, which Daly described as the old channel of Elk River, are the Roosville Road and, at the international boundary, the United States and Canadian Custom Houses.

When the ice front receded northward, the ponded water found lower outlets west to the glacial lake at altitudes of 2,500 to 2,600 ft in the Rocky Mountain Trench. Cuts along the Tobacco River and the Great Northern Railway below Eureka afford several good exposures of glacial, stream, and lacustrine deposits. Tobacco River is cutting into upturned Belt rocks at the dam site 3 to 4 miles northeast of Rexford and at several places farther east. Near the bridge below Eureka the north bluff exposes 50 to 60 ft of loose gravel, coarse and fine, with cross bedding dipping southward. This gravel is probably outwash from the ice front when it stood to the north. It is overlain by about 3 ft of stratified sand and silt, which caps the smooth flat terrace above the bluff. A short distance above the dam the railroad tunnel cuts through a narrow spur composed of compact buff-gray till. East of the tunnel a sharply incised meander has cut a narrow gorge through the till and into the Belt rocks. This meander is now cut off and the stream cuts through a narrow nearby spur of till for 50 ft, and into underlying gravel for 10 to 15 ft. This cut-off may have been made artificially when the railway was graded. A short distance east of the eastern tunnel, which is in rock, there is a big exposure of till so compact and hard that erosion has carved the face into remarkable sharp pinnacles and buttresses. Another nearby exposure in the south bluff appears to have similar features. This very compact till may be of pre-Wisconsin age. Cuts in the west edge of the upper terrace on the highway about 3 miles northeast of Rexford expose lacustrine silt overlain by stratified sand. Lower down near the Tobacco River a cut exposes till overlain by sand and gravel. A mile or two north of the river, coarse gravel cemented to hard conglomerate projects from the face of the bluff as ledges, and a short distance east between the highway and Lake Irene, drumloidal hills of glacial drift rise above the surrounding moraine and terrace.

When the ice front continued its recession northward into Canada and a lower outlet became available, the water ponded in the Kootenai valley was drawn off and the reestablished river began cutting away the valley fill. For 2 to 3 miles south of Gateway the lower terrace is of coarse gravel. From a 25-ft bank east of the road and railroad an intermediate terrace extends 1½ and 2 miles eastward to the foot of the uppermost terrace. Farther south both lower terraces are mostly cut away. Very few remnants of the upper terrace exist south of Rexford. There are some remnants of the intermediate terrace and much of the road to Libby (State Route 37) is on the third and lowest terrace. Both of the lower terraces are composed of stream gravel.

By the time the ice had melted from the northern part of the rocky ridge between Rexford and Eureka the valley of the Kootenai River was probably free of ice as far downstream as Bonners Ferry, Idaho, so that water previously ponded in the Tobacco River valley found outlet into the Kootenai River. It is of interest to note that the altitude of the upper terrace between Gateway and Rexford is about 2,500 ft, which is about the same as that of the upper terraces of the Kootenai River at Libby and Troy and of the pass at Bull Lake south of Troy. From this pass there was outlet south via Bull River to the Clark Fork. In Idaho, the upper terraces between Bonners Ferry, on the Kootenai River, and the Pend Oreille River and Lake are also between 2,300 and 2,500 ft above sea level, and the bottom of the pass at Elmira, Idaho, is about 2,150 ft above sea level. Apparently the fill in these two passes controlled the level of the glacial lake and the upper terraces to the east in the valley of the Kootenai River at least as far north as the Canadian boundary. The impounding of proglacial waters north of the divides in the several through valleys south of the valley of the Kootenai River and now tributary to it may be regarded as initial stages of a glacial Kootenai Lake as distinct from glacial Lake Missoula, but tributary for a time to it.

THE SOUTH FORK AND FLATHEAD GLACIER

It seems probable, from the general relations of the features described above, that by the time the front of the great Flathead glacier had been melted back to the vicinity of Whitefish, the several great branch glaciers occupying the valleys of the Middle, and South Forks and the upper main stream of Flathead River had become nearly, or quite, dissevered, and the ice was no longer crowding westward through Bad Rock Canyon.

The front of the South Fork glacier may have been slowly receding southward where now the rather extensive deposit of morainal drift lies between the river bend 2 miles south of Coram and Hungry Horse Creek. As the South Fork glacier gradually melted away its tributary glaciers became dissevered and melted back up the mountain gorges on the east and west. (See Nyack topographic map.) This was a long, slow process and the escaping waters swept a great deal of coarse outwash gravel down stream. Later, when the South Fork was clearing its inner valley and in places was cutting narrow inner gorges into the bedrock, much of the till and gravel was swept away. What is left of the gravel now forms the terraces bordering the stream here and there.

A dam has been constructed to impound water in the South Fork valley for the Hungry Horse Reservoir. The dam is about 4 miles downstream (north) from the mouth of Hungry Horse Creek in sec. 21, T. 30 N.,

R. 19 W., in the narrow gorge west of Lion Hill. A report was prepared by Erdmann (1944) on the geology of the dam and reservoir sites giving the results of studies of the glacial, Tertiary, and older bedrock formations of this part of the valley of South Fork by Erdmann, J. T. Pardee, and others.

For a long time, while the glaciers on the east flank of the Whitefish and Galton Ranges (*see* Stryker and Kintla Lakes maps) continued tributary to the north Flathead glacier, the ice may have continued southward through the gorge west of the Apgar Mountains and have added to the morainal deposits near Spoon and Bailey Lakes, 8 to 10 miles north of Columbia Falls. Probably the ice no longer overtopped the crest of the Apgar Mountains south of Huckleberry Mountain. The gorge at points about 3 and 6 miles south of Big Creek is partly blocked by what resemble small recessional moraines. At one place the highway passes what looks like a morainal deposit, but it may be a slide. A well-preserved terrace extends southward several miles from this deposit on the west side of the river.

Less than a mile from its junction with the Flathead River, Big Creek cuts through a point of its terrace, exposing the following:

Deposits on Big Creek

	Feet
D. Drift (till?), coarse, bouldery	15
C. Sand, cross-bedded, and interbedded thin red clay layers	5–6
B. Sand, coarse, cross-bedded	5–6
A. Sand, very fine, buff, grading to sandy clay, beautifully rippled	35
Talus cover	20

The lower beds (*A*) suggest deposition in standing water about 3,400 ft above sea level.

About a mile north of Mud Lake, in the gap between Big Creek and Coal Creek, a landslide has exposed till overlying soft, loose, buff to greenish and gray laminated clay and sandy clay. This laminated deposit was probably laid down in a small lake and then overridden by the advancing glacier. It may, however, represent a small remnant of Tertiary "lake beds" such as those in Flathead Valley.

The general aspect of the slopes and gulches near Big Creek, as shown on the topographic map of the Kintla Lakes quadrangle, suggests stream erosion rather than glaciation, yet it is evident that the glacier did move down the main valleys, even if it did not scour all the gulches sufficiently to give them U-shaped profiles.

There is no doubt that the valley of Coal Creek was glaciated. There are well-defined cirques at its head, and in 1913 the writer and C. S. Corbett found a glaciated ledge on the south side of Coal Creek Ridge (sec. 30, T. 34 N., R. 21 W.) about 1,000 ft above the creek, showing striae trending S. 60° to 79° E. along the slope. No drift was seen on the crest of the ridge where examined.

Ice, either of Coal Creek glacier or of a glacier in the valley of Dead Horse Creek, crowded into the pass 3 miles west of Mud Lake, for there are two small moraines lying directly across the pass, and about 1½ miles to the northeast ledges show striae trending S. 5° to 35° E., indicating that ice moved up the slope and across the spur in that direction.

There seems to be no doubt that at the maximum stages the mountain glaciers heading high up on the flanks of the Livingston Range in the western part of Glacier National Park were tributaries of a great branch glacier which filled the Flathead Valley from side to side and even overtopped some of the ridges on the west. Whether at the late stage the ice in the valleys of Camas and McGee Creeks extended southward over McGee Meadow and joined the glacier in the basin of Lake McDonald near Apgar is not known. Glacial till is exposed at intervals in the creek banks and along the road between Logging Creek and the foot of Lake McDonald. Mr. Seashore (written communication) informed the writer that he found one or more limestone pebbles containing Devonian or Carboniferous fossils near the foot of this lake. Such pebbles may have been brought to this place by the glacier from ledges near the Canadian boundary, 2 to 4 miles west of the Flathead River.

The several lake troughs in the western part of Glacier National Park head in the pre-Cambrian rocks (Belt series) and extend southwestward in the belt of soft Tertiary rocks. Several of these lakes were sounded in 1913 by M. R. Campbell and the writer, with the following results.

Results of soundings

	Feet
Bowman Lake	145–256
Quartz Lake	175–252
Logging Lake	130
Lake McDonald	400–440
Kintla Lake (Daly, 1912)	300

All the troughs in which these lakes lie trend southwestward and face directly toward the afternoon sun. This relation and the presence of recessional moraines in the valleys below some of the lakes suggest that the glaciers during the later part of the Wisconsin stage may have extended only a few miles below the lower ends of the lake basins. The trough of Lake McDonald has a broad-bottomed basin with rather steep sides and extends clear across the belt of soft rocks. Its bottom lies about 2,700 ft above sea level, nearly as low as the bottom of Flathead Lake. The valley below Logging Lake was not examined, but a well-defined terminal moraine was found 3 to 4 miles farther southeast, lying athwart the valley of Anaconda Creek, which contains no lake. C. S. Corbett also found a morainelike belt of hummocks and boulders extending southeastward across this creek about a mile below the road.

A well-developed terminal moraine surrounds Middle Quartz Lake and another extends about a mile below Lower Quartz Lake. Traces of moraines were seen 2 to 4 miles farther down the creek; about 4 miles downstream one exposure shows 150 ft of gray till containing many striated stones, mostly of Belt rocks.

There is also a small moraine about a mile farther down the valley. Numerous exposures on these creeks and along the Flathead River show glacial till and gravel overlying Tertiary deposits.

In discussing the glacial erosion of the Front Ranges, Daly (1912, p. 583) states, in part as follows:

> The detritus carried down the western valleys entered the relatively restricted Flathead trough where even the great North Flathead glacier was incompetent to handle all of the vast load of rock-matter. In consequence, the eastern side of the Flathead trough is covered with many huge moraines which are winged out from the spurs of the Clarke range. The glaciers which occupied the valleys of Kishenehn, Starvation, and Kintla Creeks built such moraines, from three to four miles in length, and from 1,000 to 1,500 feet in height. Others of similar dimensions were formed from the drift of glaciers occupying the valleys of Bowman Creek, Quartz Creek, and Logging Creek, south of the Line.
>
> * * * * *
>
> At first the writer was sceptical as to the simple morainal origin of these ridges, but a long search for bed-rock outcrops, attended with entirely negative results, and the general topographic relations of the ridges left little ground for doubt that practically the whole of each ridge is composed of drift.

The present writer does not think these interstream and interlake ridges in the Flathead Valley are huge "winged-out moraines" built by the several great glaciers that traversed the intervening troughs. (See p. 45.) They are very similar in size, form, and topographic position to the drift-and-gravel-capped erosion remnants of a Miocene or Pliocene or possibly early Pleistocene piedmont terrace at the east side of Glacier National Park, as described in Professional Paper 174 (pp. 12–17 and 32–41). The tops of these ridges in Flathead Valley correspond in a general way with the broad piedmont plain that bordered the Flathead River in late Tertiary time (pl. 4 *A* and *B*). This plain was transected by the several mountain streams in early Pleistocene time and the gorges were later scoured out by glaciers. Each of the ridges is probably capped with glacial drift, perhaps 100 to several hundred feet thick, but it seems likely that the greater part of their bulk consists of Tertiary sedimentary deposits, such as those exposed at lower levels along and near the channel of the Flathead River, north of Camas Creek. Much more thorough study of these wooded ridges is necessary before their structure and origin can be established. These ridge tops are to be correlated topographically with Flattop Mountain, Granite Park, and other benchlands bordering upper McDonald Creek, between the Livingston and Lewis Ranges (fig. 7).

Just as in the glaciated gorges east of the Continental Divide in Glacier National Park, so also at the heads of the gorges west of the Divide in the Park there are many conspicuous high-level cirques and benches. Several of these cirques are now occupied by small active glaciers. The largest at the north are Kintla, Agassiz, Rainbow, and Vulture Glaciers. East of Lake McDonald are Sperry (figs. 42, 43, and 44), Harrison, and Pumpelly Glaciers and several smaller ones. The thresholds or lower edges of many of these cirques hang at the tops of nearly vertical cliffs or very steep slopes, 500 to 1,500 ft above the adjacent parts of the main U-shaped gorge floors. If gradients are projected from the lower "lips" or thresholds of these high cirques down the gorges to about the levels at which the interstream ridge tops join the steeper mountain slopes, they may represent approximately the positions of the valley bottoms down which the first of the Pleistocene glaciers moved (pl. 4 *A* and *B*). It will be noted that some of the cirques at the heads of tributary lateral gulches hang at heights corresponding fairly well with the projected grades of these old Pliocene-Pleistocene valley bottoms. It seems probable that a large part of the down cutting between these old grades and the present grades was the result of interglacial stream cutting. Ice plucking (figs. 28 and 44), stoping, or quarrying and abrasion

FIGURE 28.—Glacial quarry in cirque at the head of Sprague Creek, near Sperry Glacier, showing the effects of ice plucking from jointed rock ledges.

during several successive glacial advances, though probably large, consisted mostly of wearing away projecting spurs and minor irregularities and of transforming V-shaped stream cuts to U-shaped cross profiles by wearing away and stoping back the heads of the troughs and the lower side slopes (fig. 29). There are evidently large amounts of glacial till and stream deposits in Flathead Valley and the valleys of the Middle and South Forks, but it is probable that much of the material derived from excavation by the Pleistocene

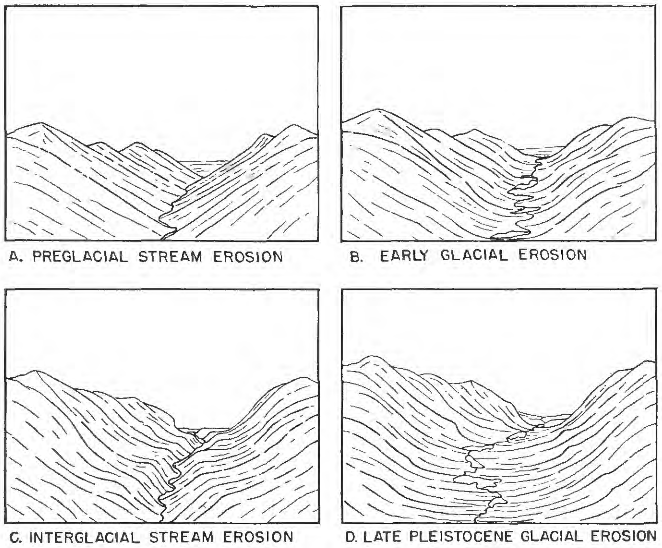

FIGURE 29.—Diagram showing preglacial and interglacial stream-cut valleys as modified by glacial erosion.

streams and glaciers was carried out through the Bad Rock Canyon and spread out broadly in the Flathead basin as sheets of till, gravel, sand, and laminated glaciolacustrine silt.

GLACIERS OF McDONALD CREEK AND THE MIDDLE FORK FLATHEAD RIVER

One of the largest of the Pleistocene glaciers that headed within the limits of Glacier National Park occupied the valley of McDonald Creek. Heading on the intermontane plateau known as Flattop Mountain, in the adjacent gorges, and on the high bench known as Granite Park (fig. 7), the ice moved south-southeastward to the rectangular bend below Haystack Butte; there it swung to the right, and advanced southwestward, scouring the great cliff, shown on the topographic map as the "Glacier Wall", and other steep slopes along its course to a height of 3,000 ft or more. Above the head of Lake McDonald the valley floor of pre-Cambrian bedrock is exposed in places, but subsequent vigorous erosion by the creek, as at the falls and the pot holes, has generally removed the glacial polish and striations. At several places on the slopes in the upper part of the basin glaciated ledges were observed in 1911 and 1913, showing striae trending south to southeast. One of these places is on the trail several hundred feet below the rim of the Granite Park bench. At one place about 3 miles west of the rectangular bend in the valley and 2,700 ft above the creek to the south, striae on a diorite ledge trend S. 10° E. directly toward the crest of the Glacier Wall. These striae may perhaps have been formed at the maximum stage of glaciation when the ice was crowding southward over the crest of the high bench above the great rock cliff. At this place the eroded surface of the Siyeh limestone, both above and below the glaciated surface of the diorite ledges, has been so roughened by solution as not to retain striae.

Cuts made in 1936 and 1937 along the newly graded road along the southeast shore, between the Belton Hills and the head of Lake McDonald, exposed finely laminated silt and sandy clay from which there was considerable seepage of water and consequent slumping. Above the road, on the wooded northwest slope of Snyder Ridge, similar seepage and slumping were noted along the trails, suggesting the presence of much porous and poorly consolidated material of either Pleistocene or Tertiary age.

Road cuts near Fish Creek, 3 to 4 miles north of the outlet of Lake McDonald, expose laminated or varved chocolate-red clay in which striated pebbles are embedded. In places this clay is overlain by gravel and in places till is exposed higher up in the slope. These exposures are about 3,600 to 3,750 ft above sea level. The laminated clay may have been deposited in a small marginal lake held at some time by the ice of the McDonald Creek glacier. It is not certain that glacial Lake Missoula at any stage extended this far north at these altitudes, although it may have done so.

Down stream from the ledges of Belt rock exposed above the head of Lake McDonald the valley slopes several hundred feet where the glacier passed from the harder pre-Cambrian to the softer Tertiary rocks. Lake McDonald, which now occupies this part of the trough for 7 miles or more, ranges from 400 to 440 ft in depth. The depth of the lake may be due largely to glacial scouring. In the lower mile the lake shallows rapidly from a depth of 350 ft between the Belton Hills and the mouth of Fish Creek on the north, where there are ledges of Belt argillite.

East of the village of West Glacier the Middle Fork Flathead River issues from its narrow, rock-walled gorge and, for a short distance below the old bridge, flows across the upturned edges of Belt strata. From the north end of this bridge the road ascends westward on a grade cut into stony till 50 to 100 or more feet thick. North of the short spur of till, are the office of the Superintendent of Glacier National Park and adjacent buildings on the smooth flat terrace about 50 ft above the river. For about 2 miles the mile-wide terrace extends to the village of Apgar at the foot of Lake McDonald with the steep slopes of the Belton Hills and the Apgar Mountains to the east and west. After passing the rock ledges near the old Belton bridge, the river flows westward along the base of a 50-ft bluff for about half a mile, past the new bridge; it then swings north to west to south in a broad ox-bow meander, cutting back the terrace east of the mouth of lower McDonald Creek. A lower gravel terrace borders the river on the south within the big bend. Another extends northward along the creek to the foot of the lake. The soil on the broad upper terrace, which was formerly wooded, is light-colored sandy silt. Near the lake outlet this silt is 2 to 3 ft thick, overlying gravel.

The silt appears to thicken southward until the whole bluff along the creek below the flat is composed of well-stratified sandy silt 20 ft or so thick. East of the river bend, near the new highway bridge, only 1 to 3 ft of silt overlies coarse bouldery gravel. The depth of bedrock under this flat terrace is not known. The finely stratified silt capping the terrace appears to have been deposited in slack water following recession of the front of the McDonald Creek glacier. Either water was impounded for a time, as high as the 3,200-ft level, by rock hills and morainal drift north of Coram, near Lake Five and Halfmoon Lake, or else the early Flathead Lake (part of glacial Lake Missoula) extended to the Lake McDonald basin as it did to the basin of Whitefish Lake.

Between the lower Middle Fork and Lake Five, southwest of West Glacier, glaciated hills of Belt rocks rise several hundred feet above the river. Striae observed on ledges near the railroad at Grizzly trend S. 55° W. East of the railroad and north, east, and south of Lake Five and Halfmoon Lake there are rather extensive deposits of drift with well-defined morainal knolls and ridges and numerous boulders, some 10 to 15 ft in length; also many swales, some containing ponds. Some of the railroad cuts along the highway (US 2) have exposed grayish compact stony till 10 to 50 ft or so thick. In one railroad cut at the west end of a ridge north of Coram, gray till is underlain by 40 to 50 ft of stratified gravel with deltalike forest beds dipping south above the track level. These beds might have been deposited in a glaciomarginal lake, possibly an arm of early Flathead Lake (glacial Lake Missoula) when the combined McDonald Creek and Middle Fork glaciers were forming the moraines as a recessional deposit.

At several places north of Coram (in secs. 17 and 20, T. 31 N., R. 19 W.) some deposits exposed in the river bluff below the railroad appear to be of pre-Wisconsin age. Unfortunately, owing to seepage and consequent slumping, the exposures, when seen by the writer in 1930 and later, did not permit accurate determination of their relations. Below the railroad grade, and apparently underlying the Wisconsin drift, there is unstratified "mudstone", semi-indurated, in part reddish and in part gray, and containing pebbles, mostly small. In places the reddish mudstone is bleached to gray along joint cracks. On none of the included stones examined by the writer were glacial striae seen. Underlying this mudstone is 4 ft of reddish-gray sandstone underlain by conglomerate composed of rounded water-worn pebbles.

At the base of the bluff there is an unstratified, indurated deposit of dark-reddish to salmon-pink color. In it are abundant subangular and some rounded pebbles of gray, greenish, and maroon-red rocks of the Belt series, ranging from a fraction of an inch to 1 ft in diameter, embedded in a matrix of finer material cemented by calcium carbonate. This deposit looks like an indurated glacial till, or tillite, though none of the included pebbles examined showed glacial striae. It closely resembles some of the early Pleistocene tillite exposed at the east side of Glacier National Park on the bench high above the north shore of Lower Two Medicine Lake (Alden, 1932, p. 39, pl. 16, *A*), but it may be a fanglomerate of Tertiary age. Some of it and some of the associated reddish deposits resemble Tertiary and supposed Tertiary deposits in the valleys of the several branches of the Flathead River in this region. It is also reported (Dumblazer, R. E., written communication, 1937) that "coal" was found at a nearby locality in the NE¼ sec. 19, T. 31 N., R. 19 W.

Erdmann (1944), who examined these same deposits and others south of Coram in connection with his studies of the Hungry Horse dam site on the South Fork, concluded that there may be deposits here representing three distinct stages of glaciation and two interglacial stages. This conclusion may be true, but the present writer does not feel sure of it.

The present inner gorge of the river below the mouth of the Middle Fork is cut 50 to 150 ft or more below the gravel terrace on which Coram and the railroad are situated. This terrace is cut away through Bad Rock Canyon but is continued between the canyon and Columbia Falls. There are remnants of two lower gravel terraces preserved in places, as at Columbia Falls and West Glacier. They may represent stages in cutting outlets through the moraines near Kalispell and Polson after the further recession of the ice front and the lowering of glacial Lake Missoula. The highway (US 2) between West Glacier and the Theodore Roosevelt (Marias) Pass is in places on remnants of one or another of the three gravel terraces. At one place opposite the mouth of Park Creek, kettle holes in the upper terrace seem to indicate the burial of masses of glacier ice when the terrace gravel was being deposited.

In places on the Middle Fork supposed Tertiary, upturned Tertiary and sandstone and shale are exposed below the coarse terrace gravel. Between Essex and Java at the junction of Bear Creek and the Middle Fork there are conspicuous remnants of gravel terraces 100 to 200 ft or more above the river. There are exposures of till and of striated rock ledges both above and below the junction of these streams. As in the valley of Swan River, so also along the South and Middle Forks the tributary mountain glaciers in and south of Glacier National Park eventually became dissevered from the large branch glaciers and the ice fronts receded up the gorges. No recessional moraines have been observed by the writer in such traverses as have been made along McDonald Creek and the South and Middle Fork valleys above the moraine between Coram and West Glacier.

As shown on the topographic maps, there are two small glaciers, Stanton Glacier and Grant Glacier, high on the north and east flanks of Great Northern Mountain and Mount Grant in the Flathead Range west of Paola; several of the finest glaciers in the Park nestle in high-level cirques on the headwater branches of McDonald, Harrison, and Nyack Creeks. They include the Sperry (figs. 41, 42, 43, 44) Harrison and Pumpelly Glaciers. (Alden, 1914.)

THE EAST KOOTENAI GLACIER

A large part of the advancing ice that crossed the Canadian boundary between the Galton and McGillivray Ranges continued southeastward along the Rocky Mountain Trench to the Flathead basin; it has been described as part of the great Flathead glacier. The western part of the ice, however, diverged from the Rocky Mountain Trench in northeastern Lincoln County, Mont., at the north end of the Salish Mountains. This part of the ice continued down the valley of the Kootenai River beyond the site of Jennings, Mont., and for convenience it is designated the east Kootenai glacier. From the general relations and from Daly's descriptions (1912, pp. 584–555) of the mountains and valleys near the Canadian boundary, it is probable that only the highest parts of the ranges were not overridden by the southward-moving ice. The main glacier may have been joined by many small tributary mountain glaciers. Glacial striae trending S. 20° W. observed on ledges of Belt rock in the Kootenai valley near the highway bridge over Big Creek and also near Gold Creek, 8 to 12 miles south of Rexford, were probably graven at the time of the last ice advance.

Evidently the ice in the Kootenai valley extended up the valley of Fisher River and its tributaries, fully 25 miles south of the Kootenai River near Jennings. Till and other glacial deposits (see topographic map of Thompson Lakes quadrangle) are exposed at many places along the road, and glaciated ledges were observed at several places. Ice that came into the valley of Wolf Creek either from the Rocky Mountain Trench or southeastward from the valley of Kootenai River engraved striae trending S. 50° E. on ledges just north of Island Lake in sec. 19, T. 29 N., R. 26 W. There are also striae trending nearly due east on ledges about 8 miles farther southeast in Pleasant Valley, in or near sec. 22, T. 28 N., R. 26 W. A glaciated ledge 3,300 and 3,400 ft above sea level, uncovered when the road near the east end of the Thompson Lakes was graded, in sec. 12, T. 26 N., R. 27 W., showed a set of striae trending S. 10° E. crossed by another set trending S. 27° to 40° E., and a newly exposed ledge nearby seen in 1937 showed striae trending S. 45° to 65° E.—that is, directly toward the gap through which the Thompson River flows southward. Near Big Bend ranger station, 8 to 9 miles down this valley, is a knolled and pitted moraine formed at the terminus of the minor lobe of the ice in this valley, about 3,100 to 3,200 ft above sea level. No glacial deposits have been noted farther south along the Thompson River.

At both ends of the basin of McGregor Lake, there are morainal deposits which may have originated in three ways: Ice coming southward over the hills may have entered the west-trending valley in which the lake is situated. (Striae on a ledge exposed in 1937 in the new road grade north of McGregor Lake trend due south.) Ice of the Ashley Creek branch of the Flathead glacier may have deposited the moraine at the east end of the lake while ice from the upper valley of Thompson River was depositing the moraine west of McGregor Lake. The ice from this valley may have extended eastward far enough to have deposited the east-end moraine; and if so, it could have deposited the western moraine later, on recession, leaving the intervening basin unfilled.

There appears to be another moraine, a ridge 100 ft high, 4 miles farther west. McGregor Creek cuts through this ridge, forming a narrow gorge. The ridge may have a rock core, but no outcropping rock ledges were noted.

Bootjack Lake, Horseshoe Lake, and other small lakes occupy basins interspersed with knolls and ridges of glacial drift composing a morainal deposit, 3,400 to 3,500 ft above sea level, extending 4 miles or more west of Thompson Lakes in Pleasant Valley. This deposit suggests that lobes of the Cordilleran ice may have advanced southward and crossed the relatively low passes at the heads of McGinnis Creek, Elk Creek, and Twin Lakes Creeks in T. 25 N., R. 28 W.

Cuts on the new grade of U. S. Highway No. 2 along the north side of the Thompson Lakes, examined in June 1937, gave fine exposures (at about 3,400 ft above sea level) of 20 to 25 ft of finely laminated buff to brownish, rather plastic lacustrine silt. In some of the cuts these beds have been disturbed by slumping and in some the silt overlies gravel. The silt was evidently deposited in a glacial lake bordering the front of the melting Cordilleran ice. Other cuts exposed only gravel and till. One 30-ft cut east of McGregor Lake exposed till overlying stratified silt.

Eastward trending striae on a ledge at the outlet of Fishtrap Lake (12 miles southwest of the Big Bend ranger station) and drift near the lake shore are probably products of a local glacier heading near Two Trees Point to the west. As shown by the topographic map of the Thompson Falls quadrangle, there were probably several local glaciers heading in cirques which scallop the east flank of the mountain ridge between Two Trees Point, Mount Headley, and Marmot Peak, 7 or 8 miles farther south. Most of these areas were drained by Fishtrap Creek to the Thompson River, 3 or 4 miles south of Big Prairie.

There were probably several small glaciers heading on the northeast flank of the Cabinet Mountains in and east of the northeastern part of the Trout Creek quadrangle and the southeastern part of the Libby quadrangle. It is not known whether they extended down the headwater tributaries of Fisher River as far north as Manicke in the Pleasant Valley. Such examinations as the writer has made seem to indicate that at Jennings (altitude about 2,100 ft) the ice may have had a maximum thickness of 4,000 ft. The east Kootenai valley lobe extended at least as far south as Manicke and the lakes to the east, a distance of 20 to 25 miles, and up to altitudes of 3,500 ft or more. Either this ice extended farther south up the East Fisher Creek or the drift with striated stones exposed near Miller Lake and Sylvan Lake was dropped from ice floating on a lake impounded north of the pass, which is about 3,700 ft above sea level.

The presence of deposits of till overlain by laminated lacustrine silt in the lower parts of the valleys of the West and East Fisher Creeks a few miles southwest, west, and northwest from Manicke suggests that small terminal lobes of the Kootenai glacier blocked those valleys for a time and maintained proglacial lakes in them. A similar small ice lobe evidently crowded westward into the mouth of Schrieber Creek valley and made small morainal deposits above and below Schrieber Lake, in sec. 13, T. 27 N., R. 30 W. From the low moraine above the lake the highway (US 2) crosses a low divide in the through valley that extends down Swamp Creek. For several miles the bottom of this gorge is largely flat and marshy, with alluvial fans at the mouths of side gulches. In places the side walls are steep and rocky. For 8 or 9 miles north of the moraine above Schrieber Lake nothing indicated that glacier ice had traversed this valley in either direction. Glacial till and boulders in the vicinity of the small butte known as Paul Bunyan's Grave and about half a mile south of the junction of Swamp and Libby Creeks (secs. 3 and 4, T. 28 N., R. 30 W.) appear to mark the approximate southern limit of the glacier that advanced southward up the valley of Libby Creek.

How far northward glacial Lake Missoula extended up the valley of the Thompson River is not certainly known. It may have reached the ice front when the terminal moraine at the Big Bend ranger station was deposited. When the front of the East Kootenai glacier began to retreat northward, either glacial Lake Missoula expanded so as to cross the divide (about 3,350 ft above sea level) near Bootjack Lake, or local proglacial lakes ponded in the headwater branches of Fisher River expanded until they formed a single branching lake.

About 2 miles southwest of Little Bitterroot Lake a small rocky gorge (about 4,100 ft above sea level) extends westward to the broad Pleasant Valley. In the upper part of this valley is a deposit of gray lacustrine silt. Possibly a small proglacial lake may for a time have been held high enough to use as a spillway the rocky gorge leading to the Little Bitterroot Valley. The silt is very powdery when dry and the absence of lamination suggests that it may have been either deposited or redeposited as windblown dust. Edges of some of the quartzite ledges south of Pleasant Valley School are smoothly rounded but do not show glacial striae, so far as noted, such as are so plainly marked on a ledge a few miles east of the school.

One of the best exposures of lacustrine silt overlying till is beside the highway along Fisher River (about 3,000 ft above sea level), west of Manicke. It contains the following:

Deposits west of Manicke (SE¼, sec. 5, T. 26, N., R. 29 W.)

	Feet
Laminated silt (varved?)	20±
Coarse gravel	2–3
Laminated silt	30±
Glacial till containing striated pebbles, largely covered by talus.	

That the lake actually bordered the front of the glacier may be indicated by the fact that coarse gravel was washed into the lake between two periods of silt deposition. Variation of conditions of sedimentation, either seasonal or periodic, is indicated by the thin, "winter" (?) beds of dense unctious clay (1 to 3 in. thick and splitting into paperlike laminae when dry) alternating with "summer" (?) layers of less finely laminated sandy silt 8 to 18 in. thick. Many curiously shaped clay concretions, washed out of the bedded silt, are strewn on the talus below the vertical scarp.

There are many exposures of grayish laminated silt at intervals along the road northward down Fisher River and in the valley of Wolf Creek. In places either till, gravel, or boulder material underlies the silt, and one scarp about 2 miles below the mouth of Wolf Creek shows three or more beds of coarse gravel, each overlain by laminated silt 10 to 30 ft thick.

Near the bridge 6 to 7 miles south of Wolf Creek there is a terrace remnant about 2,650 ft above sea level and about 100 ft above the river. An exposure here shows 5 to 10 ft of buff oxidized clayey silt, partly laminated at the terrace top below which is 8 to 10 ft of coarse, bouldery gravel and in places stratified sand. Beneath the gravel is finely laminated silt partly covered by talus. The above-cited sections and others show an alternation of conditions resulting in stream and lacustrine deposition subsequent to the deposition of the glacial till in the valley of Fisher River and its tributaries. Apparently the silt capping the valley fill, of which the high terraces above the present stream are remnants, was not built up to the surface of the proglacial lake, for there is no outlet southward to Thompson River below an altitude of 3,350 ft. The top of the laminated silt, which overlies till west of Manicke and also farther east, is about 3,000 ft above sea level.

The laminated silt exposed along the Fisher River north and south of Cow Creek and that to the east in the lower part of the tributary valley of Wolf Creek may have been deposited in water ponded in front of the ice of the Wisconsin stage when it began receding northward and before an outlet was opened westward via the valley of the Kootenai. Many of the cuts along the south side of Wolf Creek on the abandoned grade of the Great Northern Railway are in till. One cut 10 miles east of Fisher River shows a great deposit of glacial boulders overlying rock, overlapped on the west side and top by laminated silt. Island Lake is held by a morainal dam at the south end.

Some of the higher terrace remnants in the Kootenai valley, such as that about 2,400 ft above sea level in the bend of the river north of Jennings, are of bouldery gravel and were probably formed at or near the mouths of tributary streams when the ponded waters had begun to drop below the highest level of the outlets via Bull Lake and south of Bonners Ferry. Apparently, however, the ponded water did not drop below an altitude of 2,500 ft before the ice front receded north of the international boundary.

In places along the highway north of the Ural ferry, bouldery gravel appears to have been washed down over laminated silt. A gravel pit at Parsnip Creek, opposite Tweed, exposes 75 ft of gravel stratified in south-dipping beds.

When the Kootenai valley was so cleared of ice as to open a lower outlet westward to the Columbia, the river began to cut away the higher lake and stream deposits and to develop the lower terraces of which two or more are composed of gravel.

GLACIATION NEAR LIBBY, MONTANA

There has been insufficient examination by the writer of the mountains and valleys within the great bend of the Kootenai River south of the international boundary in northern Idaho and northwestern Montana to determine more than the barest outline of the Pleistocene history of this area. Other than traverses of the valley of Kootenai River itself, only brief traverses were made in the Moyie and Yaak River valleys and on Bobtail and Pipe Creeks north of Libby. From these traverses it appears that glacier ice occupied these creek valleys and extended southward across the valley of Kootenai River and up Libby Creek to a point about 14 miles south of Libby to the junction of Coniff and Libby Creeks (in secs. 3 and 4, T. 27 N., R. 30 W.). This is shown by the presence of glacial till apparently derived from the north. Other glacial deposits in the valley of Libby Creek and the tributary valleys appear to be the products of local glaciers, which headed to the southwest in the high cirques that scallop the flanks of the rugged Cabinet Mountains. (See Libby topographic map.) A glaciated ledge of rock was observed about 5 miles north of Libby on the logging road beside Pipe Creek, in the NE$\frac{1}{4}$ sec. 10, T. 31 N., R. 31 W. This ledge showed striae trending southwestward down the valley.

Rusty, oxidized till was exposed in the bluff east of the mouth of the gulch that Pipe Creek has cut below the upper terrace, about 3 miles northwest of Libby. The top of the compact till is about 100 ft above the creek and is overlain by about 50 ft of finely stratified, sandy lacustrine silt, above which coarse gravel extends to the top of the terrace, 2,500 ft above sea level.

It is not certainly known that the Cordilleran ice extended up the valley of Libby Creek for 14 miles south of the Kootenai during the Wisconsin stage, although it is so indicated on plate 1. The character of the till and the degree of induration and oxidation suggest that at least some of it may be of pre-Wisconsin age. It may be that the ice depositing this till and that occupying the valley of Quartz Creek north of the Kootenai was entirely local and headed in the Purcell Mountains not far north of the river. If, however, Daly's statement is correct concerning the volume of ice entering this area within the great bend of the Kootenai River, the glacier that crossed the river and advanced southward up the valley of Libby Creek may be regarded as one of the smaller lobes of the Canadian Cordilleran ice. Daly (1912, pp. 586–587) writes as follows:

Purcell Mountain system

For the Purcell system the upper limit of the ice was rather definitely fixed on the high ridge running south from the Boundary Line just east of the 118th meridian. As in the Galton range the limit is practically at the 7,300-foot contour. The highest summit bearing actually observed striae is 7,100 feet in elevation. The direction of average movement across the ridge-tops was S.S.W. Strong deflections were, however, observed at many elevated points where local topography controlled the directions of the ice-currents. In the lower levels the ice was similarly controlled by bed-rock relief. At all times the flow was southward along the depressions for the ice which filled the Rocky Mountain Trench, the Yahk river valley, the Moyie river valley, and the Purcell Trench. These great troughs naturally controlled the drainage of the ice flood.

The depth of the ice over the Yahk river valley must have been about 4,000 feet; over the Moyie, 4,500 to 4,600 feet; over the Purcell Trench, about 5,500 feet. The average depth for the whole Purcell system at the Forty-ninth Parallel was about 2,500 feet. At the summits of the Yahk and McGillivray ranges, a few small nunataks projected a few hundred feet. Elsewhere the whole mountain system, including ninety-nine percent of the Boundary belt, was completely smothered under the ice. This fact doubtless partly explains the relative rarity of cirques in these mountains (about a dozen in the Boundary belt). The relief was not sufficient to generate valley ice-sheets which could endure long enough for the quarrying out of many amphitheatres. The glacial erosion of the Purcells was thus chiefly accomplished under the all-mantling ice-cap and not at the head-walls of local glaciers.

It seems probable that, at its maximum, the surface of the Cordilleran ice was 6,000 ft or so above sea level at Libby and Troy, and that there was as much as 4,000 ft of ice in the valley of the Kootenai River in this vicinity. At that stage the local mountain glaciers must have been relatively short and their ice probably merged with that coming up the valleys of Libby Creek and Lake Creek from the north.

Till is exposed in cuts on the Roosevelt Highway (US 2) beside Kootenai River, 8 to 10 miles below Libby. It is not known whether or not the deep narrow part of the gorge between the rugged slopes of the Purcell Mountains on the north and the Cabinet Mountains on the south was traversed from east to west by glacier ice. The ice may have crowded into it from both the east and the west. It is not certainly known whether or not the Kootenai gorge between Jennings and Libby was invaded by the East Kootenai glacier or by ice from the Libby Creek glacier, or by both. It seems likely that the gorges both east and west of Libby were occupied by glacier ice, at least at the times of its maximum extent. Till containing abundant striated stones was exposed in places in 1938 in cuts along the highway (US 2) east of the Kootenai Falls. The river is flowing over ledges at Jennings and also at and some distance below the Kootenai Falls, which are 11 to 12 miles below Libby. At Libby the river is actively cutting a narrow winding inner gorge below a wider rock terrace. It also appears to be cutting in rock near the mouth of Lake Creek, 1 to 2 miles southeast of Troy. Apparently the gorge in these parts never has been deeper than now.

Thirty feet of till, with striated pebbles, is exposed in a road cut 9 miles south of Libby. Till is also exposed along the road southwest up Big Cherry Creek, a tributary of Libby Creek, as far at least as the mouth of the canyon 2 to 3 miles below Leigh Lake. Evidently local glaciers extended northeastward down Leigh, Snowshoe, and Big Cherry Creeks to a point east of Little Hoodoo Mountain, and also down the headwater branches of Libby Creek to the southeast. The canyon of Granite Creek, which was partly traversed by the writer, has been scoured by glaciers and a small glacier—Blackwell Glacier—now lies on the east flank of Snowshoe Peak. In Pleistocene time Granite Creek glacier brought down great quantities of boulders from the granite mountains in which it headed. The glacial till exposed in the bluffs on lower Granite Creek, however, probably came from the north, possibly during a pre-Wisconsin stage of glaciation.

The higher parts of the piedmont tract that borders the east front of the Cabinet Mountains for 8 or 10 miles south of Libby have not been examined by the writer. The lower parts consist of a gently undulating ground moraine. In general it slopes northeastward down Libby Creek until, between altitudes of 2,500 and 2,400 ft it is covered by the smooth flat surfaces of the upper terraces. The configuration of the surface of this ground moraine ranges from nearly flat to moderately hilly, and some of the small hills have the oval forms characteristic of drumlins. Their longer axes trend somewhat east of south. This drumloidal trend, together with the lithologic composition of the till, seems to indicate that this ground moraine was deposited by a southward-moving lobe of the Cordilleran ice sheet.

The till is well exposed in places in the bluffs at the sides of the inner valleys where the streams have cut into the ground moraine. One of these exposures shows the following:

Deposits south of Libby (SE¼ sec. 34, T. 30 N., R. 31 W.)

	Feet
Silt, loamy	10–20
Till, rusty-buff to brownish, very stony and compact, standing in vertical face with erosion buttresses and pinnacles	70±
Gravel, coarse, with abundant disintegrating granite pebbles	5

In the till are some pebbles of a peculiar porphyry which may have come from outcrops on Bobtail Creek about 8 miles north of Libby. At a similar exposure of till less than a mile farther south the face of the bluff is eroded into pinnacles and buttresses. The compact rusty till also forms the bluff west of the mouth of Big Cherry Creek, and about the same thickness of oxidized till, with erosion pinnacles and buttresses, may be seen about a mile north of Deep Creek in sec. 14, T. 29 N., R. 31 W.

One of the most interesting features of this ground moraine is a small drumlin east of Granite Creek (NW¼ sec. 35, T. 30 N., R. 31 W.), a short distance west of the highway grade (US 2). At this place the crests of two small, nearly buried drumlins project 20 to 50 ft above the flat surface of the surrounding upper terrace. In excavating its inner valley, Granite Creek has swung back and forth across the broad flat bottom land and at this place it is now cutting at the base of a bare bluff, 100 to 150 ft high. In eroding thus, the creek has cut away nearly half of one of the drumlins, giving a vertical section slightly oblique to its north-south axis. The section is overgrown and obscured by slumping at the north and south ends of the drumlin, but the scarp between is sufficiently clean to show the structure. The top of the section, shown at the left in figure 30, is the eroded western edge of the upper terrace (altitude about 2,430 ft); at the right the profile of the drumlin rises above the terrace. The buried part of the north slope of the drumlin can be traced at the top of the till buttresses sloping downward to the left beneath the overlapping terrace deposits. In this part the base of the

FIGURE 30.—Drumlin south of Libby, Mont. Longitudinal section showing the northern half of the drumlin with glacial till 30 to 100 ft thick. The till thins northward (to left) and is underlain and overlain by stratified stream gravel. The bluff face is marked by buttresses of Recent erosion.

drumlin rests on undisturbed, horizontally stratified stream deposits. Farther to the right the base of the drumlin and the underlying material are covered by talus. The basal stream deposits consist of about 15 ft of poorly stratified, coarse gravel and boulders overlain by a foot or less of fine stratified gravel and sand. A large percentage of the pebbles and boulders in the basal stream gravel are granite from the mountains north of Snowshoe Peak. These rocks are so badly decomposed as to suggest that the gravel is of early Pleistocene age. The till in the drumlin, like that seen farther south, is rusty buff in color, very stony, compact and hard; its maximum thickness is about 135 ft. Many of the rocks in the till, including one large boulder of limestone, are well striated.

This exposure is unique, in the experience of the writer, in showing the base of a drumlin composed of dense, hard, bouldery till, more than 100 ft thick, resting upon undisturbed, fine, stratified material. Perhaps the sand-and-gravel material was saturated with water and frozen solid and thereby escaped deformation when the glacier advanced over it and formed the drumlin. The terrace gravel overlapping the sides of the drumlin was evidently deposited as, or after, the glacier ice melted away from this locality.

While the Cordilleran ice was occupying the valley for 12 to 14 miles south of Libby, water must have been ponded in this valley and its tributaries in front of the advancing ice, spilling over southeastward through the lowest available pass, which was the narrow gorge now drained by Swamp Creek. The southern limit of the ice, 14 miles from Libby, is represented by till containing striated pebbles that is exposed in a road cut; there is no well-defined terminal moraine. Striated pebbles were also observed on benches (as high as 2,900 or 3,000 ft above sea level) on the north slope of the valley near this place. Sixty feet of coarse stony till-like material is exposed in the bluff below the terrace on which the road is situated, east of the mouth of Swamp Creek, but no included striated pebbles were found. There are doubtless numerous exposures of glacial till in the valley of Libby Creek other than those examined by the writer.

It may be that this Cordilleran ice was met, near the junction of Swamp Creek and upper Libby Creek, by a local mountain glacier that was advancing northeastward from the headwater branches of Libby Creek near Hayes Ridge and Elephant Peak. Till and striated pebbles were observed by the writer at several places near the road to Howard Lake. Near the junction of Swamp Creek and Libby Creek the small flat-topped butte locally known as Paul Bunyan's Grave is an erosion remnant of the upper terrace 2,900 ft above sea level. A bare scarp at the south end of this butte exposes the following section:

Deposits at "Paul Bunyan's Grave" on Libby Creek

	Feet
3. Gravel, coarse	10
2. Silt, fine, stratified, and sandy; ripples in places	50
1. Till, very stony clay, many pebbles, striated	30–40

These beds are illustrative of the three different types of deposits in this basin—(1) glacial, (2) glaciolacustrine, and (3) fluvial or glaciofluvial. Laminated silt also is exposed farther up Libby Creek. The silt was evidently deposited in a temporary lake dammed when the front of the Cordilleran ice was retreating northward. If this lake rose to a height permitting it to discharge southeastward across the pass (about 3,350 ft above sea level) to Thompson River, there must have been 400 to 500 ft of water at "Paul Bunyan's Grave." If glacial Lake Missoula extended northward up the valley of Thompson River at an altitude of more than 3,350 ft at that time, the water in Libby Creek valley must have been correspondingly deeper.

Although the time relations of the proglacial lake in the valley of Libby Creek are not entirely clear, it is evident that such a lake occupied the basin for a considerable length of time after the melting of the ice that deposited the till described above. This is indicated by the considerable thickness of undisturbed laminated silt that underlies the smooth high terrace (2,400 to 2,500 ft above sea level) east of lower Libby Creek. Nearly the full height of the bare bluff, which was examined east of the Libby sawmill in the NW¼ sec. 11, T. 30 N., R. 31 W., consisted of light-colored silt 300 ft thick, so fine and dense as to be almost massive and without distinct laminae, yet splitting along smooth horizontal bedding planes when dry. No pebbles, boulders, or fossils were seen embedded in the silt, but at one place 15 ft of cobblestone stream gravel was exposed below the silt.

The stream gravel capping Paul Bunyan's Grave and the corresponding terrace remnants (2,900 ft above sea level), and also lower ones on the east and west and farther north, must have been deposited after the ponded waters had been drawn to lower levels by the opening of a lower outlet westward down the valley of the Kootenai. The coarse gravel capping the terrace east of Libby Creek was spread out as alluvial fans by creeks, such as McMillan Creek, heading in the hills to the east. These gravels are in general above the upper level of the lacustrine silt in this basin—that is, more than 2,450 ft above sea level.

About 3 miles northwest of the Libby bridge, silt overlain by gravel is exposed along the road up the bluff between Bobtail Creek and Pipe Creek. In the same locality (sec. 20, T. 31 N., R. 31 W.) 50 ft of stratified sandy silt is exposed in a gulch east of Pipe Creek overlying till and overlain by a thick deposit of coarse cobblestone gravel that caps the upper terrace and surrounds a small hill of pre-Cambrian argillite. Evidently this upper terrace gravel came from the north. The high terrace is transected by the gorges in which Bobtail and Pipe Creeks flow southward to the river. Where the creeks emerge from the hills, 4 to 5 miles north of the river, the altitude of the terrace is about 2,600 ft. From this level the terrace slopes down to an altitude of 2,400 ft at the crest of the bluff about a mile north of the Kootenai River and 350 ft above it. East of Pipe Creek, along the Pipe Creek road and the logging railroad, the high terrace has been so eroded as to develop several lower terraces bordering the river. As exposed along this terraced gulch, the upper terrace is capped with coarse gravel from the north. Under the next lower terrace is fine stratified sand and silt like that east of the sawmill on the south river bank, apparently with no included pebbles. Below the next minor terrace is fine sand, unstratified at the top and stratified in thin horizontal layers below, with some half-inch cemented layers. Cuts at the lower edge of the next terrace show pebbles over stratified sand, below which is unstratified sandy material containing subangular cobblestones and 1- to 2-ft boulders—material that looks somewhat like till but in which no striated stones were found. Beneath the next terrace is coarse cobblestone gravel, about 2,200 ft above sea level. Similar gravel is also seen beneath the next two lower terraces, which are just above the north end of the Libby bridge.

The road cut at the north end of the Libby bridge shows 15 ft or more of coarse bouldery gravel overlying the eroded fine laminated lacustrine silt. The gravel locally shows cross beds dipping westward or downstream. Some of the stones measured as much as 2 by 3 by 4 ft. The relations of the several deposits and terraces seem to indicate that when the level of the glacial lake was lowered by the opening of a new outlet down the valley of the Kootenai, the river was reestablished and began cutting away the lacustrine beds, developing terraces and depositing, in place of the silt, coarse material such as could be transported only by a vigorous flow, with some assistance, perhaps, from floating ice to carry the larger stones. The gravel terraces include still another, the lowest, on which the town of Libby is built south of the river. There are remnants of these gravel terraces, but not of the silt, at intervals all along the Kootenai River from Rexford to the international boundary at Gateway. The altitude of the upper terrace, 2,400 to 2,500 ft above sea level, appears to have been controlled by an outlet southward to the Clark Fork by way of the pass near Bull Lake south of Troy.

TROY GLACIAL LOBE

PRE-WISCONSIN(?) GLACIATION

To what extent the mountains within the great bend of the Kootenai River in the United States were overridden by the Cordilleran ice is not yet definitely known. Apparently, as indicated by Daly's studies, the mountains along the international boundary were nearly, if not wholly, submerged beneath the ice during one or more stages of glaciation. Judging from local features as well as from conditions to the east and west, a lobe of this ice appears to have extended southward past Troy, to and beyond the divide at the head of Bull Lake, and to have terminated at a moraine 10 miles down the valley of Bull River near the junction of the East Fork with the main stream.

Judging from the topographic map of the Libby quadrangle, much of the ice in the through valley of Lake Creek and Bull River came from tributary glaciers that occupied the gorges heading in cirques on the Cabinet Mountains to the east and west. So also there may have been some tributary glaciers heading in the Purcell Mountains north of the Kootenai River. It seems probable, however, that there was a trunk glacier, a lobe of the northern ice, which advanced southward down the Yaak River valley, up the valley of the Kootenai, and thence southward past Troy. The eastern part of this ice may have surrounded Yaak Mountain, 7 miles north of Troy, crowded through the gap containing Kilbrennan Lake 2 miles farther north, and moved thence southward down the valley of O'Brien Creek, submerging the adjacent hills and extending farther southward up the valley of Lake Creek. The writer has made insufficient examination of the valleys of O'Brien Creek and Yaak River to determine whether or not such a deployment as is indicated on plate 1 actually occurred north of Troy, but the narrow through gorge in which Kilbrennan Lake lies, as seen from the road that passes the lake, does not now look as though it had been glaciated. There is, however, what appears to be a low morainal ridge, possibly a recessional moraine, near the junction of Kedzie Creek and O'Brien Creek (sec. 7, T. 32 N., R. 34 W.), 4 to 5 miles north of Alvord Lake.

Pardee found till in T. 34 N., R. 33 W., near the old sylvanite mining camp, on slopes as high as 1,000 ft above the creek. The present writer found abundant rounded boulders along the road in this vicinity above Seventeen Mile Creek. Large boulders of diorite also are numerous near the falls of the Yaak River, 3 to 4 miles north of Kilbrennan Lake, but, so far as noted, none of the boulders showed glacial striae. In July 1938, good exposures were seen on U. S. Highway No. 2 where it ascends from the Kootenai River bridge north of the mouth of the Yaak River in sec. 5, T. 32 N., R. 34 W. At one place, about 250 ft above the river, there was a smoothly rounded and highly polished rock ledge with glacial striae trending S. 25° E. It was overlain by finely laminated lacustrine silt. In places higher up the slope, coarse gravel lies on bedrock and is overlain by laminated silt; the terrace above, 350 to 375 ft or more above the Yaak River, is capped with coarse bouldery gravel northward past the inner gorge. This narrow gorge is several hundred feet deep and is cut largely in sharply folded rock of the Belt series. North of the Yaak River bridge the inner gorge of the Kootenai River narrows and the low terrace (1,850 ft above sea level) is bordered by a 2,300-ft gravel-capped terrace. Three to four miles south of the Yaak River bridge, unsorted stony material, which may be till though no striated stones were found in it, is poorly exposed below a well-defined terrace about 600 ft above the river and also along the road across the river east of Troy.

There are indications of the former presence of glacier ice about a mile north of Troy where a large excavation has been made in the face of the bluff beside the railroad. Till containing striated stones was exposed in July 1938, below terrace gravel in cuts along the new grade of the highway (US 2) below the high terrace north of Savage Lake. At no place farther south between Kootenai River and Bull Lake did the writer recognize any glacial till; neither were any glaciated rock ledges observed. All the exposures seen were of laminated silt, sand, or gravel. Two to three miles north of Bull Lake there is a small rock hill of argillite and quartzite beside the road near Camp Creek. It rises abruptly for 100 ft or so above the surrounding flat terrace. The upturned rock strata are thin and the edges show no glacial striae, although the hill must have been overridden by any glacier that traversed the valley, as striated pebbles are scattered over the top, 2,500 to 2,600 ft above sea level. These pebbles, however, might have been dropped from floating ice, if the lake surface reached that altitude, or they might have been left there by a local glacier that moved down Camp Creek from the mountains to the east. More thorough examination may reveal definite evidence that a glacier from north of the Kootenai River actually traversed this valley. It seems probable that there was such a glacier and that it advanced southward up the valley of Lake Creek and down the valley of Bull River for 10 or 11 miles to the moraine that obstructs the valley below the mouth of East Fork of Bull River. This moraine (sec. 18, T. 27 N., R. 32 W.) is about 150 ft high and its top is pitted with kettle holes. Unsorted, coarse, gravelly drift is exposed where the stream swings against the north foot of the moraine. The moraine may originally have extended eastward as a dam clear across the valley, but now there is a broad gap east of the road through which the stream flows. The valley of East Fork, which heads in cirques on the northeast flank of Saint Paul Peak, was also glaciated and contains, 1 to 3 miles above the moraine, a rather thick fill forming a flat-topped terrace about 2,500 ft above sea level into which East Fork has cut a narrow inner gorge. This terrace, which is capped with silt if not wholly composed of it, may have been built in water ponded by the moraine, or in glacial Lake Missoula when that lake extended northward at the 2,500-ft level as the front of the glacier finally receded. There is also some morainal drift along the road for 2 or 3 miles up the valley of Bull River above the bridge. Through much of the distance between the outer moraine and the divide south of Bull Lake the stream flows through a flat marshy bottom land and in places water is said to stand 20 to 40 ft deep, owing to the obstructed drainage. The writer has found no definite evidence that a glacier advanced farther down the valley of Bull River than the moraine noted above. Such erratic boulders as have been observed on the sides or bottom of the lower part of the valley, as much as 4,200 ft above sea level, may have been dropped from ice floating on glacial Lake Missoula. Pardee, however, found glacial striae on a ledge southwest of the mouth of Copper Creek.

WISCONSIN STAGE OF GLACIATION

Although the Troy glacial lobe in pre-Wisconsin time may have extended as far down the valley of Bull River as the terminal moraine just below the mouth of the East Fork, the terminus of the corresponding lobe during the Wisconsin stage was probably near the pass just south of Bull Lake. There is no well-defined terminal moraine there, but what appears to be a rather large morainal deposit is situated at the west side of the pass south of Ross Creek; furthermore, at the east side of the pass an extensive gravel terrace 2,400 to 2,500 ft above sea level evidently represents outwash that extends southward for about a mile and a half from Bull Lake to a steep bluff, where it is cut off by the upper Bull River coming from the east. This terrace is composed of loamy soil underlain by coarse gravel. It may originally have extended half a mile to a mile farther across the pass and subsequently have been partly cut away by the outflow of water ponded in the valleys of Lake Creek and Kootenai River by the receding ice front. As before, this trunk glacier was probably joined by several tributary glaciers heading in the Cabinet Mountains on the east and west.

The topographic map of the Libby quadrangle shows several passes across the interstream mountain ridges west of Lake Creek which at times may have served as spillways for glacial waters flowing southward to glacial Lake Missoula when the great lobe of ice occupied the main valley. They range in altitude from 4,400 to 2,500 ft. Those lower ones south of Troy were doubtless traversed and scoured out by the ice itself. Those east of Preacher, Goat, and Grouse Mountains are on the supposed line of the Lenia fault. Those west of Preacher Mountain and Grouse Mountain appear to be on the lines of minor faults. The trough containing Bull Lake appears to be in a graben dropped between the Lenia fault on the west and the Bull Lake fault on the east (Gibson, 1948). There are conspicuous remnants of a gravel terrace built around some of the lower hills and in the mouths of tributary valleys, 2,400 to 2,500 ft above sea level. They appear to be the correlatives of the highest terrace tops of the fill along the east side of the valley at about the same altitude. Most of the deposits observed in the broad valley north of Bull Lake appear to have been laid down during the recession of the ice front.

The writer has made a detailed examination of the deposits north of Bull Lake only at a few places. Four or five miles south of the Kootenai River, only lacustrine silt is exposed. Near the top of the bluff at this place there is a small pond in a kettle hole indicating the burial of a large body of ice. About 3 miles farther north landslides in the face of the bluff above the road afforded a large exposure above the talus accumulation. To about 115 ft above the road the material exposed is fine stratified lacustrine silt. Overlying this is about 15 ft of coarse gravel partly cemented to conglomerate and above is 30 ft or more of sand and fine silt. The edge of the terrace above the bluff is about 2,300 ft above sea level. So far as noted, the beds are undisturbed and show no evidence of having been overridden by the glacier. Some of the silt layers are 1 ft thick or more, and, as in the silt at Libby, there is little or no indication of seasonal deposition such as would be expressed in varved clays. No included pebbles or fossils were noted. Inasmuch as the lower silt is overlain by a thick bed of stream gravel, which is in turn overlain by silt, it is possible that this lower silt was deposited in water ponded earlier than the last stage of glaciation. The laminated silt, however, is undisturbed.

About 3 miles south of Savage Lake a road cut has exposed fine sand interstratified with laminated silt. In it are some consolidated layers about half an inch thick. The terrace which surrounds the ice-block depressions containing Savage Lake and an adjacent pond, is capped with coarse gravel. It was probably completed when the glacial front had receded so far north and the fill of silt in ponded water had reached such a level as to permit gravel to be washed out upon it by the Kootenai River from the gorge to the east. There is a most conspicuous remnant terrace on the northeast side of the river opposite Troy. On the smooth flat at the top of the steep bluff is a farmhouse overlooking the river from a height of nearly 600 ft. Bedrock and talus are exposed in places in the lower face of the bluff below this terrace. Along the road graded up to the farmhouse only till-like gravelly material was observed.

The several terraces below the 2,400-ft level were developed by cutting into the valley fill and spreading coarse stream gravel over the lacustrine silts. Where the newer grade of the highway (US 2) extends southeastward from the Lake Creek bridge up onto the 2,000- to 2,100-ft terrace a deep cut exposed (in July 1938) stratified sand and silt overlain by coarse terrace gravel and underlain by greenish to gray thin-bedded argillite into which Lake Creek has cut a narrow gorge below the reservoir dam. There is a remnant of this 2,000-ft terrace nearly a mile wide east of the narrow spur cut by a railroad tunnel on the north side of the river. There is also another remnant to the west between Lake Creek and Callahan Creek. Troy stands on a lower terrace at an altitude of 1,880 to 1,900 ft.

An interesting exposure in the bluff at the Troy railroad yards shows deformation of the uppermost silt beds. At this place there has been considerable excavation, and the exposure seen there in 1930 was better than that seen in 1938. Near the south end coarse gravel was exposed for 25 ft above the railroad—that is, as much as 40 or 50 ft above the river. This gravel is overlain by a thick deposit of finely laminated lacustrine silt. Above the silt, and lapping over the cut-off north ends of the silt beds, is coarse bouldery gravel with some cross bedding dipping downstream like a torrential deposit. The pebbles and boulders, some of them 2 to 4 ft in diameter, are in part smoothly rounded and in part subangular. None, so far as noted, showed glacial striations. This upper gravel extends to the top of the bluff—that is, to the eastern edge of the flat terrace about 2,000 ft above sea level, or more than 100 ft above the river. The uppermost silt beds are very much contorted, with small folds overturned from north to south as though the disturbance were due to the push of glacier ice advancing up the valley from the northwest. No glacial till was observed in the section, but the deformation of the silt beds suggests that they were deposited prior to, or immediately in front of the last glacial lobe that traversed this part of the Kootenai River valley. The bouldery gravel overlying the silt and capping the terrace was probably deposited by Kootenai River after the water ponded by the last retreating ice front had been drawn down from the 2,500-ft level for 500 ft or more, as a result of the opening of the present outlet of the valley.

About 6 miles north of Leonia, Idaho, a glaciated ledge beside the highway on the 2,400- to 2,500-ft bench near the Idaho-Montana State line shows striae trending S. 45° E., indicating that the ice moved up the valley of the Kootenai River. From this ledge glacial till extends along the road northwestward to the valley of the Moyie River. These features seem to indicate that glacier ice from the lower valley of the Kootenai and the valley of the Moyie River extended as far up the Kootenai as the lower Yaak River and may have contributed to the ice lobe that reached Troy and Bull Lake.

The branch road that extends from U. S. Highway No. 2 on the 2,200-ft terrace down to the Kootenai River bridge at Leonia, Idaho, is graded along the face of the bluff below the several terraces. The terraces, of late Pleistocene age, are cut into upturned strata of the Belt series, which form the east side of the inner river gorge; they are capped with the following unconsolidated material:

Deposits east of Kootenai River at Leonia, Idaho

	Altitude (feet)
Silt, stratified, overlying a dissected rock bench and slopes	2,400–2,175
Gravel, coarse, over argillite	2,175–2,150
Gravel, coarse, on narrow terrace	1,975–1,950
Rocks of the Belt series, upturned beds nearly vertical forming cliff face	1,950–1,810

The inner gorge is 300 to 400 ft deep and barely wide enough for the river channel and the railroad.

GLACIATION OF THE PURCELL TRENCH

PRE-WISCONSIN GLACIATION

The width and depth of the inner valley of the Kootenai River in Boundary County, Idaho (pl. 2), at the time of the first glacial invasion is not known. The bottom was probably not as low as the present outlet from the west arm of Kootenay Lake near Nelson, British Columbia, which is about 1,730 ft above sea level (p 59); it may have been as much as 2,000 ft above sea level.

There were probably at least three glacial invasions of this region and an equal number of recessions of the ice fronts. It has not yet been found possible to differentiate the effects of the earlier of these stages in the part of the Purcell Trench near and below Bonners Ferry from those of the last (Wisconsin) stage. There is, however, some doubtful evidence that an early Pleistocene lobe of the Cordilleran ice sheet advanced southward up the valley of the Pend Oreille River to and across the hills near Sacheen and Diamond Lakes, southwest of Newport, Wash., and that it reached the vicinity of Cheney, Wash., 15 miles southwest of Spokane (fig. 19). There are also indications that the Flathead lobe of the Cordilleran ice advanced equally far south in the Rocky Mountain Trench reaching the Jocko Valley in the vicinity of Dixon, Mont. It is probable, therefore, that there was at least one similar extension of the Cordilleran ice in early Pleistocene time southward along the Purcell Trench, and that it reached the vicinity of Coeur d'Alene, Idaho.

Conditions east of the mountains in the Mississippi basin indicate that there were at least three stages of advance of the continental ice sheets prior to the last (Wisconsin) stage of glaciation and that these stages alternated with stages of deglaciation during which the ice sheets melted away and the streams resumed their cutting in the glaciated valleys that were partly filled with drift. A similar alternation of stages probably took place in the Purcell Trench. The Kootenai River may have appreciably widened the inner valley below (north of) Bonners Ferry during the interglacial stages, but it could not cut appreciably below the outlet at the West Arm of Kootenay Lake. The depth of valley cutting by glaciers, however, is not limited by such base levels as a rock sill in an outlet. In many places glaciers are known to have excavated basins in the rock to depths of several hundred feet below the levels of the outlets of the basins. The maximum depth of Kootenay Lake known to the writer is about 450 ft, and this much, at least, of the deepening of Purcell Trench north of the boundary is probably the result of glaciation unless some of it is due to Pleistocene or Recent faulting. The depth of glacial scour below the level of the outlet probably decreased southward in northern Idaho to a minimum in the vicinity of Bonners Ferry, where the bedrock is exposed above the flat bottom land.

There is more certainty about the glaciation of the Purcell Trench during one of the later pre-Wisconsin stages than about the earlier ones. This rather late glacial advance is perhaps to be correlated either with the Illinoian stage of glaciation of the Mississippi basin or with the deposition of the Iowan drift in Iowa and adjacent states. During this stage, which Bretz (1923, p. 580) has designated the Spokane glaciation, a lobe of the Cordilleran ice advanced southward up the valley of the Pend Oreille in northeastern Washington, crossed the divide near Sacheen and Diamond Lakes southwest of Newport and reached its limit near Spangle, Wash., about 15 miles south of Spokane. At the same time other lobes invaded the Columbia Basin and Okanogan Valley farther west in Washington. One lobe, designated by Anderson (1927, p. 14, pl. 1) the "Rathdrum lobe", advanced southward along the Purcell Trench, crossed the divide south of Bonners Ferry and reached its limit in the broad Spokane Valley between Coeur d'Alene, Idaho, and Spokane, Wash. The thickness of glacier ice in the vicinity of the 49th parallel was probably fully as great during the succeeding stage—that is, it was about 5,500 ft thick as determined by Daly; so great was its volume that for some distance south of the international boundary all but the highest crest of the Selkirk Mountains on the west and of the Purcell Mountains on the east were probably submerged and overridden, and the ice crowded far up on the flanks of the Cabinet Mountains in Boundary and Bonner Counties, Idaho. Morainal and terrace deposits of drift that accumulated at the margins of this lobe are still preserved near Spirit and Twin Lakes and near Post Falls in Kootenai County, Idaho, and much of the great fill of sand and gravel in the broad valley between Pend Oreille and Coeur d'Alene Lakes and Spokane was probably deposited as outwash at this stage by water from the melting ice. Farther north the deposits of this and earlier stages are overlain by those of the Wisconsin stage and are either not now exposed or are not readily distinguished.

It is probable that every time the Rathdrum lobe of the Cordilleran ice advanced southward along the Purcell Trench in northern Idaho it crowded southeastward from Pend Oreille Lake basin into the valley of Clark Fork whose drainage became completely dammed. The name glacial Lake Missoula was given by Pardee to the extensive branching lake thus formed in the valley of Clark Fork and its tributaries. The highest levels of this lake and the longest continued lake stage are presumably to be correlated with the stage of glaciation during which the Rathdrum lobe extended farthest beyond the outlet of Clark Fork valley; that is thought to have been during the so-called Spokane glaciation. The highest levels of the lake definitely indicated by shore lines are nearly 4,200 ft above sea level in the vicinity of Missoula, Mont.

Saint Regis Pass between the Clark Fork drainage and the South Fork of Coeur d'Alene River is 4,727 ft above sea level where crossed by the Northern Pacific Railway. There is no known lower pass farther south that could have served as an outlet of the lake and there are no known indications of submergence to so high a level as this. It thus appears that Lake Missoula first spilled over a col farther north. About 6 miles southwest of the village of Clark Fork, Idaho, there is a col at the head of Granite Creek between 4,000 and 4,100 ft above sea level, as shown on the topographic map of Priest Lake.

Stebinger (unpublished notes) in 1914, found glacial boulders on top of Antelope Mountain, east of Clark Fork village, at an altitude of 4,350 ft, or 2,300 ft above the present level of Pend Oreille Lake; it is therefore certain that the glacial ice dam was more than high enough to have held a lake up to the level of this col. The present writer found striated stones on the slope northeast of this col as high as 3,800 ft above sea level. It may be that this col was at first as high as the uppermost of the observed shore lines (about 4,200 ft above sea level) and was later cut down by the outflows; or the glacier may at first have crowded the outflow a little farther up on the mountain crest. After passing this col the water, flowing southwestward along the margin of the ice in Pend Oreille basin, may for a time have been so held as to have spilled over southward into the valley of the North Fork Coeur d'Alene River by way of a col south of Bernard Peak, at 4,100 to 4,200 ft above sea level, and thence by a roundabout course to the main Coeur d'Alene River and Lake. A little later it may have found egress into Hayden Creek basin through the col southeast of Cedar Moutain at 4,000 to 3,800 ft and so have lowered glacial Lake Missoula to the 4,000-ft level noted above.

Between 5 and 7 miles southwest of the foot of Hayden Lake a small plateau on the north side of the Spokane River, known as Ross Hill, stands 200 ft or more above the river on the south, and 50 to 100 ft or more above the gravelly plain on the north and east. The surface of this plateau is sprinkled with boulders and marked by swells and swales, suggesting that it is a remnant of a moraine formed at the south side of the Rathdrum lobe. There is also a belt of swells and swales between 1 and 3 miles north of Post Falls, which extends northeast-southwest past Evergreen Cemetery. A short distance west of a line from Rathdrum to Post Falls there is a short, abrupt drop of 20 to 50 ft from the upper plain to a lower plain. West of this terrace front there are great numbers of boulders 1 to 10 ft in diameter; they may have been dropped by bergs detached from an adjacent glacial front, or they may belong to a partly buried moraine from which the finer material has been washed away.

Extending northeast from Ross Hill is a similar belt of low swells with many large boulders like a nearly buried continuation of the same moraine. This belt may not mark the most southeasterly limit reached by this side of the ice lobe, but it probably does represent one rather prolonged stand of the ice front while outwash gravel was being swept eastward and southeastward to dam Hayden, Fernan, and Coeur d'Alene Lakes. Until there was further recession of the ice front the outflow from glacial Lake Missoula would join these waters and escape westward down the Spokane Valley. Anderson (1927, p. 18) gives the height to which the water ponded by the glacier in the confluent valleys of Coeur d'Alene, Saint Joe, and Saint Maries Rivers rose to 2,700 ft above sea level or nearly 600 ft above the present lake level. This height is indicated by the uppermost of the berg-dropped boulders found on the bordering valley sides. To this body of water Anderson gave the name "glacial Lake Coeur d'Alene." To have held this lake up to the 2,700-ft level the glacier, for a time at least, must have crowded against the lower slope of the mountains west of the lake and have overlain the 2,500-ft basalt bench west of Coeur d'Alene. There are drift boulders as high as 2,600 ft or more above sea level scattered on the upland north and west of Hayden Lake, which were dropped either from floating ice or directly from the glacier.

Where the writer examined the top of Tubbs Hill, which is an isolated hill of gneiss and schist 350 ft high, forming a short peninsula on the north shore of Coeur d'Alene Lake, no drift or other evidence that glacier ice had overridden the hill was seen, though the hill stands almost in the middle of a dammed valley. Examination of the western part of the top of the narrow basalt bench (2,500 ft above sea level), northwest of the outlet of the lake, showed no evidence of glaciation, but granite boulders, perhaps berg-transported, lie in the east-west sag or channel that separates the basalt cap from the slope to the south.

It is probable that the ice entirely overrode Lone Mountain, about 3 miles northeast of Twin Lakes as the mountain crest is 800 ft above the flat on the east; but, the writer found neither drift nor striated or polished ledges for 300 to 600 ft up and down the rounded north end and the southwest slope. There appears to have been sufficient etching and spalling of the exposed surfaces of the schist and gneiss ledges since the disappearance of the glacial lobe to remove any definite evidence of glacial abrasion.

A brief examination of the ledges of gneiss at Post Falls was made, but the writer saw no glacial striae. Anderson (1927, p. 15), however, reports "striations or scorings on the granitic rocks at Post Falls, showing that the ice there moved S. 80° W." He also states that "polished bedrock of granite and pegmatite with glacial striae or scorings on the top composed some low knobs which project 50 feet above the valley fill between the towns of Trent and Opportunity, 12 to 14 miles farther west, in the Spokane Valley" and that "this shows the ice traveling southwest at an angle of approximately S. 40° W. in direct line with the west face of the low mountainous spur on the south side of the valley facing the plateau," (Manito Prairie) south of Spokane. The present writer visited these same low knobs south of Trent but failed to find such evidence of glaciation, although there was considerable evidence of wind blasting.

To what extent the ice of this early stage crowded up onto the slopes and spurs of the mountains north of Spokane Valley, the writer cannot state. In traversing the auto road leading northeast to the top of Mount Spokane, 8 to 10 miles west of Spirit Lake, Idaho, the writer saw no drift above an altitude of 2,800 ft. Either at its maximum limit or when the west front of the Rathdrum lobe had receded to the eastern foot of this and the adjacent mountains, rather extensive morainal deposits were laid down. Much of the triangular plateau (2,500 to over 2,600 ft above sea level) between Athol, Idaho, and Spirit Lake appears to be a morainal deposit of this stage. South of the main road and east and west of the bend of the Chicago, Milwaukee, St. Paul & Pacific Railroad the surface is pitted with kettle holes and on it are numerous big granitic boulders.

A well at Athol (about 2,375 ft above sea level), which is just east of this plateau and about 150 ft below its level, is reported by the owner, Sam Yates (written communication), to have been put down to a depth of 380 ft. No solid rock was encountered, but the material in the lower part was somewhat cemented so that it was blasted in order to drive the pipe. The bottom of this well is said to be 35 ft lower than the lake level at Sandpoint. George R. Charters stated that a well was dug by hand through about 500 ft of sand and gravel at the Coleman and Charters ranch on the plateau east of Spirit Lake. At the bottom, rock, possibly a boulder, was struck; a hand drill was driven into it for 10 ft. The bottom of this well is nearly as low at the Pend Oreille River in the vicinity of Laclede. The deposition of this great amount of drift directly in front of the valley of Brickel Creek completely blocked that valley and formed Spirit Lake. R. E. Seely said that a sounding showed a depth of 90 ft of water about 300 yd offshore in the southeastern bay.

The mouth of the valley of Fish Creek also was dammed by the glacial drift so that the basin of Twin Lakes (Fish Lake) was enclosed. The moraine may at first have been continuous southward from Spirit Lake to Lone Mountain. However, it is now cut by a gap 1 to 2 miles wide through which the lower gravel terrace extends southwestward to the shore of Twin Lakes. Between this gap and the southwestern foot of Lone Mountain is another plateau remnant of the moraine about 2 sq mi in extent and 2,500 to 2,600 ft above sea level. It is partly wooded and has an abrupt bluff margin rising 50 to 200 ft above the adjacent lower terraces on the northwest and southeast, and more than 200 ft above Twin Lakes. It is possible that the lower 4 miles of Twin Lakes was not at first so narrow or so crowded over onto the lower rock slope as now. The westward dip of cross bedding in fine gravel about the north shore suggests that the constriction of the lake was due to the deposition of delta foreset beds in a wider and higher lake when the lower terrace, which is about 100 ft above the present lake level, was being developed.

The material exposed at the margins and on top of the morainal plateau was glacial drift composed of fragments of sedimentary rocks of the Belt series and granitic rocks, some of the latter 10 ft or more in diameter. No basalt was noted in the drift and none was seen cropping out in the bluff or on the plateau. The west margin of the ice may have split over Lone Mountain; and if so, the moraine in its lee was deposited between a minor lobe on the northwest and the main glacier on the southeast.

Within a mile southwest of the foot of Twin Lakes the mouth of a short gulch east of Rathdrum Bald is blocked by a wooded lateral moraine 200 to 250 ft in height and 2,500 ft above sea level. The abrupt east slope of this moraine is loaded with boulders of granite, gneiss, and schist ranging from 1 to 25 ft in diameter. Similar large boulders are scattered on the adjacent lower flat southward through the Nelson ranch nearly to Rathdrum. In the basin west of this moraine there was probably a small lake that drained southward through the narrow gap behind the abrupt hill of rock to the south. Between this rock hill and Rathdrum, a shallow reentrant at the foot of the mountains is occupied by a glaciomarginal gravel terrace 2,300 to 2,400 ft above sea level, above the top of a 100-ft, southeast-facing bluff bordering Rathdrum Creek. This terrace consists of fine stratified gravel overlying schist. The presence of the morainal deposits and of the big boulders between Lone Mountain and Rathdrum, of glacial striae on the rock at Post Falls, and of the moraine forming Ross Hill shows that the Rathdrum lobe extended southwestward at least as far as a position within 4 miles of the Idaho-Washington State line. If, as Anderson has indicated, there are southwest-trending glacial striae on the rock ledges south of Trent, the Rathdrum lobe must have extended 9 miles or more west of the State line. There seem to the present writer, however, to be some reasons for thinking there may have been an interval between the end of the Rathdrum lobe and the ice of the southward-moving "Spangle" lobe and that this interval was occupied by an extension of the glacial lake which Anderson has called "Lake Spokane".

There are, on both sides of Spokane Valley west of Rathdrum, several tributary valleys and gulches whose mouths have been obstructed by fills, as were those in which Spirit and Twin Lakes lie. (See topographic maps of the Spokane, Wash.-Idaho quadrangle.) In three are, respectively, Liberty, Newman, and Hauser (Sucker) Lakes. Other such basins have been drained. About 2 miles southwest of Rathdrum a marginal boulder-strewn ridge 200 ft high of fine gravel lying on gneiss (about 2,360 ft above sea level) backs a shallow basin, the bed of a former lake, about a square mile in extent. To the southwest of an intervening spur of the upland is a triangular flat terrace about 2,350 ft above sea level. Along the 200-ft marginal bluff below this terrace a cut on the road exposes fine stratified gravel with few boulders. Similar fine stratified gravel appears to compose the glaciomarginal terrace fills below Hauser Lake, altitude 2,300 ft, and below Newman Lake, altitude 2,200 ft. So far as noted, the only evidence that these fills may be lateral moraines is that they shut in lake basins north of them. They are neither rough nor bouldery like typical lateral moraines. Though somewhat lower, their levels may have been determined by that of water flowing southward through the narrow pass (2,500 ft above sea level) north of Mica, Wash., which is now traversed by the Union Pacific Railroad, Oregon Short Line.

One to two miles southeast of the Spokane River bridge there is a small gravelly bench 2,200 ft above sea level at the north end of the rock ridge west of Skolan Creek, Idaho. Fine stratified gravel is exposed at one point below this bench and there are some slight sags and boulders on its top. This is either an ice-margin terrace or, like Ross Hill east of Post Falls, a remnant of a south lateral moraine of the Rathdrum lobe.

The gravel fill that retains Liberty Lake has a smooth top about 2,150 ft above sea level, is more than a mile wide, and has an abrupt lakeward margin, but it looks more like a lacustrine bar or an erosional remnant of the original top of an outwash fill than a glacial moraine. Across the ridge to the west the main, smooth, flat, gravel plain, practically unmodified, extends southward for about 2 miles into the mouth of the valley of Saltese Creek, and there ends in an abrupt south-facing margin; south of it is the flat floor of a former lake basin, now drained and farmed.

Beyond the next ridge to the west, in S½ of T. 25 N., R. 44 E., Washington, a similar but much broader fill of sand and fine gravel has a smooth, nearly flat top, a long north slope, and an abrupt south margin 50 to 100 ft high. This fill extends nearly 4 miles from east to west and lies across a broad triangular reentrant in the north margin of the granitic hills. The south-facing gravelly bluff overlooks a basin which formerly held a lake. Water ponded in this basin by the glaciers found an outlet southward to California Creek through the narrow pass north of Mica, Wash. At its maximum this marginal glacial lake occupied the valleys of Saltese Creek, Liberty Creek, and other creeks and extended northeastward to the vicinity of Post Falls, Idaho. The basin now drains northwestward through a narrow gap in the bluff traversed by the Union Pacific Railroad.

About two miles west of Dishman at East Spokane Heights is another smooth-topped gravel bar or terrace 2,000 to 2,100 ft above sea level. It also looks more like an erosion remnant of the higher part of the outwash deposit to the northeast than a moraine. A pit in it exposes fine gravel with granite and quartzite boulders and a smaller percentage of basalt boulders. Striated boulders were seen on a higher terrace or bench 2,300 to 3,400 ft above sea level, about a mile farther south. They may have been dropped from floating ice.

About a mile to the west the Inland Empire Interurban Railroad extends through a large excavation in a low ridge 2,200 ft above sea level, north of Pantops station. It exposes about 50 ft of stratified, coarse and fine gravel, and scattered through it are many boulders 1 to 10 ft in diameter, some of them striated. They consist very largely of granite and gneiss. Some of the boulders and a large percentage of the small pebbles are of quartzite.

The character and relations of all the above described deposits west of the longitude of Rathdrum are not such as clearly indicate that the Rathdrum lobe actually extended westward beyond the Idaho-Washington State line. They look more like erosion remnants of the main gravel fill that was washed into ponded waters in Spokane Valley and tributary valley mouths from the front and margins of the Rathdrum lobe as it was receding up the valley. When the Spokane River valley northwest of Spokane was cleared by melting of the Spangle lobe, the next ice lobe to the west, the ponded water was released.

The upper plain east of a line from Rathdrum to Post Falls appears to be the correlative of the uppermost or Lidgerwood terrace, that lies 2,000 to 2,100 ft above sea level at Spokane. The abrupt steplike terrace margins to channels and to broad lower sections of the plain indicate that over considerable areas the original surface of the valley fill was lowered subsequently by erosion, either by water from the melting of the pre-Wisconsin Rathdrum lobe or from the glacier of the Wisconsin stage when its front lay north and east of Athol. One of these abrupt terrace margins extends northeastward past Garwood from a point about 2 miles southeast of Rathdrum. North of the southern limits reached by the later ice advance (that of the Wisconsin stage), features that are due to earlier glaciation cannot, in general, be differentiated from the later ones.

The exact time when the Pend Oreille River first became established in its present course between Sandpoint, Idaho, and Newport, Wash., is not known. The water may have found outlets east and west of Priest River valley worn down below altitudes of 2,400 or 2,500 ft—that is, low enough to overflow when the ice fronts of this stage had receded north of the present channel. Even then, however, the Columbia Basin may for some time have continued to be so thoroughly blocked with ice and drift as to force the glacial waters to cross the Columbia Plateau west of Spokane by way of Grand Coulee, about 1,600 ft above sea level.

Because the effects of glaciation in pre-Wisconsin time cannot be sharply separated from those of the Wisconsin stage, only a tentative interpretation of pre-Wisconsin conditions is warranted. It would seem, however, that, owing to the northerly trend of the Pend Oreille River valley below Newport in northeastern Washington, glacial Lake Missoula extended into that part of the valley in pre-Wisconsin time and continued to be ponded at altitudes of 2,300 to 2,400 ft until the south front of the ice in the lower valleys of the Pend Oreille and Columbia Rivers had receded to a position 4 or 5 miles north of the international boundary and there opened a lower outlet. That the ponded water remained for so long at an altitude of at least 2,400 ft appears to be indicated by the present height of erosion remnants that mark the top of the drift fill in the Purcell Trench near Athol in northern Kootenai County, Idaho, and between Newport and Spokane in Washington. Further, under such conditions, water of glacial Lake Missoula, ponded at the 2,400-ft level, evidently extended northward along Purcell Trench into the valley of the Kootenai River, where the ice front receded simultaneously with the fronts of the other glacial lobes. The present altitude of the erosion remnants in the pass near Elmira, north of Pend Oreille Lake, ranges from not higher than 2,100 to about 2,400 ft above sea level. The water in the valley of the Kootenai did not drop below this level until the ice in Purcell Trench, in the lower valley of the Kootenay River (British Columbia), and in the Columbia Basin, had melted back so far north as to open a lower outlet through the West Arm.

WISCONSIN STAGE OF GLACIATION

During the Wisconsin stage of glaciation, following an interval of deglaciation and stream erosion, there was a vigorous readvance of the Cordilleran ice across the 49th parallel and of each of the local mountain glaciers. Several lobes of the Cordilleran ice were not quite so extensive as at the earlier stage of glaciation. The Okanogan lobe, however, so blocked the Columbia River gorge in eastern Washington that the Grand Coulee again served as an outlet, about 1,600 ft above sea level, for such water as came to it from the east (fig. 16). The Columbia Basin was occupied by glacier ice above the mouth of Spokane River, and another ice lobe advanced southward up the valley of the Pend Oreille River in northeastern Washington nearly or quite to the headwaters of Little Spokane River in the vicinity of Newport.

Concerning the ice lobe in Pend Oreille County, the most northeasterly county in Washington, Salisbury (1901, p. 723) states:

> In the Pend d'Oreille Valley there was another ice lobe, which extended down [southward up] the valley to a point three miles southwest of Davis Lake. To the northwest this moraine is believed to connect with that of the Colville lobe, north of Old Dominion Mountain, though this connection was not established. The moraine of this lobe crosses the Pend d'Oreille River to the eastward at the great bend of the stream eight or ten miles above [below] Newport. East of the Pend d'Oreille the moraine of the east side of this ice lobe was judged, on the basis of topography, to turn northward.

GLACIAL LAKES AND SPILLWAYS

In the southern part of Pend Oreille County there is a belt of rock hills south of Diamond Lake and 8 to 15 miles south to southwest of Newport, Wash. Some of the water from the ice lobe may have flowed southward through the broad gap in these hills, in which are

Sacheen Lake and Trout Lake, and thence down the valley of West Branch Little Spokane River in which are Horseshoe, Fan, and Eloika Lakes. (See topographic map of Newport, Wash. quadrangle, 1940.) There was also an outlet southeastward through Spirit Valley near Blanchard, Idaho. Much of the water flowed southwestward from the vicinity of Newport and escaped through the gap west of Mount Pisgah. During the later stages this outflow scoured a well-defined spillway which now hangs 100 ft or more above the Kootenai River, about a mile west of Newport. The Little Spokane River in this spillway heads less than 2 miles from the Kootenai River and flows through the narrow rock gorge known as Little Scotia Canyon into Chain Lake and to the wider part of the valley below the village of Elk.

The work of the glacial waters south of the valley of Pend Oreille River appears to have been largely the erosion of deposits made by the earlier glacier and the development of the lower terraces. Though the relations have not as yet been accurately determined, it seems probable that during the Wisconsin stage the south front of the glacial lobe extended to the rock hills west of Newport, and it may have reached the vicinity of Horseshoe, Trout, Sacheen, and Diamond Lakes south of these hills.

A conspicuous feature near Newport is the high, wooded, gravel terrace on the southeast, south, and west, whose top is 2,350 to 2,400 ft above sea level, or 250 to 300 ft above the river. It borders the east and south flanks of Cooks Mountain west of Newport and extends thence southwestward toward Diamond Lake, except where rock ridges intervene or where it has been completely cut away. Newport (2,137 ft above sea level) is situated on a low terrace at the Idaho-Washington State line. From the southeastern part of the town an intermediate terrace, 2,200 ft above sea level, extends eastward. A long excavation in the lower edge of this terrace beside the Great Northern Railway exposes loose gravel with cross beds dipping westward. In excavating the gravel, many 1- to 8-ft embedded boulders have been left exposed in the bank or lying beside the railroad. Above and behind this terrace there is a steep slope to the head of the high south-sloping sandy terrace 2,400 ft above sea level. This terrace extends westward to the Little Spokane spillway southwest of Newport, and appears to correspond in height with the upper terrace farther west near Cooks Mountain. The altitudes and topographic relations, so far as studied by the writer and as shown on the topographic map of the Newport quadrangle, indicate that this high terrace was formed while glacier ice lay in the Pend Oreille valley and impounded water high enough for it to spill southward through several passes between the rock hills to the valley of Little Spokane River. In this water a great fill was made to a height of 2,400 ft above sea level. It is probable that the Little Scotia Canyon, whose bottom is now less than 2,100 ft above sea level, was then not lower than 2,300 ft. After passing the hills the water partly eroded the sand and gravel in the valley of Little Spokane River to the south and thus formed the lower terraces there, but south and southeast of Fivemile Prairie the Lidgerwood terrace (2,000 to 2,100 ft above sea level), the site of Hillyard and the northern part of the city of Spokane, was left uneroded as far south as the Spokane Valley. Later, continued outflow deepened the Little Scotia Canyon and cut the spillway, which is now drained by the upper part of the Little Spokane, to within 2 miles of the Pend Oreille River at Newport.

The eastern limit of the glacial lobe that occupied the valley of Pend Oreille River during the Wisconsin stage has not been traced by the writer. Judging from the topographic map of the Newport quadrangle, it seems probable that the lobe extended nearly to Newport; to the north, the ice lay along the flank of the mountains on the east in such positions as to obstruct the drainage of several of the mountain gulches and to cause the deposition there of the gravel and other drift behind which Freeman, Shearer, Bead, Mystic, North and South Skookum, Kings, and Browns Lakes are impounded. The intervening rock spurs are transected in several places by gaps, which may have served as spillways for water flowing southward from the ice front. The upper gravel terrace ranges in altitude from about 2,860 ft near Bead Lake to 2,400 ft 1 mile east of the Newport bridge. These altitudes correspond with those of the high terrace remnants on the opposite side of the Pend Oreille River, indicating that the surfaces were probably parts of one continuous gently sloping deposit.

Further evidence that a glacial lobe advanced southward up the valley of the Pend Oreille River is a glacially smoothed, polished, and striated limestone ledge exposed in a cut on State Route 6 on the west side of the river, 2 to 3 miles south of Metaline, Wash. Overlying the glaciated surface of this ledge is fine sand and laminated silt which was deposited in a lake that occupied the inner valley for a time while the glacial lobe was being melted northward but before an outlet to the Columbia Basin was freed of ice. Rather large deposits of such glaciolacustrine silt are exposed at Metaline Falls, Wash.

During the Wisconsin stage of glaciation the Selkirk Mountains in northern Idaho were again nearly but not quite submerged beneath the ice for some distance south of the international boundary, and a lobe, probably fed in part by local mountain glaciers, lay in the valley now occupied by Priest Lake and Priest River (pl. 2). (See topographic map of Priest Lake, Idaho-Mont. quadrangle.) This lobe appears to have extended southward to a transverse morainal ridge 1 to 3 miles north of the mouth of Priest River 2,200 to 2,500 ft above sea level. Some cuts here expose till and others expose coarse bouldery gravel overlying fine laminated sandy clay or lacustrine silt. The somewhat uneven top and south slope of the ridge are strewn with boulders 1 to 10 ft in diameter. It is bordered on the south by an outwash gravel terrace about 2,200 ft above sea level, below which, on a terrace about 100 ft lower, is the town of Priest River. Both before and after the ice front stood at this morainal ridge, water ponded in the Pend Oreille valley appears to have extended northward into the valley of the Priest River and in it was deposited fine lacustrine silt that underlies the broad flat tracts. Glacial till was observed in road cuts south of Nordman, and striated pebbles were seen nearly as far up the road as the pass between the heads of Granite and Pass Creeks. Some may have been the product of glaciers heading in local cirques on this ridge. The uppermost erratic boulders seen on the mountain road to Stone Johnny lookout, 7 or 8 miles northwest of Priest River village, were nearly 3,800 ft above sea level and 1,500 ft above the West Branch of Priest River.

During the Wisconsin stage the Purcell Trench was occupied by a great glacial lobe that extended as far as the south end of Pend Oreille Lake and the vicinity of Athol, Idaho. There appear to have been minor terminal sublobes of this glacier, one of which lay in the valley of the Pend Oreille River. Glacial till and smoothly rounded, polished, and striated ledges exposed in grading the highway (US 195), indicate a southwesterly extension of the West Kootenai lobe of the Wisconsin ice down the Pend Oreille valley to a point about 4 miles below Laclede. Stratified gravel exposed at some places, with delta foreset beds dipping southwestward, and fine, laminated sand and sandy clay exposed at other places along this part of the valley indicate that the front of this part of the ice was for some time bordered by ponded water. Evidently a lake was held between the oscillating front of this part of the ice and the end of the more westerly lobe near Newport.

Loamy clay deposited in this lake underlies the terraces (2,100 to 2,200 ft above sea level) along Cocolalla Creek two-thirds of the way through the gap in the rock hills east of Laclede. Granitic ledges west of the lower end of Cocolalla Lake are smoothly rounded as if by glacial abrasion but, where examined by the writer, the surfaces have been so roughened by etching and spalling as to remove any glacial polish and striae that may have been there.

The axial flow of this great glacial lobe to the earlier advance of which Anderson (1927, p. 14, pl. 1) gave the name "Rathdrum lobe", was southward along the deep trough in which Pend Oreille Lake now lies. At the south end of the trough the ice was forced westward into the broad gap between Cape Horn Peak on the north and Bernard Peak on the south. During its maximum advance some of the ice may have entered the Hoodoo Valley. In the eastern part of this valley there is a great depression, nearly 3 miles long, and half a mile to one mile wide. It is shut in on the west by a great deposit of gravel with an abrupt ice-contact bluff nearly 100 ft high. From the crest of this bluff a smooth flat surface (2,200 to 2,300 ft above sea level) slopes westward like an outwash terrace. The great depression, or fosse, is such as is sometimes found where a great mass of ice, or the front of a glacier, has lain unmelted while the adjacent gravel was being swept out and deposited against the retaining ice wall. The floor of the fosse is now occupied by ranches and hay fields.

The position of the main south front of this glacier during the Wisconsin stage is not very clearly marked. The gravelly plateau (2,400 to 2,600 ft above sea level) between the hills near Spirit Lake on the west and Athol on the east was probably the product of pre-Wisconsin glaciation. As shown on the topographic map of the Rathdrum quadrangle, this plateau is cut off sharply on the north, northeast, and east by an abrupt bluff 100 to 200 ft in height. This bluff may represent a pre-Wisconsin ice-contact margin somewhat modified through erosion by water flowing from the southeast past Clagstone, and from north past Athol from the front of the Wisconsin glacier. Bordering the foot of the northeast-facing bluff are two or three terrace steps marking stages in the erosion of the Hoodoo Valley by waters issuing from the Wisconsin ice front while it was gradually being melted northward through Pend Oreille Lake basin.

Northeast of Athol is a very extensive, southward-sloping outwash plain that heads at the crest of another and lower steep bluff, 100 to 200 ft in height. Near U. S. Highway No. 95, 2 miles north of Athol, the upper (north) border of this broad plain or terrace is marked by swells and swales typical of morainal topography, suggesting that here the south front of the Wisconsin glacier extended between the plateau northwest of Athol and the southwest end of Pend Oreille Lake basin. If, during interglacial time, the broad plain or valley bottom that extends southward from Pend Oreille Lake to and beyond Rathdrum Prairie was dissected or cut lower than its present surface, then sand and gravel washed from the Wisconsin ice front doubtless refilled the eroded tracts and smoothed the plain. Where the plain is not now relatively as high as when left by the melting of the earlier glacier, the surface was probably lowered in consequence of erosion by the Wisconsin glaciofluvial stream after it had dropped its load. Some channels and some steps down to lower levels, such as are found at several places between Pend Oreille Lake and the Idaho-Washington State line in the Rathdrum quadrangle are probably due to such glaciofluvial erosion. To such erosion may also be due the terrace that lies about 100 ft lower than the main floor of the Spokane Valley and extends from a bluff 1 to 2 miles southeast of Trent westward down the valley. On this terrace most of the business part of Spokane is built (1,800 to 1,900 ft above sea level). While this terrace was being developed, Columbia River was probably flowing across the basalt plateau via the lower part of Grand Coulee, about 1,500 ft above sea level (fig. 14, p. 57). When further melting of the Okanogan lobe reopened Columbia River gorge below the head of Grand Coulee, all the tributaries to the east rapidly cut into the valley fills and the glaciofluvial water from Pend Oreille Lake was diverted down the Pend Oreille River. For a time water flowed directly west from the head of Squaw Bay to the Hoodoo Valley. Later the flow went through the narrow, rocky gorge west of the village of Granite and thence northward down Hoodoo Creek to the river; still later all the outflow followed the Pend Oreille valley below Sandpoint.

During the Wisconsin stage a large sublobe of the ice again crowded into the valley of the Clark Fork east of the Pend Oreille Lake basin (fig. 14, and pls. 1 and 2). Glacially smoothed and striated ledges are exposed in some cuts on the highway (SR 3) between the Pack River and Hope, Idaho. About a mile southeast of the village of Clark Fork a large vertical face of limestone at the southwest side of Antelope Mountain was smoothed and striated by southeastward-moving ice. The striae are nearly horizontal and obliquely cross the edges of the rock strata, which dip southeastward at low angles (fig. 31). The dam formed by this ice lobe may

FIGURE 31.—Vertical face of glaciated bluff near Clark Fork, Idaho. Nearly horizontal striations cross the edges of eastward-dipping strata obliquely. The glacial lobe that striated this bluff was crowding eastward (left to right) from Pend Oreille Lake basin into the gorge of the Clark Fork and formed an ice dam impounding glacial Lake Missoula.

not have been quite as high as that formed during the preceding stage, but it again ponded water so as to cause another filling of glacial Lake Missoula. The water during this stage may have had nearly as great an areal extent as before and may have risen 3,500 ft or more above sea level before the ice dam was again lowered by melting and erosion. So long as the gorge of the Columbia River was dammed by the Okanogan ice lobe in Washington, the outlet for glacial water and other tributary drainage was by way of Spokane River and the Grand Coulee to the lower Columbia River, and the earlier fill in these valleys was in part increased and in part cut away.

The upper terrace of the glacial Lake Missoula basin on the Clark Fork near and east of the Idaho-Montana State line is 2,400 to 2,500 ft above sea level—that is, high enough for water flowing thereon to have spilled over the part of the basalt plateau south and west of Spokane, if the Grand Coulee was not open.

There are extensive flat tracts at two or more levels in the broad trough between Pend Oreille Lake and the valley of the Kootenai River at Bonners Ferry, Idaho. The highest are 2,400 to 2,500 ft above sea level—that is, they are at altitudes corresponding to outlets for glacial waters flowing southward to Spokane River across the divides near Athol, Idaho, and south of Newport, Wash. There are remnants of the upper level east and southeast of Elmira, but the lower level continues northward through the narrow part of the trough (2,149 ft above sea level) near Elmira. In general, where the material is exposed, these flats are underlain by fine, laminated sand and silt, and in places, as near Samuels and north of McArthur, the fine sand has been blown about, forming low swells or dunes. North of the village of Naples, Deep Creek and its tributaries have cut hundreds of feet into the valley fill, and where there are railroad cuts in the steep bluffs of the inner valley, 100 ft or more of fine, stratified silt is exposed. Near Naples some coarse gravel is exposed at the top of one cut, and farther north coarse gravel and glacial till are exposed below the lacustrine silt. Here and there hills of rock rise above the surrounding flat tracts in the midst of the great "trench". In places coarse drift is present on slopes higher than the silt terrace. The relations of these unconsolidated deposits seem to indicate that, when the front of the last glacier was melted back northward from the Pend Oreille Lake basin and the Pend Oreille River valley in Idaho and northeastern Washington, the waters of glacial Lake Missoula were drained from most of the valley of the Clark Fork in Montana. The lake in its closing stages thus extended westward into the Pend Oreille valley with an altitude of about 2,400 ft; there it expanded northward as the ice front retreated from the vicinity of Newport, Wash., to that of the 49th parallel, and from the Pend Oreille Lake basin in north Idaho to and down the valley of the Kootenai.

GLACIATION IN THE VALLEY OF KOOTENAI RIVER IN IDAHO

It has not yet been found possible to differentiate clearly any of the glacial features in the valley of the Kootenai River near and north of Bonners Ferry, Idaho, as the products of pre-Wisconsin glaciation. They may, therefore, be treated here as though they were mostly the products of a single glacial advance and recession comprising the last or Wisconsin stage of glaciation.

As stated above, the maximum thickness of the ice was very great. Daly (1912, pp. 587–588) estimates the thickness of ice at the international boundary as about 4,500 ft over the valley of the Moyie River and about 5,500 ft in the Purcell Trench. Possibly it was not quite so thick during the Wisconsin stage as before, inasmuch as its southward extension was not quite so great. Daly found that in the Selkirk Mountains, west of the Purcell Trench, the summit ridge of the Nelson Range projected as a long nunatak above the surface of the great ice sheet, which to the eastward was about 7,300 ft above sea level; also, that cirques, in which small local glaciers headed, are common along this nunatak. He states, "The observations on the striae occurring on the ridges and peaks showed that the general movement of the ice on the eastern slope of the Nelson Range was in the direction S. 30° E."

Daly records southward-trending striae observed on the rock ledges near Porthill, Idaho, and the present writer found the surface of a granite ledge, exposed in a railroad cut 2½ miles north of Bonners Ferry, to have been smoothly rounded, polished, and striated by the advancing glacier. This ledge is only 30 or 40 ft above the river bank. Southeast of Copeland, Idaho, there was exposed on the highway (US 95) in 1938 a smoothly rounded rock ledge, well striated by southward-moving ice, and at points about 1½ and 5½ miles farther northeast near Mission Creek, striae on ledges beside the road trended S. 75° W. toward the Kootenai River. In a cut south of Brush Creek, 2 miles south of Copeland, Idaho, disintegrated granite was not removed by the overriding ice, but is buried beneath glacial till. Till is exposed in several other of these railroad cuts. Till was observed also at numerous places along the highway (US 95) on the Porthill bench east of Copeland. Thirty feet of glacial till overlain by coarse gravel is exposed in a road cut at Moravia near the Great Northern Railway tunnel, 5 miles southwest of Bonners Ferry.

Till with abundant boulders, many of them striated, can be seen along the road east of Bonners Ferry, north past Dawson Lake, and east down Meadow Creek, and thence north up the valley of the Moyie River. That the ice in Moyie River valley extended southward into and part way up the valley of the Kootenai River is shown by the presence of a bed of till exposed on both sides of the narrow gorge east of Moyie Springs railroad station. This till is underlain by coarse gravel with some stratified sand layers and is overlain by finely laminated lacustrine silt. Till is exposed also farther southeast on U. S. Highway No. 2 in the Kootenai River valley, and, as stated above, a rock ledge on the highway near the Idaho-Montana State line shows glacial striae trending S. 45° E. In 1938 the writer observed a glacially rounded and polished rock ledge beside the highway (US 2) about one mile northwest of the Yaak River bridge. This ledge, which was overlain by laminated lacustrine silt, showed striae trending S. 25° E. It thus seems probable that the glacier advanced up the valley of the Kootenai River to the vicinity of Leonia, Idaho, and may have merged with ice that advanced southward down the valley of the Yaak River in Montana toward Troy and the pass near Bull Lake. It may be that Clifty Mountain (6,707 ft above sea level) 7 miles southeast of Bonners Ferry, was not overridden by the glacier at any stage.

Till is underlain by gravel at several places; one is near the mouth of the broad outer valley of Moyie River. The coarse gravel overlies the bedrock at the falls and it may be a preglacial or interglacial deposit formed by Moyie River at a time when the valley of Kootenai River was not occupied by glacier ice. Similar and possibly correlated coarse stream gravel with some interbedded sand is exposed 1 to 3 miles southwest of Bonners Ferry in the Great Northern Railway cut in the lower part of the bluff. This gravel is overlain by laminated glaciolacustrine silt. Gravel, possibly of similar fluviatile origin, is said to have been taken from a large pit at the west side of the low rock hill a mile west of Bonners Ferry.

Water was probably ponded temporarily in front of the glacier in the valley of the Kootenai River during each advance and retreat of the ice front, forming what might be regarded as early stages of a glacial Lake Kootenai. Twenty to twenty-five feet of laminated silt, deposited during one of these lake stages prior to the last one, is exposed in the lower part of the bluff at the south end of Main Street in Bonners Ferry. This lacustrine deposit is overlain by 50 ft or so of very bouldery till which slumps down over the unconsolidated silt. In one of the railroad cuts, 5 to 6 miles southeast of Porthill, stratified silt, which had been overridden by the ice has been disturbed and partly mixed into the till.

In numerous places, finely laminated lacustrine silt overlies the glacial till. Where the highway is graded down the steep sides of the lower gorge of Moyie River near Moyie Springs railway station there were good exposures of the unconsolidated Pleistocene deposits above the rock ledges over which the river falls. The following is a generalized section as exposed in 1930:

Pleistocene deposits at Moyie Springs, Idaho

	Thickness (feet)	Altitude (feet)
Upper terrace:		
(h) Gravel, coarse, bouldery; west of railroad	100	2,300
Terrace on which Moyie Springs railway station is built:		2,200
(g) Gravel, coarse, bouldery	5–10	-----
(f) Sand, fine, stratified; partly covered	----	2,175
(e) Silt, buff, laminated, lacustrine	50	2,150
(d) Till	----	2,100
(c) Gravel, coarse, bouldery	----	-----
(b) Gravel, coarse, stratified; with some interbedded sand	----	-----
Bedrock:		
(a) Northeast-dipping strata in sides of narrow gorge above and below the falls	80	2,050

The bed of till (d) was probably deposited during the last, or Wisconsin, stage of glaciation and the underlying sand and gravel (b and c) may be of interglacial age or may have been washed out in front of the Wisconsin ice as it advanced southward. Following the recession of the ice front, the laminated silt (e) and fine sand (d) were deposited in glacial Lake Kootenai. As the fill approached the level of the Elmira outlet (2,200 ft above sea level) the torrential flow of water from the melting ice in the valley of Moyie River swept the coarse gravel (g and h) out over the finer lacustrine deposits in the valley of the Kootenai River. As the outlet was lowered this deposit was partly cut away, developing the terrace 2,200 ft above sea level, clear across to the hills on the south near Crossport.

In the exposure southeast of the Moyie bridge a bed of glacial till is both underlain and overlapped by lacustrine silt. At one point, 3 to 5 ft of coarse gravel lies in a channel cut in the silt and this is overlain by about 10 ft of silt, above which is coarse gravel. These relations suggest that the glacier front was nearby while the silt was being deposited in the valley of the Kootenai.

There is much laminated silt coating the Porthill bench from Goat River, British Columbia, southward to the vicinity of Bonners Ferry. Cuts on the highway (US 95) and in the sides of the irrigation ditch at Mission Creek southeast of Copeland show the laminated silt overlapping the uneven surface of the till, and a cut at Rock Creek about 5 miles farther south exposes about 150 ft of laminated silt overlying glacial till.

GLACIAL LAKE KOOTENAI

From the relations of the lacustrine deposits overlying the till and from the heights of the terraces capped by or composed of silt it is evident that when the front of the last glacier was melted northward along the Purcell Trench, water was ponded in the valley of the Kootenai River to such levels as permitted its outflow southward through the pass near Elmira, Idaho, and also in part southward past Troy through the pass to Bull River and the Clark Fork in western Montana. The silt on the Porthill bench is 2,100 to 2,300 ft, or even more, above sea level. A great thickness of stratified silt and sand is exposed in the bluff north of Bonners Ferry along U. S. Highway No. 2. Thicknesses of 100 to 300 ft of this silt and very fine sand are exposed in cuts along the roads and railroads, which traverse the ravines and the marginal bluff of the high terrace south of Bonners Ferry. The smooth flat terrace, which is partly wooded and partly cleared and farmed, is many square miles in extent and in its highest part, at Paradise Valley church 4 miles south of Bonners Ferry, it is 2,427 ft above sea level. This part is slightly undulating in consequence of drifting of the sandy soil by wind action.

During part of the time that the Pend Oreille River valley in northeastern Washington and southern British Columbia was blocked by ice, water appears to have been ponded up to these levels by the drift fill in the spillways south of Newport, Wash., and southwest of Pend Oreille Lake basin in the vicinity of Athol, Idaho. This ponding may be regarded as the closing stage of glacial Lake Missoula, inasmuch as it resulted from the recession of the ice front northward from the Pend Oreille Lake basin; when this basin was cleared the lake extended up the valley of Clark Fork nearly to Vermilion River in Montana. When a lower outlet was opened down the Pend Oreille River to the Columbia, however, the part of the lake south of Elmira was gradually lowered below the level of the passes near Elmira and near Bull Lake, Mont., south of Troy, and was finally entirely drained.

So long as the glacier blocked outflow down the valley of the lower Kootenay River in British Columbia, the discharge continued southward over the fill in the pass near Elmira, even after the lake north of the pass had become separated as a result of lowering of the water to the south. It is probable that ponding in the Kootenay River valley during this stage began in the region of Troy, Libby, and Jennings, Mont., with an outlet southward at an altitude of 2,400 to 2,500 ft through the pass at the head of Bull Lake south of Troy. The remarkable terraces formed in this initial stage of what may be called glacial Lake Kootenai and the gravel terraces leading to them are well shown on the topographic map of the Libby quadrangle; they range from 2,300 to 2,500 ft above sea level. Even as far north as Rexford and Gateway, Mont., where the Kootenai River diverges from the Rocky Mountain Trench, the heights of the main terraces correspond approximately to a southerly outlet through the Bull Lake pass. When the lake level in the valley of Clark Fork was lowered below an altitude of 2,400 ft, the outflow at Bull Lake began cutting away the fill, the level of glacial Lake Kootenai in Montana began to drop, and erosion of the highest terraces near and above Troy commenced. The present altitude of the pass at Bull Lake is 2,340 ft. When the ice in the valley between Troy and Bonners Ferry melted sufficiently, the lake in Montana merged with that in the Purcell Trench north of Elmira in Idaho, and the silt and sand derived from erosion of the terraces farther up the valley were swept into the lake in the Purcell Trench and formed the great delta deposit that now forms the extensive high terrace north and south of the river near Bonners Ferry. This deposit of finely laminated silt and sand extends southward from Bonners Ferry through the pass, and its nearly flat surface gradually lowers from Elmira to the shore of Pend Oreille Lake, where laminated silt is well exposed in cuts near Sandpoint. The present altitude of the pass a mile north of Elmira is about 2,150 ft above sea level, but the remnants of the deltas, or alluvial fans of Sand and Grouse Creeks southeast of Elmira are 2,300 to 2,400 ft above sea level; therefore it appears that the initial height of the pass may have been cut down somewhat as the outflow from the valley of the Kootenai continued.

It is not known how far north of Moravia the high terrace was continuous westward across the trench. The flat, undissected part of the lacustrine deposit capping this terrace now lowers gradually northwestward to about 2,100 ft above sea level between Rock and Mission Creeks south of Copeland; it apparently represents the original surface slope of deposition. Daly (1912, pp. 587–588) has suggested that, when the melting glacial lobe shrank from the mountain slopes on either side of the valley, it gradually uncovered the top of the Porthill bench while a long narrow tongue of ice still persisted, stagnant or nearly so, in the inner trench. He has also suggested that Goat River in British Columbia swept silt southward into the marginal lake while its valley was being deglaciated. The lake extended northward over the Porthill bench beside the waning glacier, in consequence of the persistence of the ice therein, and the inner trench was not filled up. In accordance with this suggestion it may well be that the silt mantling the Porthill bench as far south as Copeland came from Goat River and that Mission Creek and streams from the Selkirk and Cabinet Mountains also contributed to the fill. Daly did not extend his studies as far as Bonners Ferry and he did not determine how far south the inner trench remained unfilled. The present writer's studies have not been sufficient to answer that question. The inner trench may have been filled, or partly filled, as far as the point 7 or 8 miles north of Bonners Ferry where the river now swings to the east side of the bottom land. The persisting ice tongue, however, may have protected the inner trench from filling as far south as the rock hill west of Bonners Ferry on which the Indian Mission is situated.

The glacial Lake Kootenai was probably lowered somewhat, possibly as much as 200 ft, by erosion of the fill in the outlet near Elmira while the northward outlet was still blocked by the glacier. When the water ponded in the valley east of Bonners Ferry was drawn down, that part of the lake gave place to the rejuvenated Kootenai River. This stream began at once to cut away the fill in its valley, and its flow combined with that of its tributary, the rejuvenated Moyie River which headed in the melting glacier to the northeast, transected the emerging delta near Bonners Ferry and formed the somewhat lower gravel-capped terrace that is crossed by U. S. Highway No. 2 from Moyie Falls for nearly 4 miles west to Fry Creek. The deposits of this terrace are described in the section for exposures near Moyie Springs, Idaho (p. 151). The stream terrace on which the railroad station at Moyie Springs is located may be correlated with the closing stage of the southward discharge of glacial Lake Kootenai. The gravel capping the two terraces was probably deposited by Moyie River when the further lowering of the lake and the cutting away of the high terrace caused an increase in the stream gradient. It must have been about this time, or soon afterward, that an outlet about 2,000 ft above sea level was opened northward along the west side of the stagnant ice in the inner valley between Bonners Ferry, Idaho, and Proctor, British Columbia, and thence southwestward along the south side of the lower valley of the Kootenay River to the Columbia River. Probably by that time also, if not before, Columbia River had abandoned the Grand Coulee outlet and was flowing past the front of the Okanogan glacier, clearing out the fill below the terrace (1,600 to 1,800 ft above sea level) in its present canyon in northeastern Washington. From this time on glacial Lake Kootenai was gradually lowered as the outlet was cleared of ice.

The relations of the terraces and channels formed east of Bonners Ferry as the lake and river lowered seem to indicate that vigorous discharge from Moyie River forced the Kootenai River to the south side of its valley and caused it to cut around the south side of the low rock hill on which Crossport station is situated, 4 to 5 miles east of Bonners Ferry. From there the Kootenai had to swing in a reverse curve, first northwestward then southwestward over the broad terrace northeast of Bonners Ferry. The establishment of this course started excavation of the broad embayment in the edge of the high terrace north of Moravia. Recurving to the north, the river entered the glacial lake, flowing either to the east or the west of the hill on which the Indian Mission is situated. Deep Creek, coming from the south by this time, had begun the excavation of its narrow valley west of Moravia. Lateral shifting of the Kootenai River as the lake lowered finally developed the broad low terrace northwest of Bonners Ferry, the bottom land below it, and the bottom land south of Mission Hill which formerly contained two lakes.

DEPOSITS OF KOOTENAY LAKE

As the tongue of stagnant ice melted, the open lake extended northward, and into this lowering lake was swept the silt derived from the cutting of the new stream channels to the south and east of Bonners Ferry. When the Purcell Trench and the West Arm were freed of ice to a point north of Proctor, British Columbia, and when the outlet had been cleared to its present depth (1,730 ft above sea level) the Pleistocene conditions merged into those of Recent time (fig. 14). Just how far south the melting of the ice left the head of Kootenay Lake at the present level is not known. There may have been open water at approximately the present high-water level (1,758 ft above sea level) nearly, if not quite, as far south as Mission Hill. There appears to be an ancient beach along the western base of this hill at about 1,760 ft above sea level where granite is exposed. This stage may be referred to as "Kootenay Lake extended."

Inasmuch as the depth of the West Arm and of that part of the Kootenay Lake south of Proctor, British Columbia, is so much greater than the depth of the outlet, evidently none of the coarse material that was washed into the head of the lake was swept along as far as the outlet. Only a very small part of the finest of the silt that could remain so long in suspension was carried through the outlet and down the valley of the lower Kootenay River. It is evident, therefore, that the material derived by postglacial excavation of the inner gorge of the Kootenai River above the vicinity of Bonners Ferry has mostly been deposited in the southern part of "Kootenay Lake extended." With this material there must also have been considerable material derived by the streams from the tributary inner gorges and from the adjacent higher lands of the mountain slopes.

No careful estimate of the amount of material derived by erosion of the inner gorge has been made, but inspection of the topographic maps of the Priest Lake, Idaho, and Libby, Mont., quadrangles, together with the writer's observations in the Kootenai River valley from Gateway, Mont., to the vicinity of Bonners Ferry, Idaho, indicates that the amount of material swept away while the river was cutting below the level of the upper lake and stream terraces was very large. The inner gorge is less than half a mile wide in some places, but in other places it ranges from three quarters of a mile to 2½ miles wide. There are two or more terraces below the highest one in some places. At Libby there is a maximum width of about 3 miles between the eroded edges of the remnants of the highest terrace. The differences in vertical distance between the present stream channel and the eroded remnants range from 250 to 300 ft at Gateway, Mont., to 500 to 600 ft at Bonners Ferry, Idaho.

So far as is known to the writer, no test borings have been made on the Kootenai flats, and there are therefore no adequate data for direct determination of the volume and character of the lacustrine fill in the inner trough of the Purcell Trench. Doubtless there were many glacial boulders, much fragmental rock, and considerable gravel washed into the southern part of the extended lake, inasmuch as there is a good deal of such material exposed in the eroded bluffs below the level of the upper terraces near Bonners Ferry. So far as is known to the writer, however, no material other than fine sand and silt is exposed in the river bank and in the cultivated lands on the flats, and none has been encountered in any excavations or wells on the bottom land below Mission Hill. Thomas R. Newell of the United States Geological Survey (written communication) reports that a well on the flat 2 miles west of Copeland (NW¼ sec. 11, T. 64 N., R. 1 W.) was driven to a depth of 120 ft in loose fine material (silt) without encountering bedrock or any other hard material, such as dense stony till. Evidently a large part of the material derived from erosion of the fill between Gateway and Bonners Ferry was very fine sand and silt, for thicknesses of 50 ft or more of such material are now exposed below the high terrace remnants at numerous places, and in some places, as at Libby, Mont., and near Bonners Ferry, Idaho, as much as 300 ft of such fine material is exposed.

The 380-ft depth of water at the point about 9 miles below the head of Kootenay Lake, indicates the approximate position of the bottom of the basin as left by the melting of the glacier—that is, about 1,378 ft above sea level. The bottom of the well noted above as 2 miles west of Copeland, Idaho, is about 1,645 ft above sea level. A rise of the bottom of the glaciated trough at a rate of 7½ ft per mile for 36 miles southward from the place of sounding would reach the level of the bottom of the well west of Copeland, and a further rise of 8 ft per mile thence southward for 14 miles would reach the surface of the flat at the north end of Mission Hill (1,758 ft above sea level). If this is approximately the gradient of the bottom of the "Kootenay Lake extended", the thickness of the fill at the present head of the lake is about 312 ft. Thence northward the submerged part of the delta would thin from 312 ft to nothing in 9 miles or less. The average thickness of the fill along the deepest part of the trough in the 27 miles between the present head of the lake and the well 2 miles west of Copeland would be 216 ft and the average thickness along the deepest part of the trough in the 14 miles south to Mission Hill would be 60 ft. The width of the bottom land (that is, the top of the fill) north of Mission Hill ranges from 1¼ to 3 miles, and the glaciated bottom of the trough below the fill is probably broadly U-shaped in cross section.

Such a crude comparison as is outlined above gives the impression that the excavation of the inner gorge of the Kootenai River below the level of the high terraces between the vicinity of Bonners Ferry and Gateway, Mont., must have yielded sufficient sediment to entirely fill that part of "Kootenay Lake extended" from Mission Hill northward to the present head of the lake and also to form the submerged part of the present delta; that this is where the material transported by the river was redeposited; and that a very large part of it must have been very fine sand and silt.

Aerial photographs (by the Royal Canadian Air Force in 1929) of Kootenay River valley between the international boundary and the lake show the two distributary channels of the river flowing into the head of the lake between two pairs of long, narrow, and wooded natural levees. Between these channels is a lagoon, and the eastern levee, where it swings to the east side of the valley at Sirdar, British Columbia, encloses the basin of Duck Lake. These photographs show, in marvelous detail, the present and abandoned channels of Kootenay and Goat Rivers and of other and minor streams and the inclosed lagoons and marshes in the Kootenay flats. The meandering stream channels are bordered by natural levees and there appear to be no erosion remnants of the Porthill bench or of other high lands in the Kootenay flats. Similar conditions characterize the flat bottom land all the way south from the 49th parallel to Mission Hill west of Bonners Ferry, as shown by seven of the nine sheets of the detailed map the "Plan of Kootenai River, Idaho, international boundary to a point 1 mile below Moyie River" (U. S. Geological Survey, scale 1:12,000 or 1 in. per 1,000 ft, contour interval 2 ft, surveyed in 1928). From careful examination of these maps and from brief field examinations of parts of the bottom land and adjacent features south of the boundary, there can be little doubt that most of the bottom land north of Mission Hill is due to the incomplete filling of the glacial Lake Kootenai, with fine silt and other material washed into the lake principally by Kootenai River after the lake had been drawn down below the highest level of the southward outlet near Elmira, Idaho (2,300 to 2,400 ft above sea level). It is also evident that the bottom land was brought to its present altitude and condition by such filling after the more extended glacial Lake Kootenai had lowered approximately to its present high-water level, but while it yet extended southward nearly to Mission Hill. This filling is still going on at the present time and, unless some distinct change in the controlling conditions takes place, it will probably continue far into the future until all that part of Kootenay Lake south of the West Arm, and the West Arm itself, is obliterated and converted into bottom land like the present Kootenay flats.

GLACIAL LAKE MISSOULA

GENERAL FEATURES

In the preceding descriptions of the Pleistocene deposits and other features west of the Continental Divide many references have been made to glacial Lake Missoula and the relations of the great ice dam that brought it into existence, probably during two or more distinct stages of Pleistocene glaciation. It may be well, however, to consider somewhat further the history and deposits of this large but now extinct body of water.

The well marked but delicately carved, shore lines of this lake are plainly visible on the slopes of the Clark Fork and its tributary valleys at many places at and below Missoula (fig. 32). They are best observed on smooth grassy slopes where there are few or no trees or exposed rock ledges, when the sun's rays strike at such angles as to throw into relief the delicate scorings that are due to wave action. They are accentuated in places by slight accumulations of gravel on the incipient benches, where there is, in consequence, some difference in the vegetation, or when there is a thin coating of snow. In some places, although plainly visible from a short distance under suitable conditions, the shore lines are scarcely traceable by a person actually climbing the grassy slopes. The highest of the lines distinguishable on the steep west slopes of Mount Jumbo (fig. 32) and University Mountain, which flank

FIGURE 32.—Shore lines of glacial Lake Missoula on Mount Jumbo at the mouth of Hell Gate Canyon, Missoula, Mont., with the remnant of a rock terrace at the foot of the slope.

the portal of Hell Gate Canyon just east of Missoula, are about 4,200 ft above sea level, or about 1,000 ft above the terrace on which the city of Missoula and the University of Montana are built. So far as is known to the writer, no one has attempted the tracing of any individual shore line for such a distance up and down the valleys as would afford proof of differential movements of the land that tilted the old lake shores during or since the time of their development. In fact, the shore lines are so closely spaced and delicate that it is doubtful if any one of the lines could be accurately identified and traced from hill to hill for sufficient distances to permit spirit leveling. One could not be sure even that the highest of the lines recognizable on each of a series of hill slopes really marked one and the same level of submergence. These shore lines are visible in places south of Missoula as far as Skalkaho Creek on grassy east slopes of the Bitterroot Valley, on the west side in places north of Lolo Creek, and on grassed slopes along the Clark Fork for some distance below Missoula. Among others, W. M. Davis (1920, pp. 135–138) observed and commented on their development where they are visible on the slopes of the Jocko Valley near Arlee, Ravalli, and Dixon. Farther west along the valleys of Flathead River and Clark Fork, the slopes are in general too wooded or too rocky to show the lines. The shore lines show quite plainly in aerial photographs of the mountain slopes near the Idaho-Montana State line south of Cabinet, Idaho.

At many places erratic pebbles and boulders, many of them striated, are scattered over the slopes of the hills to altitudes as high as 4,000 ft. Many of the boulders were undoubtedly dropped from icebergs that floated away from the fronts of such glaciers as invaded the temporary lake basin. Here and there such striated stones have also been found either lying on finely laminated, lacustrine silt or embedded in it.

There seems to be no doubt that the mouth of the gorge of the Clark Fork was dammed at least twice near the Idaho-Montana State line east of Pend Oreille Lake basin (fig. 13 *B*), and inspection of the topographic map of the Priest Lake quadrangle shows a narrow notch in the crest of the Bitterroot Range, 6 to 7 miles southwest of the village of Clark Fork, Idaho, which is between 4,000 and 4,200 ft above sea level, or approximately the same as the altitude of the highest lake shore lines on the valley sides as far upstream as Missoula. There was no lower outlet available across the Bitterroot Range, or elsewhere in western Montana or northeastern Idaho, when the Cordilleran ice was so extensive and so thick as to tightly dam the gorge between the State line and the Pend Oreille basin. That the ice was thick enough to form a dam 2,000 ft high at this place is evident from the fact that F. C. Calkins (1915) observed glacial striae on a ledge on the mountain slope north of the nearby village of Hope, Idaho, at a height of 2,500 ft above Pend Oreille Lake, or more than 4,500 ft above sea level. Many glaciated rock ledges were observed by the present writer along the newly graded highway at the foot of the mountains near the lake shore between the village of Clark Fork, Idaho, and the Pack River. Striae on these ledges trend southeastward directly toward the mouth of the gorge of the Clark Fork (fig. 31). Striae seen on one rock face near the State line about a mile northeast of Cabinet, Idaho, trend nearly due east. This rock was on the terrace about 200 ft above the river. It may possibly be a partly buried boulder rather than a ledge in situ, however.

On the benched spur of the mountain south of the river and about 3 miles west of the bridge at Clark Fork, the writer observed a glaciated ledge about 2,650 ft above sea level, or 600 ft above the lake, showing striae trending S. 15° E. Striated pebbles were seen between 3,200 and 3,800 ft above sea level beside a logging road on the slope a mile or two southwest of the above ledge. Ice 2,000 to 2,500 ft thick, crowding snugly against the high curved mountain wall above the south shore of the lake between 10 and 16 miles west of the State line, must have impounded the waters in the valleys of the Clark Fork and its tributaries where they were not filled with glacial ice, up to the height of the notch in the mountain crest southwest of the village of Clark Fork. Eugene Stebinger (unpublished notes) found an erratic granite boulder about 4,300 ft above sea level on Antelope Mountain east of the village. Inasmuch as the surface of the ice adjacent to the mountains decreased in height southwestward along the Purcell Trench toward its terminus during both the Wisconsin and pre-Wisconsin stages of glaciation, there was probably at all times a glaciomarginal stream or connected chain of marginal lakes and streams discharging to a tributary of the Columbia River, (pl. 2, fig. 16 and p. 56).

The relatively slight amount of wave work recorded along each of the several delicate shore lines would seem to indicate that no one stand of the lake was of long duration. The close spacing of the shore lines seems to indicate that the lake level fluctuated a number of times. A drop in the lake level may have resulted when the outflowing water cut down into either the rock sill of the outlet or the opposing wall of glacier ice. So also, increased melting of the ice dam may have permitted an outlet stream to migrate down the rocky slope to lower and lower levels, only to be shoved back up the slope and probably not to exactly the same levels when the mobile ice crowded forward. Each lowering of the ice dam would probably result in an increased outflow of water for a time, and such outflow, especially if sudden, might result in floods of great magnitude farther south and west in Idaho and Washington, even if Lake Missoula were only partly drained. Such may, perhaps, have been the origin of many violent floods that are supposed to have swept over the scablands on the great basalt plateau west of Spokane. The total maximum area of the branching lake, as estimated from planimetric measurement, was about 3,300 sq mi, and its depth ranged from a few feet in places to 2,000 ft. at the ice dam, so that the amount of water impounded was very large.

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During each stage of deglaciation, glacial Lake Missoula may have been so completely drained that the Clark Fork and its tributaries were reestablished, but locally, they began to clear out the unconsolidated glacial and lake deposits in new courses and here and there to cut new inner gorges into the underlying hard rocks.

It seems probable, although not certain, that the highest stages of the lake occurred at the time, or times, when the pre-Wisconsin ice dammed the Clark Fork, inasmuch as the ice appears to have been somewhat more extensive south of the Pend Oreille Lake basin during those stages than during the Wisconsin stage and so may have maintained the ice dam somewhat longer at the higher levels.

The laminated lacustrine silts that were deposited in glacial Lake Missoula, although widespread, are not coextensive with the maximum area of the lake. Much of the silt, of course, has been removed by stream erosion and slope wash. Some of the earlier silt was subsequently covered by glacial till or stream deposits. No very careful and detailed examination of the silt has been made by the writer, but so far as noted, most of the silt is laminated and is of very fine, even texture (figs. 15 and 33), and was evidently deposited in still water where it was slowly precipitated from suspension. In general, included pebbles are few and those present were probably dropped from floating ice. There is not much gravel or sand interbedded with the fine silts. Other things being equal, most silt was deposited in those parts of the impounded waters to which the most "gletscher milch" came from active glaciers and in which there was least disturbance of the water.

Although the outflow from many large glaciers entered the arm of glacial Lake Missoula that lay in the Bitterroot Valley, laminated glacial silt was not observed in those parts examined south of the railroad bridge above Fort Missoula, where the altitude is between 3,100 and 3,200 ft.

Glacial Lake Missoula apparently did not extend into either the Deer Lodge Valley or the valley of the Little Blackfoot River and no glaciolacustrine silt was seen there, although plenty of glacial water must have flowed into them. Such silt, if any is present, was probably accumulated in local pondings. No laminated silt or shore lines, or other lacustrine features, were noted in the narrow valley of the Clark Fork above Bonner although, judging from present altitudes, the impounded water during the highest stages of glacial Lake Missoula must have extended about as far east as Goldcreek, which is 4,201 ft above sea level. Either the silt has been removed or it is largely covered, or there was a strong enough current to carry the silt westward down the narrow valley to points below Bonner.

At Bonner the highest water was nearly 900 ft deep, but the Pleistocene deposits seen in this vicinity are mostly coarse bouldery stream gravel, probably of later deposition. A great deal of glacial water must have come down the Blackfoot Valley to the Clark Fork at Bonner. Finely laminated silt is exposed in some railroad and highway cuts between Bonner and the mouth of Hell Gate Canyon.

At the highest level of glacial Lake Missoula the impounded water evidently reached the ice front in the Blackfoot Valley. The altitude of Blackfoot River is less than 4,100 ft above sea level nearly as far east as Ovando, but the glacier in the valley of the Stillwater River appears to have blocked the Blackfoot Valley for several miles below Clearwater (in T. 14 N., R. 14 W.) during two or more different stages of glaciation. North of Greenough, the terrace known as Ninemile Prairie (3,640 to 3,780 ft above sea level) is underlain by very coarse drift containing boulders 1 to 10 ft in diameter and is coated with glaciolacustrine silt 10 ft or more thick.

The stratigraphic relation at Ninemile Prairie seems to indicate that the west front of the pre-Wisconsin glacier here extended nearly as far west as the exposure below the mouth of Elk Creek and terminated in the glacial lake. Either when this ice front receded, or during the Wisconsin stage of glaciation, the lake water extended eastward over the bouldery drift and covered it with the silt. This is the most easterly place where the silt has been observed by the writer. Some of this silt was deposited in the lower valley of Union Creek below Potomac village. Much of the silt seems to have been carried on down the gorge of the Blackfoot River past Bonner.

There are some things about the great deposit of laminated silt in the valley between 3½ and 15 miles west of the city of Missoula that indicate that the silt was deposited during a Wisconsin stage of glaciation. One indication is the relatively large amount of erosion that has occurred since the silt was deposited. As now preserved, the silt underlies a terrace, about 100 ft above the Clark Fork 15 sq mi or more in extent, whose surface, once smooth and flat, is somewhat cut by ravines. Judging from its present disposition, this silt terrace was probably once coextensive with the whole floor of the valley below the city. That even so much of the deposit is preserved appears to be due to the protection from the meandering streams afforded by the coarse bouldery gravel in the southeastern salient of the terrace 4 to 5 miles west of the city (in secs. 22 and 23, T. 13 N., R. 20 W.) and to the limestone and coarse gravel in the bluff salient 6 miles farther northwest around which the railroads and the highway extend (sec. 30, T. 14 N., R. 20 W.). As it is, less than one-fourth or one-fifth of the probable original areal extent of the upper 50 to 100 ft of the deposit is now preserved within 15 miles below the city. This suggests that the silt was deposited during a pre-Wisconsin stage of glacial Lake Missoula, and that the coarse gravel forming the upper of the two or three terraces below the silt terrace was washed down the valley, and much of the silt was washed away while the lake level was being lowered near the end of the Wisconsin stage. It is noteworthy that, although there are well-marked shore lines and many berg-dropped pebbles and boulders on the adjacent hill slopes as high as 4,200 ft above sea level, the higher parts of the silt terrace are only 3,200 to 3,300 ft above sea level. Nowhere to the north or northwest has the silt been observed by the writer to extend to higher levels.

Some of the silt is present in places below Frenchtown, in the valley of Ninemile Creek, and west of Saint Regis. In the Jocko Valley a good deal of the whitish silt has been cut away, leaving a narrow silt terrace along the northeast side of the valley above the broad gravel terrace of Wisconsin age. The silt, overlying till, is also present in places south of the Jocko River and near lower Valley Creek south of Ravalli. Silt is exposed at Ravalli, but it does not extend upstream through the gap (about 3,130 ft above sea level) along the road to Saint Ignatius. The deposits noted in this gap are south-dipping, cross-bedded stream gravels and till. In the valley of Flathead River for about 20 miles below Dixon, small remnants of the lake-silt terrace are preserved.

Whitish, very finely laminated silt, 30 to 100 ft thick, is exposed near the Jocko River bridge east of Dixon in a narrow dissected terrace, 2,650 to 2,700 ft above sea level, bordering the hills of the National Bison Range and northward for several miles up Mission Creek. Near Moiese there is considerable silt with maximum exposures of about 100 ft (figs. 15 and 33).

This silt overlies till west of Saint Ignatius. North of Post and Mission Creeks it overlaps till along the south margin of the Mission moraine. The silt does not, so far as noted by the writer, overlie the top of the Mission moraine between Crow Creek and Post and Mission Creeks. As this top is only about 2,850 to 2,950 ft above sea level, it suggests, although it does not prove, that most of the silt to the south was deposited when the foot of the great Flathead glacier lobe was resting on and building up the Mission moraine. The shore lines of glacial Lake Missoula are plainly visible on the grassy slopes of the adjacent hills, in places 4,000 ft or more above sea level—that is, up to levels fully 1,000 ft above the top of the Mission moraine. This relation suggests that before the ice front began its retreat from the Mission moraine the outlet past the ice dam in the Pend Oreille Lake basin had lowered the lake by shifting down the north slope of the mountain west of Clark Fork, Idaho, either to or below the prominent notch in the rock spur, which is about 3,100 ft above sea level.

So also, much of the finely laminated whitish silt in the Little Bitterroot Valley between the mouth of the

FIGURE 33.—Glaciolacustrine silt near the National Bison Range east of Moiese, Mont. Photograph by J. T. Pardee.

Big Draw near Niarada and the junction with the Flathead River near Sloan may be of pre-Wisconsin age. Regarding these deposits Meinzer (1917, p. 15) states:

> The lake beds underlie practically the entire valley from the mouth of the Big Draw to the cliffs overlooking Flathead River. At many places they are well exposed to the depth of nearly 100 feet, the depth to which the stream has cut, and they have also been penetrated in numerous dug wells to depths not generally greater than 100 feet. Most of the drilled wells extend about 300 feet below the lake plain and end in gravel, but the deposits they penetrate above the gravel are apparently fine sediments like those exposed in the upper 100 feet. Most of the drilled wells are reported to pass through 5 to 20 feet of "quicksand," which generally lies between 100 and 150 feet below the surface. In the dug well of J. J. Taylor (SW¼ sec. 14, T. 22 N., R. 24 W.) about a foot of gravel was encountered at a depth of 80 feet between the ordinary clayey beds, but gravel or even coarse sand is rare except at the horizon in which the drilled wells end.

Silt-bearing water probably came down the Little Bitterroot from the ice fronts that lay in the gap at the head of the valley near Little Bitterroot Lake and in the smaller gap to the southeast near Rogers Lake; possibly also from one in the McGregor Lake basin. This may account for the whitish silt in low places west of the hills, west and northwest of Niarada. Most of the silt on Sullivan Creek north and south of Niarada and that so extensively preserved farther south in the Little Bitterroot Valley may have come westward through the Big Draw from the big arm of the Flathead glacier (fig. 23). Some of this silt, although probably a small part, may have come southward from an ice front near the pass 12 to 15 miles north-northeast of Niarada. Although there was, and is yet, a very large quantity of the whitish silt in the Little Bitterroot Valley and along Sullivan Creek, the valleys never were filled with it. The silt does not appear to extend far up the surrounding hill slopes and the flat top of the main silt terrace, the site of the village of Lonepine (about 3,000 ft above sea level), is hundreds of feet below the upper lake shore lines which show so well on the smooth unforested slopes. In places, there are cobbles and boulders scattered on the slopes and many of these stones show glacial striae. Most appear to have been dropped from icebergs floating on the glacial lake. In a small gulch beside the road 2 miles northwest of Niarada (in sec. 23, T. 24 N., R. 24 W.) the writer found a small exposure of what appeared to be glacial till. This material also may have been dropped from floating ice. None of the rock ledges examined on the adjacent hill slope shows evidence of glaciation and no till or glaciated ledges are known to be present anywhere in the Little Bitterroot Valley between this place and the mouth of the valley west of Sloan in T. 20 N., R. 22 W. There seems to be no clear evidence that any glacier invaded this part of the Little Bitterroot Valley. If a glacier did occupy this valley, it was probably during a pre-Wisconsin stage, and its melting may have furnished much of the silt-bearing water.

The Flathead glacier in pre-Wisconsin time appears to have blocked the mouth of the valley about 5 miles west of Sloan where till is exposed and to have been the source of some of the water that deposited silt in the lower part of the Little Bitterroot Valley. Similar conditions caused the deposition of silt in the valley of White Clay Creek between the hills south of the Big Draw and the Flathead River, 10 to 12 miles southwest of Polson.

Near the village of Lonepine there are rather large tracts of little-eroded flat land on the silt terrace which are so smooth that they are irrigated and under cultivation. The Little Bitterroot River has cut an inner valley 100 to 200 ft deep below the level of the silt plain and about a mile in width. In this inner valley, for 10 miles or so above Lonepine, there are remnants of two or three terraces capped with coarse gravel. They were developed by the river while and after the lake was drained during late Pleistocene and Recent time.

GULCH FILLS IN GLACIAL LAKE MISSOULA

In the mouths of numerous gulches tributary to that part of Clark Fork within 100 miles east of the Montana-Idaho State line there are certain depositional features—gulch fills—that appear to have been developed in connection with the flooding of the valleys by the waters of glacial Lake Missoula. They are particularly well preserved and readily accessible on the northeast side of the Clark Fork between Paradise and Plains and also in the lower valley of the Flathead River between the mouth of Camas Creek at Perma and the junction of the Flathead with the Clark Fork above Paradise. At these places several gulch fills have been examined by the writer, and some were examined and described by Davis (1920, pp. 122–132). Several have also been seen, from points on the highway, farther down the Clark Fork and also in the mouths of gulches tributary to the lower parts of Thompson River and to the Vermilion River, as shown on plate 1. They have not been noted farther east either up the Clark Fork or the Flathead, or in their tributary valleys. If present in these upstream localities, their altitudes may be so low that they do not lie much above the adjacent streams and hence may not be distinguished from alluvial fans. The only determinations of their altitudes by the writer were by barometric readings, according to which they vary somewhat in altitude and appear to have been formed at different levels of the lake. The good state of preservation of most of them suggests that they are not older than the Wisconsin stage of the glacial-lake submergence. These features were also studied by Pardee (1942, pp. 1589–1593) and are described in his paper as "high eddy deposits" formed by unusual currents in glacial Lake Missoula.

One of the best preserved of the fills examined is in the mouth of twin gulches, 4 to 5 miles west of Perma (sec. 5, T. 18 N., R. 24 W.). As seen from across the river (fig. 34), the generally light color of the grass-covered fill gives it a striking appearance. The material seems to be loose and unconsolidated, largely gravel and composed of local rock debris. The top, where not eroded, is about 3,050 ft above sea level, or 550 to 600

FIGURE 34.—Gulch fill or gravel bar west of Perma, Mont. Adjacent slopes are largely bare rock.

ft above the river, and is sprinkled with pebbles and boulders, some striated and probably dropped from ice floating on the waters of glacial Lake Missoula. It was probably formed mostly of material brought down the gulches by streams and partly rearranged as a bar by wave action. The front slope is very steep and the uneroded part of the top edge is ridged with a shallow depression behind it. The top of the bar may indicate the approximate level of the lake at the time the fill was completed. A V-shaped gulch has been cut in the fill by storm waters since the lake was drained, but much of the general drainage water seems to seep through the fill and to emerge as spring water lower down near the river.

On the same side (north) of the river nearly opposite Perma is a similar but smaller and less eroded feature, one of those W. M. Davis described and illustrated as probably a glacial "lateral moraine." Above the low gravel terrace near the river bank is a remnant of a terrace composed of lacustrine silt about 100 ft above the river, or about 2,600 ft above sea level; and above this a steep grassy slope rises to the top of what appears to the present writer to be a lacustrine bar formed in a small reentrant between the rocky hill slopes on either hand. To the north, behind the ridge, is the basin known as Camas Prairie Basin. There is no considerable gulch at this place. The top of the fill (2,950 ft above sea level, or about 450 ft above the river) is rounded, and between it and the crest of the rock ridge at the back is a swale not wholly drained by the small gulch through which excess water flows. The ordinary drainage water appears to percolate downward from the swale and emerge as spring water lower down the slope. The writer found no definite evidence that this fill is a lateral moraine or that a glacier ever occupied this part of the valley of Clark Fork. The boulders and cobbles, some striated, which were found scattered on this ridge were probably dropped from floating ice. No till or striated ledges have been found. Directly opposite this place is one of the benched rocky slopes described and illustrated by W. M. Davis (1920, pp. 130–131, fig. 13) as "scourd and cleft" by glacial action. Some gulch fills have been very largely cut away by post-lacustrine erosion and the material has been partly redeposited as alluvial fans on the terraces below.

One of the highest and most remarkable of these gulch fills is almost directly behind the Northern Pacific Railway shops just west of Paradise (fig. 35), sec. 17, T. 19 N., R. 25 W. It was described and illustrated by W. M. Davis (1920, pp. 124–125, fig. 8) as a "moraine embankment on a side valley." This fill apparently never was built out even with the rocky, benched slope of the main valley on either side of the sharp V-shaped gulch in which it lies. The steep grassed front slope of the fill, which is a quarter of a mile to half a mile back in the mouth of the gulch, rises at an angle of 25° to 30° to

FIGURE 35.—Gulch fill or gravel bar at Paradise, Mont.

a height of 850 ft (barometric) above the low flat gravel terrace on which the railroad shops are built. The surface of the fill rounds over smoothly, then drops abruptly about 50 ft to a basin in which at times there is a small pond; beyond this the gravelly fill slopes gently northward in the narrow gulch. A small gully, 15 to 20 ft deep, is cut across the top of the bar near the mountain slope on the southeast; it apparently serves as an outlet for some excess water, as that from melting snow. Ordinarily drainage water, except that which is held by the silted bottom of the pond, must percolate downward through the gravelly filled and underlying talus and emerge as spring water near the mouth of the Gulch. This percolating water may have carried some of the finer material down into the interstices of the underlying talus and so have induced settling and deepening of the basin at times during and after the level of glacial Lake Missoula was lowered. Evidently the inwash down the short gulch has been insufficient to obliterate the basin by filling it up to the top of the bar. There are a few large rocks on the fill and numerous 1- to 3-ft blocks, which probably slid from the adjacent higher craggy slopes, though some may be erratics dropped from ice floating on the lake. Were there more definite evidence of glaciation of the adjacent part of the valley of Clark Fork, one might be more inclined to accept Davis' explanation of this gulch fill as a "moraine embankment." In such time as the present writer spent examining this and other features in the part of the valley between Perma and Plains, on several different occasions, no definite evidence of such glaciation was found. It is not impossible, however, that satisfactory evidence of such glaciation may yet be found.

This particular gulch fill is a somewhat anomalous feature. Were it built as a lateral moraine by a great glacier moving southeastward past the mouth of the gulch as postulated by Davis, it seems as though it would have been built out directly in the lee of the rocky spur on the northwest (shown at the left in fig.

35) instead of being set so far back (a quarter to half a mile) in the mouth of the gulch. True, one might also ask why the same result did not occur if the deposit was built as a lacustrine bar composed partly of material swept into the mouth of the gulch by waves and currents of the lake working along the adjacent craggy slopes and backed by material washed down the gulch and from its higher side slopes. However, until other and more definite evidence of glaciation of this part of the valley of Clark Fork is found, the present writer is inclined to regard this and other similar features as of lacustrine origin.

About 3 miles southeast of Plains a large part of one of these gulch fills on Henry Creek (in sec. 1, T. 19 N., R. 26 W.) was removed in cutting an inner **V**-shaped gulch through it when the lake was lowered. Much of the material derived from it was redeposited as an alluvial fan below the mouth of the inner gulch. This fan was later partly removed when transected by the creek and a lower fan was formed as the river deepened its channel. The top of the transected gulch fill slopes gradually northeastward until it is 500 ft or more above the level of the river—that is, about 3,000 ft above sea level. The material of the fill on top and along the steep grassed side of the inner gulch consists mostly of angular or slightly worn fragments of grayish quartzite, with some of diorite. No foreign material or glaciated stones were observed. Apparently this gulch, like the others, was partly filled when glacial Lake Missoula in this vicinity was 500 ft or more deep.

Although no accurate determinations of the heights of the several gulch fills were made by the writer, it is evident that they do not correspond very closely in altitude. Most of them appear to be between 3,000 and 3,500 ft above sea level, or at altitudes known to have been reached by the waters of glacial Lake Missoula during the Wisconsin stage of glaciation. The height of any particular fill would depend on several factors, namely: the height of the lake when the filling ceased, the length and depth of the gulch, and the rate at which material was swept into the gulch.

Fine stratified sand and whitish laminated silt were exposed in cuts along the highway grade bordering the northeast bank of the river between Paradise and Plains. Two to three miles south of Paradise in the angle of the junction between the Clark Fork and the Flathead River the upper terrace about 100 ft above the river is underlain by the lacustrine silt, and the lower terrace on which the highway is located is composed of coarse stream gravel. For 2 or 3 miles north of Plains also, the whitish lacustrine silt underlies the upper of the two terraces traversed by the roads.

FILL ALONG THE VERMILION RIVER

The Vermilion River (secs. 4, 8, and 9, T. 24 N., R. 30 W.) and its tributaries have one of the most remarkable fills in western Montana. Three to four miles above the mouth of its gorge the Vermilion River has cut a very narrow inner gorge into an underlying rock spur through a narrow ridge of sand and gravel, an erosion remnant of the fill. A road extends around the slope and crosses the spur above this inner gorge. Cuts along the road expose delta foreset beds in the coarse gravel. From the slope above the road the top of the partly eroded fill appears as a flat, sharply marked terrace on the mountain side 500 ft above the Vermilion River and about 3,250 ft above sea level. It extends eastward up the Vermilion River gorge and southward into the mouth of the gulch of Cataract Creek (fig. 36). In eroding its inner gorge at the south side, Cataract Creek has encountered a rock spur over which it cascades several hundred feet to the Vermilion River. From the river bank at one place a bare scarp rises to woods on the upper slope and terraced top of the great fill. P. T. Jenkins, who climbed and examined the lower half of the scarp, reports the following deposits as exposed:

Deposits in the gorge of Vermilion River

	Feet
Upper slope and terrace top largely overgrown.	
Glacial till, gravelly, many striated stones; face of the thick deposit eroded as buttresses	?
Silt, laminated	20±
Gravel, stratified	50±
Sand or silt in lower part.	

Judging from the contour lines on the topographic map of the Thompson Falls quadrangle, there were numerous glaciers heading in high cirques in the adjacent parts of the Cabinet Mountains and one or more may have extended down into the gorge of the Vermilion River where till (or glacial outwash) was deposited in this arm of glacial Lake Missoula. The altitude of the terrace top is not very different from that of the gulch fills noted above, and the terrace may have been completed while the outlet of glacial Lake Missoula was across the notched mountain spur west of Clark Fork, Idaho (pl. 15*B*).

This terrace is about 700 ft higher than the well-preserved remnant of a gravel-capped terrace on the west side of the mouth of the Vermilion gorge. This latter terrace, which is 2 miles east of Trout Creek in sec. 25, T. 24 N., R. 30 W., is 2,500 to 2,600 ft above sea level. It may have been formed as an alluvial fan, composed of terrace gravel derived from erosion of the great fill in the Vermilion gorge, when glacial Lake Missoula dropped to lower levels. Later it too was transected when the Vermilion River cut down to an altitude of 2,400 ft and formed the alluvial fan around which the Clark Fork now flows. Transecting this lower fan is the small gulch through which the Vermilion now flows to join the Clark Fork about 2,250 ft above sea level. Remnants of fills are also found in the mouths of several tributary gulches 1 to 2 miles above the mouth of the Vermilion gorge.

FIGURE 36.—Glaciolacustrine terrace on Vermilion River in the Cabinet Mountains east of Trout Creek, Mont. Cataract Creek cascades over rock ledges at the right.

Two miles south of this locality, where the State Route 3 crosses Beaver Creek, 10 to 15 ft of dense chocolate-colored laminated lacustrine clay is exposed overlying 30 to 40 ft of coarse gravel. This lacustrine clay is similar to the beautifully laminated clay exposed at about the same altitude on Dry Creek, about half a mile south of the Clark Fork bridge at Thompson Falls.

DEPOSITS NEAR THOMPSON FALLS, MONTANA

As shown on the topographic map, on the northeast side of the river at and below Thompson Falls there is a broad wooded bench; its origin is somewhat in doubt. In his paper on "Features of glacial origin in Montana and Idaho" W. M. Davis (1920, pp. 120–121) makes the following statement regarding this bench:

The Thompson Falls basin and moraine.—At a point 60 miles southeast of Lake Pend Oreille, the valley of Upper Clark fork widens in a flat-floored basin measuring four of five miles across. The northwestern corner of the basin is occupied by a heavy morainic mass a mile or two in width, on which I had a two-hour walk. Its rolling surface, sparsely dotted with boulders, rises from 200 to 350 feet over the basin floor next up stream. Glacial action at this point is unquestionable, altho the source of the glacier has not been determined surely. Its possible origin is suggested below. The river is turned by the moraine to the southwestern side of the basin, where it is locally superposed on a strong valley-side spur, from which it cascades into a trench deeply incised in the drift and thus enters the lower sixty-mile stretch of its valley. The village of Thompson Falls lies near by.

The present writer has found no definite evidence that this part of the valley of Clark Fork was ever invaded by a glacier. Striated erratics, such as those noted on the surface of the bench west of Belknap, may have been dropped here by bergs floating down branches of glacial Lake Missoula from the fronts of local glaciers on the flanks of the Cabinet Mountains to the northeast and of the Coeur d'Alene Mountains to the southeast, south, and west. Bergs may even have floated this far from the Cordilleran ice front on the upper reaches of the valley of Thompson River and other basins to the east. There are large boulders lying near the railroad station at Thompson Falls, some of them 5 ft or more long, which were left when the railroad was graded along the south sloping edge of the bench. These boulders appear to be waterworn and on none of those examined were striations or other marks of glaciation found. Such boulders are also scattered for a short distance up the gentle slope north of the village. Farther north the surface is covered with sandy loam and low swells or small dunes, as shown by road cuts 3 to 10 ft deep. Material from an excavation about a mile north of the railroad station and 150 ft above it consists largely of well-rounded cobbles and larger subangular blocks like torrential wash from the mountain gulches to the east. No glaciated stones were seen. At a ranch about a mile farther north a small rock ridge, like those near Whitepine, projects above the sandy flat suggesting that bedrock is not far below the bench. The narrow southeast part of the bench, 1 to 2 miles east of the village near Ashley Creek, is also underlain by rock. The remarkable regularity of the steep mountain slope to the east of the big bench suggests that this wall is a fault-line scarp. The mountain wall towering above the big bench is gashed by five or six sharp gulches and it is quite possible that torrential wash from them built up the bench by alluvial fans which so coalesced as to crowd the river over to the southwest side of the valley. Although the big bench north of the village is somewhat anomalous, there is little or no evidence that it is a glacial moraine. Considering the character of the evidence so far as known to the present writer, there seems little ground for the statement of Davis (1920, p. 134) that "the first indubitable signs of glacial action [seen in going southeast up this part of the valley] are found in the broad moraine that obstructs the valley of Thompson Falls," especially as he concludes, "but the direction from which a glacier advanced to lay down this moraine was not learned."

In cutting its channel around the southwest side of this bench after the lowering of glacial Lake Missoula, the river encountered bedrock and developed the falls, the present site of the power dam. The bedrock retards the deepening, so that farther east above the village the stream meandered from side to side and developed two well-defined gravel terraces below the highest, which heads at the mouth of Thompson River gorge. At several places below Thompson Falls the Clark Fork has cut its inner gorge into the bedrock and, so far as is known to the writer, there is no evidence that the inner gorge ever had been deeper than it now is. There may be 100 ft or more of Pleistocene fill in places under the broad bench or main valley floor near and below Belknap.

Judging from the topographic map (Libby and Trout Creek quadrangles), there were glaciers in cirques at the head of Swamp Creek (T. 26 N., R. 31 W.), in one of which is Wanless Lake, 9 miles east of Noxon. Whether on not they joined in a trunk glacier and how far such a glacier extended down the gorge of Swamp Creek, which is 2,000 to 3,000 ft deep, has not been determined. Undoubtedly an arm of glacial Lake Missoula extended up this gorge into the mouths of tributary gulches. Sloping radially from an altitude of 2,600 ft at the mouth of the gorge is a great fanlike terrace, about 10 sq mi in extent, which spreads southwestward to a small rock ridge in the valley of Clark Fork. The relations suggest that, as glacial Lake Missoula dropped to levels below 2,600 ft in late Wisconsin time, this great fan was built out into the valley by the deposition of material swept from the gorge by waters from the melting Swamp Creek glacier. At the mouth of the gorge the creek now swings to the right and flows down the northwest sector of the fan and has cut a narrow gulch there, 50 to 100 ft deep. The Clark Fork, when it was reestablished after the lake was drained, appears to have been crowded over to the west of the low rock hills, as it now swings close to the foot of the rock cliff about half a mile below Tuscor. Some of the cuts on State Route 3, which traverses the outer part of this great fan, expose dense, reddish lacustrine clay below the coarse alluvial-fan gravel.

Near the bridge east of Trout Creek, there are four stream-terrace steps between the river and the railroad which extends along the marginal slope below the broad 2,600- to 2,700-ft bench on the southwest. These terraces mark the progress of deepening of the inner gorge when glacial Lake Missoula was finally drained and the river cut into the deposits. Near the highway bridge there are many large boulders in the river and in its banks. Along the roads and also in the railroad cuts for nearly 15 miles from the mouth of Vermilion River southeastward past Whitepine to a point 4 miles below Belknap, no clear evidence of a glacier having occupied this part of the valley of Clark Fork was found although the poorly sorted bouldery material seen in places looks somewhat like glacial till. These coarse bouldery deposits are probably torrential stream deposits and are partly, perhaps, of pre-Pleistocene or pre-Wisconsin age. Some of the larger boulders, may have been dropped from icebergs broken from the local mountain glaciers and floated out into the valley of Clark Fork on the waters of glacial Lake Missoula. Some of the larger stones in places are 5 to 8 ft in long diameters. So far as noted, none of them show glacial striations.

Similar bouldery gravel is exposed on Trout Creek, and near the ranger station one well-striated small boulder was seen. Bouldery gravel is also well exposed below lacustrine silt at and below the Beaver Creek bridge, and part of it is cemented to conglomerate. Several of the waterworn boulders here are 10 to 15 ft in diameter. Some of the torrential stony material exposed in the bluff above the railroad and below the broad bench 2 miles southeast of Whitepine is also cemented to conglomerate, so that it projects as ledges. The included stones are mostly angular fragments and partly rounded or subangular pebbles and cobbles of Belt rocks. Overlying this material, in places, is lacustrine silt. Some striated pebbles, probably dropped from floating ice, were found on dense red clay on the road between Little Beaver Creek and Belknap.

Between Whitepine and the river bend below Belknap there are numerous small craggy ridges of Belt rock which rise 50 to 100 ft above the smooth surface of the surrounding benchland between the highway and the river, like the tops of partly buried fault blocks. One of the most noteworthy of the rock ridges between the river gorge and the mountain front to the west is 2 to 3 miles northwest of Belknap. This narrow ridge, which is 100 to 300 ft high, trends southeastward directly in front of the mountain gorge of Little Beaver Creek, suggesting that it is not simply an erosion remnant left from excavation of the broad valley of the Clark Fork which in this vicinity is nearly 4 miles in width.

Between 1 and 3 miles above Noxon the narrow inner gorge of the Clark Fork appears to have been cut between the alluvial fan of Pilgrim Creek on the west and that of Rock Creek on the east. These fans, however, may be underlain by uneven rock benches, for ledges project in places above the flat surface of the fan near Rock Creek. Cuts on State Route 3 east of the Noxon bridge showed some 3- to 6-ft masses of contorted reddish laminated clay included in the coarse material. Near Rock Creek coarse alluvial gravel overlies reddish lacustrine clay and stratified clay and sand. At the west side of the broad-mouthed gorge of Rock Creek there is a well-preserved bench or terrace 2,700 to 2,800 ft above sea level (see topographic map). This terrace was not examined, but it may be a remnant of a fill laid down in an arm of glacial Lake Missoula, which occupied the gorge. At the head of this gorge, there were evidently small glaciers in the several cirques now containing several lakelets, and the ice may have united into one glacier that extended down to the large, bouldery terminal moraine (3,700 to 3,800 ft above sea level) at the foot of Rock Creek Meadows, 7 to 8 miles northeast of Noxon. Gravel washed out from the Rock Creek glacier may have filled the lower gorge to the height of the 2,700- to 2,800-ft bench and later have been eroded and spread out over the lacustrine clay in the valley of Clark Fork. There also appears to be a conspicuous fill nearly up to an altitude of 2,700 ft, 400 to 500 ft above the river, in the gorge of Stevens Creek 4 to 5 miles southeast of Noxon. What appears to be another gulch fill, owing to the presence of glacial Lake Missoula, hangs about 700 ft above the Clark Fork (2,800 to 2,900 ft above sea level) in the mouth of Smeads Creek gulch, 4 to 5 miles northwest of Noxon. Other smaller gulches show a similar appearance of fill.

The remarkable regularity of the straight steep southwest slope of Green Mountain in this part of the valley of Clark Fork suggests a fault-line scarp from which rocks underlying the valley floor may have been either faulted down or so fractured as to be easy to remove by the stream excavating the valley. Along this scarp there appear to have been relatively recent rock falls or rock slides, which perhaps account for the bulging out of the piedmont slope, 1 to 2 miles north of the mouth of Swamp Creek, as shown by the contour lines between 2,500 and 3,100 ft above sea level on the Trout Creek topographic map.

The narrow, steep-walled lower gorge of Thompson River shows no evidence of glaciation. Some cuts on the lower 3 miles of the branch road up the West Fork expose talus and coarse gravel with some interbedded sand layers. It is doubtful whether a trunk glacier extended this far down the gorge of the West Fork, although one striated stone was seen and small glaciers must have headed in the numerous cirques shown on the Thompson Falls topographic map near and south of Mount Headley. Several of these cirques contain glacial lakelets. A branching arm of glacial Lake Missoula must have extended up the West Fork as well as far up the main valley of the Thompson River but no laminated lake silt was observed in the lower parts of these gorges. It is possible that the unstratified stoneless clay exposed at the old dam site about 10 miles above the mouth of Thompson River may be of preglacial, possibly Tertiary (?), age.

The exposure of conglomerate and of orange-colored deposits under buff to gray alluvial sand and gravel in the sides of the inner gorge of the Clark Fork north of Whitepine suggests that there may be some Tertiary (Miocene?) sediments filling in between downfaulted masses of the pre-Cambrian rocks, as in the Mission Valley above Dixon. Similar deposits may underlie the bench north of Thompson Falls, although no definite evidence was seen there.

The high bench at the mouth of the Rock Creek gorge, the hanging valleys of Stevens Creek, 4 miles southeast of Noxon, and of Smeads Creek, 4 miles northwest of this village, and the high benches at Fatman Mountain, 2 to 3 miles north of Heron, all shown on the topographic maps but none of which has been examined by the writer, may be features of significance in deciphering the history of this part of the valley of Clark Fork. It is quite possible that Tuscor Hill, 5 to 6 miles southeast of Noxon; the rock hills at Larchwood west of Trout Creek; and the rock hills between the lower gorge of Prospect Creek and the river west of Thompson Falls may be downfaulted blocks partly separated from the adjacent mountain slope.

MORAINE IN THE VALLEY OF CLARK FORK

Although the mouth of the valley of Clark Fork must have been tightly closed by an ice dam near the Idaho-Montana State line during both the Wisconsin and pre-Wisconsin stages (pl. 2), there is no well-defined terminal moraine in the Clark Fork valley, perhaps because the glacial ice dam was bordered by water which was at times 1,000 to 2,000 ft deep. The contours on the topographic map of the Libby quadrangle show a broad upper bench extending from the west to the south of Heron, the top of which is 2,400 to 2,500 ft above sea level, or 300 to 400 ft above the river on the north. Elk Creek, after leaving its mountain gorge, flows first eastward and then northward around the east end of this bench to reach the river and has spread its alluvial gravel as a broad fan or intermediate terrace between Smead and Heron. Where it transects the terraces east of Heron, Elk Creek has cut through the capping of bouldery gravel into the underlying rocks of the Belt series. It seems probable that the bedrock also underlies the 2,400- to 2,500-ft bench at no great depth, although no such rock was seen exposed on two roads that cross the bench. Near these roads the surface of the bench is smooth and gently undulating where not eroded, and it is mantled with fine loamy clay, probably silt of glacial Lake Missoula, and a few boulders.

The railroad and the highway south of the river for a mile or more east and 2 to 3 miles west of Heron are on the 2,250- to 2,240-ft terrace; beyond this to the west they are for some distance, east and west of the State line, graded along the south side of the inner gorge. Here the river terrace gives place to the upper bench, which extends northward to the railroad and the bluff along the river bank. This part of the bench, at least, probably represents the terminal moraine. Here there are many 3- to 5-ft boulders and subangular blocks embedded in the coarse, bouldery gravel which overlies the rocks of the Belt series. Some of the boulders are as much as 10 to 15 ft in diameter. They consist mostly of green and red argillite with some granitic rock. For a mile or two east of the State line, the coarse gravel, though mostly unstratified, is in part poorly bedded, with cross beds dipping westward downstream as though the material had slumped or been redeposited during or after the melting back of the ice dam from contact with the accumulating deposit.

Near Cabinet, Idaho, the rocks of the Belt series rise, and through them the river has cut an inner rock gorge which in places is barely 100 ft wide. In this vicinity, 1 to 2 miles west of the State line, the rock rises to an altitude of 3,000 ft, or about 900 ft above the river, whose north bank forms a hill rising about 500 ft above a smooth gravelly terrace, which surrounds it on the west, north and east.

CLOSING STAGES OF GLACIAL LAKE MISSOULA

There are some low swells and swales and a few kettle holes at the head of the terrace, suggesting morainal deposition in the swale northeast of Antelope Mountain to a height of 600 ft above the flat on which the village of Clark Fork, Idaho, is situated; from this height the terrace slopes southeastward like an outwash terrace bordering a moraine or an ice-contact deposit. The relations suggest that when this terrace was formed the front of the glacial lobe had been melted back some miles from its most easterly position and the marginal parts of its surface had been so lowered as to permit glacial Lake Missoula to be drawn down to or below an altitude of 2,500 ft above sea level. As the lake lowered, the reestablished Clark Fork was gradually extended northwestward from Paradise and Plains and began to develop the lower terraces and to cut its inner gorge. Much of the finer material so derived was swept through the Cabinet Gorge and spread out in the valley to the westward to form the great delta which is still encroaching on the Pend Oreille basin west of the village of Clark Fork, Idaho.

It is probable, however, that glacial Lake Missoula did not drop much below the 2,500-ft level until the fronts of the Cordilleran ice lobes that occupied the Columbia Basin and the lower Pend Oreille valley in northeastern Washington had receded somewhat north of the 49th parallel (fig. 14), permitting the lake water to escape down the Pend Oreille and Columbia Rivers. As far as can be judged by present altitudes, outflow from the south end of the Pend Oreille Lake basin down the Spokane River valley to the Columbia did not lower the divide between the lake and Athol, Idaho, below an altitude of 2,450 ft. Water a little less than 2,400 ft above sea level could flow westward from Squaw Bay through an abandoned outlet and thence southward past Athol, near the route now followed by the Spokane International Railroad, but flow by this route was probably not long continued. Water could for a time flow through a swale west of Squaw Bay to the Hoodoo Valley and thence north and west down the valley of Pend Oreille River past Albeni Falls to Newport, Wash. Some water may for a time have flowed westward to the Little Spokane River through the gap where the Chicago, Milwaukee, St. Paul & Pacific Railroad now extends past Coleman and Blanchard, Idaho, at an altitude of 2,200 to 2,400 ft. The divide between the river at Newport and the Little Spokane River could not have been much if any less than 2,400 ft above sea level. Not until later did the southward flow to the Little Spokane cut the narrow spillway (now traversed by the Great Northern Railway) between Newport and Penrith down to an altitude of about 2,100 ft. It therefore appears that glacial Lake Missoula could not have been wholly drained and the inner gorge of the Clark Fork between the Pend Oreille Lake basin and Thompson

Falls, Mont., could not have been cut until the outlet by way of the Pend Oreille River and the valleys of the Little Spokane and Spokane River was opened to the Columbia River. The lower terraces along the Clark Fork in western Montana may mark the opening of new outlets or stages in cutting through the several rock barriers encountered by the reestablished stream between the Montana-Idaho State line and the Columbia River.

It seems clear that the valleys of the Clark Fork and Flathead River and tributaries were flooded by the waters of glacial Lake Missoula while the Polson terminal moraine was being formed during the Wisconsin stage of glaciation, for not only are lake shores plainly marked on the smooth parts of the rock hills east of the Flathead River and behind the Mission moraine, but there are also shore lines in places on the south slope of the Polson moraine itself. The lake waters may even have laved the front of the Flathead glacier and the moraine may have been deposited in the lake. The maximum height of the glacial lake at that time is not known. Lacustrine silt 10 ft thick caps the 3,200-ft terrace just outside the moraine near the Polson Dam site and similar silt 10 to 15 ft thick overlies till in places between the Polson moraine and Crow Creek inside (north of) the Mission moraine. Apparently during this stage the silt-bearing water moved slowly southwestward along the sag later followed by Mud and Crow Creeks and spread little, if any, silt over the Mission moraine. It is possible that during most of the Wisconsin stage the outlet past the ice dam in the Pend Oreille basin was not held by the glacier above the level of the 3,100-ft notch in the mountain spur 3 to 4 miles west of Clark Fork village. This interpretation accords very well with the relations of the silt terrace to the lower gravel terraces in the valleys of the Little Bitterroot and Jocko Rivers and in the valley of Clark Fork just below Missoula.

It is significant that, so far as the writer has observed, the higher shore lines of glacial Lake Missoula—those more than 3,200 ft above sea level—are not present anywhere in the Flathead basin north of the Big Draw in T. 24 N. This absence is in accordance with the suggestion that the higher stages of glacial Lake Missoula occurred before (and some of them relatively long before) the front of the Flathead glacier was melted back northward from the Polson moraine. However, water was impounded north of the Polson moraine at least to an altitude of 3,000 ft until the late stage in which the Kalispell recessional moraine and the morainal deposits near and east of Whitefish were formed. This persistence is shown by the relations of deposits of laminated lacustrine silt 10 to 60 ft or more thick and of the several terraces near and north of the Flathead Lake basin. Even after the level of the main body of glacial Lake Missoula had dropped below an altitude of 3,200 ft an early and somewhat more extensive stage of the glacial Flathead Lake was probably held up to these levels for a time while the reestablished Flathead River was eroding the outlet through the Polson moraine and slowly cutting down into the underlying rock to an altitude of about 2,900 ft at the dam site below Polson.

It does not seem probable that the Little Bitterroot arm of glacial Lake Missoula could have been standing much higher than the 3,100-ft level when the coarse gravel was being swept westward for 8 to 9 miles from the terminal moraine in the Big Draw during the Wisconsin stage of glaciation. The white laminated silt does not extend eastward into the Big Draw nor much above an altitude of 3,000 ft.

WISCONSIN STAGE OF GLACIATION EAST OF THE CONTINENTAL DIVIDE

RELATIONS TO MORAINES OF POSSIBLE ILLINOIAN OR WISCONSIN (IOWAN) AGE

The character and relations of the remnants of early Pleistocene glacial drift capping the high interstream benchlands bordering the north and east front of the mountains of Glacier National Park are described in Professional Paper 174 (pp. 31–44). Drift near the east front of the mountains as far south as the Bighorn Mountains of Wyoming was also described and need not be repeated here.

In many places along the east front of the Rocky Mountains from the Canadian boundary near Glacier National Park southward into Wyoming the relations of the terminal moraines of the Wisconsin stage of the Pleistocene mountain glaciers to the several terrace remnants clearly show that the moraines were not deposited until after the second terraces had been very greatly eroded and reduced approximately to their present extent in the interstream areas. It is evident, therefore, that these second terraces are not of late Pleistocene age. It is also clear that they are not nearly so old as the high-level early Pleistocene glacial drift on the remnants of the Pliocene(?) first terraces near Glacier National Park and elsewhere in this region. Except this very old, high-level drift, at most places the outermost moraines of the mountain glaciers along the east front of the Rockies are of the Wisconsin stage. At a few places along and south of Yellowstone River, in Montana and Wyoming, there are remnants of somewhat older moraines outside of, but near, the Wisconsin moraines. They lie on or extend down onto remnants of the second terraces but do not extend below them, indicating that the outer moraines were older than the inner valleys and the lower third terrace. They correspond to the moraines of Blackwelder's Bull Lake stage of glaciation on the "Circle" terraces near the Wind River Mountains in Wyoming (Blackwelder, 1915, pp. 323 and 325) and are probably to be correlated with the

Keewatin drift of eastern Montana that has been tentatively described in Professional Paper 174 as of either Illinoian or Iowan age.

Remnants of outer terminal moraines of similar age have been found in several of the intermontane basins drained by the Missouri River as well as in several places west of the Continental Divide. These features and their significant relations are discussed in connection with the descriptions of the associated later moraines.

MORAINES OF THE GLACIERS IN BIG HOLE BASIN

In considering the relations of the late Pleistocene glacial moraines and associated deposits the order of presentation is varied from what has gone before by describing first the features at the headwaters of the Missouri River system, beginning with the Big Hole Basin.

The several Big Hole glaciers south of Ruby Creek, which deposited the moraines in the Big Hole Basin, ranged in length from 9 to 12 miles and at their terminals were 1 to 2 miles wide.

PIONEER CREEK

The relations of the moraines in adjacent parts of T. 7 S., Rs. 15 and 16 W. (8 to 10 miles south-southwest of Jackson) were not clearly determined. Unlike the regions farther north, it seems that the glaciers were not entirely distinct in each creek valley extending from the high peaks of the Beaverhead Range down deep glaciated troughs between long spurs as farther north. The ice during the Wisconsin stage may have merged into one great piedmont lobe, which overtopped the intervening rock ridges west of Skinner Meadows and may have formed the rough kame-and-kettle moraine that extends continuously for several miles west of the national forest boundary north of Pioneer Creek. The pebbles and boulders in the drift composing this moraine are all of quartzite, so far as noted, with none of other sedimentary rocks or of granite. There appears to be an east lateral moraine banked against the rock ridge east of Big Hole River, but this morainelike deposit may be due, wholly or in part to land sliding. There is a small remnant of a 20- to 25-ft gravel terrace outside the terminal moraine, but as far as the eye can see to the west and northwest there appear to be no remnants of a terrace rising above the broad bottom lands north and east of the wooded moraines. Apparently either the big second terrace was wholly removed by erosion from that part of Big Hole Basin south of Big Swamp Creek, or what to the north is a distinct and lower outwash third terrace rises upstream at so steep a grade as to merge with or almost completely bury the second terrace. The altitude at the Pioneer Creek moraine is about 7,000 ft.

Judging from a topographic map of part of the Beaverhead National Forest (based on a reconnaissance survey by the Forest Service) there were glaciers on Andrus and Pine Creeks heading near the Bloody Dick triangulation station (9,831 ft above sea level), 15 miles south of Jackson in the northern part of T. 8 S., R. 14 W.

MINER CREEK

Five to six miles west of Jackson, in the southwestern part of Big Hole Basin (Tps. 5 and 6 S., R. 16 W.) Miner Creek cuts through the terminal moraine (6,900 to 7,000 ft above sea level) of a great glacier that headed in Beaverhead Range. The terminal moraine, at its junction with the south lateral moraine, lies in the woods just inside the boundary of Beaverhead National Forest. The road to Miner Lake extends westward for 2 miles diagonally across a great deposit of morainal drift whose higher parts are 7,300 to 7,400 ft above sea level. From the bridge, a mile below the lake, the writer climbed over two or three inner moraine ridges, one above another, to the top of the main north lateral moraine, which he followed southwestward, between altitudes of 7,600 and 7,900 ft. In this part, north and west of Miner Lake, the moraine top is broad in some places, and very narrow with steep side slopes in other places. No big granite boulders were seen, but the surface is sprinkled with pebbles and 1- to 3-ft boulders, mostly of gray quartzite. The height of the crest above the lake, 400 to 700 ft, suggests that beneath the drift there is a ridge, or remnant of an older high piedmont terrace, such as those which border La Marche Creek and other creeks in the northern part of Big Hole Basin. There is a similar ridge on the opposite (southeast) side of the glaciated trough. The tops of these ridges appear to continue southwestward rising gradually until they join the steep mountain front at either side of the portal of a deep mountain gorge. No evidence of pre-Wisconsin glaciation was noted. The view from the meadow below the lake to the high, bare, cirque-scalloped peaks at the head of Miner Creek is very grand on a clear day.

A short distance above the head of Miner Lake the road crosses a recessional moraine, strewn with abundant boulders of white to gray, cross-bedded quartzite 1 to 3 ft in diameter. As seen from openings in the woods, the great wooded spurs on the north and south appear to be 1,000 ft or more high where they join the craggy higher mountain slope.

About two miles southeast of Miner Lake and a short distance from the abrupt outer face of the great south lateral moraine spur, there is a low wooded moraine at the head of the smooth, gravelly, flat bordering Englejard Creek.

Near the forest boundary outside of the Miner Creek terminal moraine there is an erosion remnant of the second terrace 30 to 50 ft above the broad gravelly flat.

BIG SWAMP CREEK

The meadowland on the lower terrace or outwash plain traversed by Big Swamp Creek slopes down northeastward from a terminal moraine at 6,800 ft above sea level and just within the boundary of the national forest to Big Hole River, 6,150 ft above sea level in a distance of about 6 miles. So smooth is the gently sloping flat that a person traversing the road leading west-southwest to the moraine does not realize that there is a fall of several hundred feet in that distance.

The wooded terminal moraine of Big Swamp Creek glacier in sec. 16, T. 5 S., R. 16 W., is 25 to 50 ft high, uneven and bouldery. Most of the pebbles and 1- to 5-ft boulders are of gray quartzite, with some of gray granite. The relations of some outer morainal deposits on the north and south were not clearly determined during the brief examinations made by the writer.

LAKE CREEK

The wooded north lateral moraine of Lake Creek glacier (sec. 29, T. 4 S., R. 16 W.) is about half a mile south of the south lateral moraine of Rock Creek glacier. The moraine, which is 50 to 75 ft high and pitted with kettle holes, bends and extends southeastward in two curves, about a mile, into sec. 32, where Lake Creek has cut a narrow gap through it. The moraine on the south side of the creek extends about half a mile farther northeast than that on the north side, and at the forest boundary it also curves and extends southeastward through sec. 33, and thence southwestward as a lateral moraine through secs. 4 and 5 (T. 5 S., R. 16 W.).

In section 4 the wooded moraine is bordered by a well-defined spillway which separates it from an extensive treeless remnant of the great second terrace. This spillway leads northeastward to the hay fields on the lower flat or third outwash terrace. This bottom land, which is traversed from southwest to northeast by Rock Creek, Sumrun, and Lake Creeks, is 3 to 5 miles wide between the erosional bluffs of remnants of the second terrace on the north and south, and it slopes gently down from the terminal moraines (at an altitude of 6,600 to 6,700 ft) to Big Hole River. In sec. 4 outside the spillway noted above is a narrow bouldery belt of low swells and swales parallel to the big moraine. It has the appearance of a worn-down and partly destroyed moraine, somewhat older than the big moraine of Wisconsin age; it may be as old as the big second terrace, which is not entirely cut away at the outer front of the older moraine.

A short distance to the south is another low, wooded, stony ridge that may be a pre-Wisconsin north lateral moraine of Big Swamp Creek glacier. Insufficient examination of it was made, however, to make this suggestion certain.

ROCK CREEK

About 5 miles southeast of Moose Creek, above the place where the old stage road crossed Rock Creek (sec. 17, T. 4 S., R. 16 W.), the broad bottom land or lower, third terrace joins the wooded terminal moraine (Wisconsin stage) of Rock Creek glacier at an altitude of 6,650 ft. The outer margin of this moraine is nearly 100 ft high where it curves westward and merges with the north lateral moraine. Where it was examined, this moraine is pitted with large and small kettle holes and strewn with boulders of gray quartzite. The lateral moraine extends southwestward through the woods and appears to join the northeast end of the long spur on the north side of Fourth of July Lake. This part, however, was not examined by the writer. The wooded terminal moraine extends about a mile south of Rock Creek and in section 20, curves westward and merges with the south lateral moraine. The outer face of this moraine is very abrupt and rises 50 to 100 ft above the bordering flat gravelly terrace. No evidence of pre-Wisconsin drift was noted outside the big moraine of Wisconsin age.

MOOSE CREEK

The low terminal moraine of Moose Creek glacier, of Wisconsin age, is 6,750 ft above sea level in sec. 36, T. 3 S., R. 17 W. It extends southward across the boundary of the national forest and increases in height as it merges with the southeast lateral moraine, and extends thence southwestward in a succession of curves. In this part the outer front of the moraine, where examined, is a steep bluff rising to a height of 100 ft or more above the bordering third outwash terrace which drains eastward to Rock Creek. The boulders on this moraine are mostly gray quartzite 1 to 2 ft in diameter; a few measure 5 to 10 ft. A few porphyry boulders were seen, but none of granite. This moraine continues southwestward until it joins the northeast end of one of the larger interstream spurs at an altitude of about 7,400 ft. No indications of pre-Wisconsin glacial drift were seen outside the big moraine.

MUSSIGBROD CREEK

In the Beaverhead National Forest about 17 miles northwest of Wisdom, T. 1 S., R. 16 W., the road to Mussigbrod Lake crosses a well-defined bouldery terminal moraine of the Wisconsin stage of glaciation (6,400 ft above sea level), and a series of inner moraines lying in loops across the valley. They merge into lateral moraines, which extend along the sides of the valley and those on the northeast extend gradually up the slope of the big ridge. A short distance outside the forest boundary are several narrow parallel bouldery ridges, only a few feet high and separated by smooth, narrow, grassy, and less stony strips. These ridges are clearly morainal and probably represent a somewhat earlier stage of glaciation. This bouldery outer moraine may be traced up the slope to the top of the ridge 100 ft or so high on the north. On this ridge top outside the moraine and on a similar hill about half a mile farther southeast are numerous large and badly weathered boulders of granite and porphyry, which probably are the remains of a yet older glacial deposit, of early Pleistocene age. Since their deposition and prior to the formation of the two later sets of moraines, the valley of Mussigbrod Creek was deepened 100 ft or more by stream erosion. Examination was not made to see whether there is a similar deposit on the southwest side of the valley. It is possible, however, that some of the badly weathered rocks are boulders of disintegration lying on or near the parent ledges. The hills on which the much-weathered boulders lie are probably erosion remnants of the late Tertiary piedmont terrace, like those bordering the glacial troughs farther north.

HOWELL CREEK

The Wisconsin moraines along Howell Creek, about 15 miles north of Wisdom (T. 1 N., R. 15 W.) are very similar to those along Pintlar and La Marche Creeks but do not extend as far beyond the canyon's mouth. The whole series of moraines from the high, older bench on one side to its companion ridge on the other, contains an enormous quantity of granitic debris carried by the glacier and left piled up in the morainal ridges which range from 50 to 100 ft or more in height. The terminal moraine of Howell Creek glacier lies across the head of the broad flat of the inner valley which transects the broad second terrace to the southeast. This third lower flat terrace is three fourths to 1½ miles in width and 25 to 50 ft or more below the upper, or main second terrace.

THOMPSON CREEK

Four to five miles west of the Beaverhead-Deer Lodge County line, Thompson Creek has cut away the second terrace and developed a broad gravelly flat third terrace, 1 to 3 miles wide. Near the forest boundary the wooded, bouldery terminal moraine (at an altitude of about 5,400 to 5,450 ft) of the Thompson Creek glacier lies across the head of this gravelly flat between high wooded ridges on the east and west. From the terminal loop the west lateral moraine extends northwestward up along the slope of the big west ridge. Granite boulders 1 to 3 ft in diameter are scattered on the slopes and crest of this ridge. They may perhaps represent glacial drift of pre-Wisconsin age. The bulk of the ridge may be an erosional spur remnant of the Pliocene-Pleistocene bench 1, as seen elsewhere. The drift-covered east and west spurs extend northwestward to the higher rocky slope at the mouth of the mountain gorge.

PINTLAR CREEK

The valley of Pintlar Creek was evidently occupied by a very large glacier during the Wisconsin stage of glaciation. The lateral moraines at the most northerly points crossed by the writer, a mile or so outside the mouth of the mountain canyon, are 600 ft or more above the valley bottom and appear to overlie what remains of the spurlike remnants of the high piedmont terrace. From this position they slope gradually southward past Pintlar Lake, which lies in the glacial trough between them. At one point an enormous accumulation of loose granite boulders lies at an altitude of 6,900 ft, about 300 ft below the top of the upper west lateral moraine, as though there had been slumping on some underlying finer deposits. About 3 miles farther south, near the national forest boundary, the southeast-trending laterals join in a terminal loop across the valley bottom (6,300 to 6,350 ft above sea level). Here the rough and very bouldery terminal moraine extends beyond the edge of the woods and is cut through by the channel of Pintlar Creek. The relations seem to indicate that when the outer moraine was formed the valley had already been cut well below the head of the broad flat top of the big second terrace. Here also there are several closely spaced recessional moraines inside the outer moraines. It is not clear that the outermost of the terminal deposits was formed any earlier than the Wisconsin stage. The lateral moraines are generally narrow-crested ridges, one above another, on the side slopes of the valley. All the moraines seen are largely composed of and sprinkled with fresh-looking boulders of gray granite, some of them 10 to 20 ft in diameter.

FISHTRAP CREEK

Three and a half miles northwest of Fishtrap (5,825 ft above sea level) the low, wooded, terminal moraine of the Fishtrap glacier lies across the head of the broad, flat, gravelly, lower creek valley at an altitude of 6,025 ft. This is 100 ft or more below the broad, gravelly, irrigated second terrace on the south and the higher rolling upland slope on the north. The north lateral moraine was traversed back some distance in the woods to an altitude of 6,400 ft. Within the outer moraine loop several recessional moraine ridges were crossed. All are strewn with cobbles and boulders of granite, schist, quartzite, and argillite. The east fork of the valley of Fishtrap Creek heads back in the foothills of the Anaconda Range and may not have been glaciated. The Fishtrap glacier, which probably had several tributaries, was about 10 miles long.

In the southeast part of T. 2 N., R. 14 W. (about 6,200 to 6,250 ft above sea level) a small hill of black basalt rises above the large, somewhat eroded second terrace. North of the basalt hill the wooded south lateral moraine of the Fishtrap glacier rises above the broad, smooth terrace. From the relations of the terminal moraine on Fishtrap Creek to the higher second terrace on the south, it is evident that this terrace is of pre-Wisconsin age.

LA MARCHE CREEK

About 25 miles north-northeast of Wisdom on La Marche Creek, a great glacier extended southeastward down the valley between the high bench remnants described above. The terminus of the last glacier is indicated by a well-defined moraine (6,100 ft above sea level) 1¾ miles north of the river. A lateral moraine was traced up the east slope to where it lay across the flat top of the bordering high bench about 500 ft above the bottom of the valley. The uneven surface of the moraine is strewn with big boulders, some of them as much as 20 ft in diameter. The boulders consist of medium-grained gray granite, lighter pegmatitic granite with 1- to 2-ft feldspar phenocrysts, schist, diorite, other crystalline rocks, and red and gray quartzites.

The main west lateral moraine lies on top of the high bench (about 7,100 ft above sea level) west of La Marche Creek, about a mile south of the canyon mouth and 600 ft above the creek. From this point southward, the moraine extends down the gradual slope below the high bench looping westward into the sag and out again around the foot of a quartzite ledge. In the next mile the moraine drops down to 6,400 ft and finally reaches the valley bottom, forming a terminal loop about 6,150 ft above sea level and joins the east lateral described above. Inside this great moraine loop are several similar loops marking stages in the final recession of the ice margin. A short distance outside this moraine another lateral moraine slopes from the edge of the high bench on the north to the valley bottom, where it joins a terminal loop about a quarter of a mile south of the forest boundary. This moraine is not so ridged as the inner moraine; it may have been formed during an earlier advance of the ice and was subsequently partly eroded. Evidently by the time this outer moraine was formed the second terraces in Big Hole Basin had already been developed.

The smooth, partly wooded and dissected benchland above and outside of the uppermost west lateral moraine in the valley of La Marche Creek is sprinkled with cobbles and 1- to 2-ft boulders of whitish, light-greenish, and reddish quartzite; in places underlying rhyolitic deposits are exposed. No granitic boulders were noted on the bench outside the lateral moraines, although such boulders, 1 to 15 ft in diameter, are abundant on the moraines.

SEYMOUR CREEK

The Seymour Creek glacier, which was 8 or 10 miles long, headed on the cirque-scalloped flanks of Mount Tiny and adjacent peaks of the Anaconda Range in the southern part of the Philipsburg quadrangle. The partly wooded terminal moraine of Seymour Creek glacier, about 6,150 to 6,350 ft above sea level has a humpy surface strewn with boulders of granite, quartzite, greenish argillite, schist, and limestone ending in a cobble-strewn outwash plain. East of the outwash plain is a higher alluvial-gravel second terrace, from which there is a very extensive view northwest to north over the wooded foothills to the high peaks on the Continental Divide. These foothills consist of a series of long, southeast-sloping interstream spurs which, as seen from a distance, appear to merge like erosion remnants of an extensive high-level piedmont plain or bench of Pliocene or early Pleistocene age, similar to those spurs bordering the Beaverhead Range in the southern half of the Big Hole Basin.

The south flank of the Anaconda Range east of Seymour Creek was also heavily glaciated. The moraines were not examined by the present writer but they are described as follows (Calkins and Emmons, 1915, p. 11):

> The south flank of the Anaconda Range is little less heavily mantled with moraines than the north flank. They are impressive in their vast bulk and chaotic roughness but have few strong outstanding lineaments except the lateral moraines along Sullivan Creek and west of Twelvemile Creek. On the sides of the deep canyon of Seymour Creek, near the south boundary of the quadrangle, successive stages of the ice front are outlined by obscure lateral moraines that arch down toward the south in nearly parallel curves.

GLACIERS OF THE PIONEER MOUNTAINS

WISE RIVER

The Pioneer Mountains,[7] northwest of Dillon, are wholly within the Beaverhead National Forest, where they extend about 30 miles from east to west and about 35 miles from north to south. They are encircled on the west, north, and east by the Big Hole River, and are nearly bisected by the Wise River and Grasshopper Creek. The eastern and higher part of this mountain group is shown on the topographic map of Dillon quadrangle, and this part and the rest of the area are shown on more detailed topographic maps prepared by the United States Forest Service. As seen in a general view, and as shown on these maps, this mountain group as a whole is rugged, with rather steep and deeply dissected marginal slopes and with interstream crestlines culminating in bare peaks (10,000 to 11,000 ft above sea level), towering high above numerous glacial cirques and ice-scoured gorges. There are some smoothly rounded, and partly grassed, upland tracts, especially in the western part. The southern end of this mountain group is drained to the Beaver-

[7] The name Pioneer Mountains is shown on a Forest Service map of Beaverhead National Forest, 1926.

head River above Dillon by Grasshopper and Rattlesnake Creeks.

At some time during the glacial epoch, the valley of Wise River, as far north as the mouth of Pattengail Creek, about 10 miles south of the junction with Big Hole River, was occupied by a great glacier with branches in several of the tributary valleys. The most northerly moraine of Wise River glacier is between half a mile and 1½ miles south of the Pattengail Creek. The uneven bouldery surface of this wooded moraine is 6,300 to 6,400 ft above sea level. That the Wise River ice did not extend farther down the valley is probable, for just east of the northern part of this moraine (SW¼ sec. 11, T. 2 S., R. 12 W.) there is a conspicuous rock pinnacle which could not have survived had it been overriden by the great glacier. Very bouldery morainal drift exposed along the highway is separated from the west foot of this pinnacle only by the narrow inner gorge of Wise River, and there may be glacial drift even closer to its base. There is a high bouldery bench, either a torrential or a morainal deposit, near Ross Gulch on the northwest side of the river, and between it and the rock pinnacle there is morainal drift on the east side of the river, nearly opposite the mouth of Pattengail Creek. It seems probable that this drift deposit is part of the outermost moraine (pre-Wisconsin) of Pattengail glacier, laid down at a time when it extended beyond the mouth of its own valley and about 1 to 1½ miles farther northeast in Wise River valley.

The lower wooded moraine of Wise River glacier, south of Pattengail Creek, extends up the valley for about a mile south of the rock pinnacle. Its surface is uneven and bouldery. Some of the granite boulders are 10 to 15 ft in diameter; a large part of the material consists of gray and purplish quartzite. This moraine, which is transected by the narrow inner gorge of the river, may also be of pre-Wisconsin age.

Two to three miles farther up the valley is a narrower but much more conspicuous moraine (fig. 37 *A*) that extends nearly across the valley as a dam about 200 ft high (altitude 6,450 to 6,650 ft), just above the mouth of Moose Creek (T. 2 S., R. 12 W.). It may mark the terminus of the glacier during the Wisconsin stage of glaciation. This morainal dam was buttressed at the eastern end against a rock spur at the steep side of the valley. When the ice was melted back south from this moraine a temporary glacial lake was held in the broad flat valley behind (south of) the morainal dam. The outflow from this lake found a spillway through a depression in the crest, at the eastern end of the dam; while lowering this spillway the stream encountered the buried spur of broken quartzite which it has cut to a depth of 100 ft or more. The narrow crest of the moraine is pitted with a few kettle holes; the pebbles and boulders are of granite and quartzite and some are striated. The wooded north or outer face of the moraine is rather steep; the south or inner face is very abrupt and is overgrown with sagebrush.

About a mile farther north down the valley there is a similar but smaller curved ridge extending out from the east side of the valley just south of Boulder Creek. Its relations were not satisfactorily determined. It appears to be composed, in part, of glacial drift, and of pebbles and boulders of granite and quartzite; one quartzite boulder was striated. Gray quartzite is exposed in the cliff at the west end of this ridge, but the gap traversed by the river between the cliff and the west side of the valley is so much broader than the one at the east end of the moraine dam near Moose Creek that the interpretation of the ridge as a moraine of the Wise River glacier is open to doubt. It may be a

FIGURE 37.—Terminal moraine of Wise River glacier fifteen miles south of Wise River, Mont. This moraine blocked the gorge until the river cut through the drift-covered rock spur at right.

moraine of a glacier in the valley of Boulder Creek. Just north of this ridge is a big bouldery gravel fan built out into the valley of Wise River by Boulder Creek, and from it a gravel terrace extends down Wise River to the narrow gap through the outer moraine.

South of the moraine near Moose Creek the valley broadens and is evidently one of the intermontane basins in which Tertiary "lake beds" were deposited. Subsequently the loose and friable sediments were dissected and largely removed by stream and glacial erosion. They are well exposed near the mouth of Gold Creek, in the SE¼ sec. 33, T. 2 S., R. 12 W., at the lower end of a narrow abrupt spur 200 ft high which extends southward across the township line to the higher mountain slope. At the north end of this spur, Gold Creek is cutting into the base of a cliff of light, buff to gray, friable sandstone, with some interbedded coarse gravel and boulders of quartzite. North of the creek the many landslides below a bare scarp slope are probably due to the presence of sand or clay of the same Tertiary beds, and are perhaps partly due to oversteepening of the slope by stream cutting or glacial erosion. There may have been a branch glacier in Gold Creek valley, past which the great trunk of Wise River glacier moved northward. West of the friable sandstone ridge, and beyond a narrow marshy trough, a narrow, abrupt ridge of glacial drift (also about 200 ft high) is apparently a lateral moraine of Wise River glacier. Its north end appears to have been buttressed against a hill of quartzite. Gold Creek has cut a narrow V-gap through it in SE¼ sec. 33. From the creek the moraine extends southward, with varying height, into NE¼ sec. 4, T. 3 S., R. 12 W., where it joins the higher mountain slope. The coarser part of the drift consists of pebbles and boulders of granite and quartzite, some well striated.

The Tertiary beds seem to extend beneath a low bench on the east side of the valley, in secs. 4, 9, and 16, T. 3 S., R. 12 W. On the west side of the river nearly continuous morainal deposits, in secs. 8, 17, 20, and 21, extend southward for 3 miles or more beyond Lacy Creek. They were probably partly the product of branch glaciers occupying the valleys of Lacy, Odell, Wyman, and Little Joe Creeks.

In SE¼ sec. 17, T. 3 S., R. 12 W., opposite the mouth of Wyman Creek, Wise River has cut its inner valley around Big Point, a ridge 200 to 400 ft high, which projects northeastward into the basin. Quartzite is exposed in the steep west end of Big Point, the face of the cliff above the highway and the railroad being scoured smooth and in places showing glacial striae. There are many granite boulders, some 10 to 15 ft in diameter, on the surface near the road and also sprinkled over the slopes and top of Big Point. Evidently this ridge was overridden by Wise River glacier.

A big bouldery moraine in sec. 34 below the junction of Elkhorn and David Creeks is evidently a recessional moraine, the product of several big branch glaciers that headed to the south, southeast, and east in the high-level cirques that scallop the rugged peaks of Saddleback and Torrey Mountains, Tweedy Peak, and others.

PATTENGAIL CREEK

During the Wisconsin stage the rather broad valley of Pattengail Creek (the west fork of Wise River), and its tributary valleys were occupied by a branching glacier whose trunk was about 15 miles long. It headed near Sand Lake, 8 miles east of Wisdom, and extended northeastward to a low, pitted, and bouldery terminal moraine about a mile above Wise River. When the ice melted probably a temporary glacial lake was held in the basin behind this moraine. The lake was later drained through a narrow gap cut in the south end of the moraine. Some years ago an earth dam was built across this gap to flood the basin as a reservoir for irrigation. In June 1927 the dam gave way and the consequent flood rushed down the valley and scoured and broadened the creek channel and that of Wise River, in places washing out the highway and the narrow-gage railroad.

From the vicinity of Pattengail Creek, a bouldery outwash terrace extends to the valley of Big Hole River west of the village of Wise River. In the lower 2 miles the upper of two levels of this terrace is graded about 50 to 75 ft lower than the remnant of the second terrace a mile west of the village.

The east flank of the Pioneer Mountains has been deeply dissected by several streams tributary to Big Hole River. The gorges of several of these streams, namely, those of Canyon, Trapper, Rock, and Birch Creeks, were traversed by the writer as far up as the terminal moraines of the Wisconsin-stage glaciers. None of these glaciers reached the mountain front so their relations to the piedmont terraces is not shown.

CANYON CREEK

Canyon Creek flows northeastward in a deep gorge in the Pioneer Mountains and joins the Big Hole River in its narrow winding gorge near Moose Creek, 8 to 9 miles north of Melrose. The lower gorge of Canyon Creek, as seen from the cliff near Maiden Rock, which is west of the highway and north of Moose Creek, is very largely cut in upturned Paleozoic and Mesozoic strata and is so narrow as not to be traversed by a good road. Apparently, as shown on plate 1 of U. S. Geological Survey Bulletin 780, this lower part has not been glaciated. It has not been traversed by the writer. The part of the gorge above SE¼ sec. 12 T. 2 S., R. 10 W., is readily accessible by automobile, being reached about 8 miles west of Melrose by a road crossing the broad ridge northwest of Glendale. From a bouldery south lateral moraine crossed by the road there is a view of the head of the lower constricted gorge; apparently

FIGURE 38.—Glaciated gorge of Canyon Creek northwest of Melrose showing the smooth Vipond Park upland (left background) and the north lateral moraine of Canyon Creek glacier (left foreground) that extends eastward down slope below the upland. Notch in rock spur (right middle ground) is a wind gap cut by a glaciomarginal stream.

it was here that the Canyon Creek glacier terminated. To the west there is the broader, U-shaped, glaciated part of the canyon. As shown by the contours on the topographic maps (Richards and Pardee, 1926, pl. 1 and sheets 9 and 13 of the topographic map of the Wise River Division of the Beaverhead National Forest), Canyon Creek glacier headed on the flanks of Granite Mountain (10,000 ft above sea level) and adjacent peaks in the northwestern part of T. 3 S., R. 11 W., and extended eastward about 16 miles to the head of the constricted lower gorge of Canyon Creek, about 5,900 ft above sea level. Erratic boulders, largely of granite from the mountains at the head of the canyon, are strewn over the slopes below the upper limit of glaciation. From the middle of sec. 9 westward a big bouldery lateral moraine lies along the upper north side of the valley, rising gradually westward from 7,000 to 7,500 ft above sea level, until it lies along the top of the smooth upland prairie known as Vipond Park (fig. 38). At the group of old charcoal kilns in the middle of sec. 8, the glacier was evidently 800 to 900 ft thick and 1½ miles wide. About half a mile above the charcoal kilns the creek has cut a constricted inner gorge 100 ft or more deep in crumpled gray limestone (Madison). Above this side of the gorge on the south a great wall of limestone rises to a height of 1,000 or 1,500 ft; along it the canyon curves from a northeasterly to an easterly trend. From the crest of the north lateral moraine, there is a wonderful vista eastward down the glaciated canyon and northeastward to northwestward over the smooth, partly wooded Vipond Park (an upland from Pliocene time) to the surrounding hilltops. There seems little reason to doubt that the canyon was, in large part, due to stream cutting during early Pleistocene (pre-Wisconsin) time, and that it was scoured out by the glaciers of two or more stages of glaciation corresponding to those of which there is evidence on Trapper, Rock, and other creeks to the south, and on Wise River to the west. High up on the north slope above the Peter Olsen ranch on Canyon Creek, there is a sharp notch cut through a rock spur (fig. 38). Through this notch, which was seen by the writer only from a distance, a glaciomarginal stream may have flowed at a time when the canyon was filled with ice to that level.

TRAPPER CREEK

For 9 miles above Melrose, the valley of Trapper Creek is narrow; its steep, bare, and craggy side slopes are mostly cut in reddish and gray rocks. About 3½ miles above the old mining town of Glendale, rounded granite boulders 1 to 10 ft in diameter lie on the lower slopes and quartzite ledges. A little farther west, below jagged rock ledges in the slopes, is a low moraine (6,200 ft above sea level) containing pebbles of argillite and limestone, many of them striated, and many granite boulders. This moraine may be of pre-Wisconsin age. On the south side of the creek and 150 to 200 ft above it, and considerably above the top of the moraine, is a wooded bench which may represent the early Pleistocene terrace. Similar bench remnants appear on the rock spurs farther down the valley and above the narrow inner gorge.

For a mile or more the road up the valley traverses a rough, bouldery morainal deposit to, and up onto, a sharper transverse moraine whose top is 6,500 ft above sea level. Extending thence up the northwest side of the glaciated valley for some miles is what appears to be a great lateral moraine. This lateral moraine merges with the sharp terminal moraine and marks the probable limit of glaciation during the Wisconsin stage. The lower outer moraine may be somewhat, though not greatly, older. As shown on the topographic map of the Beaverhead National Forest, Trapper Creek glacier headed on the northeast flank of Granite Mountain, in the northeastern part of T. 3

S., R. 11 W., 8,500 to 9,000 ft above sea level and had a length of 8 or 9 miles.

ROCK CREEK

As on Trapper Creek, so in the canyon of Rock Creek, there is some indication of a pre-Wisconsin stage of glaciation. The canyon of Rock Creek is steep-sided and deep for several miles above (west of) the boundary of Beaverhead National Forest. At the boundary the stream emerges from the narrow canyon mouth and flows eastward for 4 to 5 miles in a much shallower narrow valley across the piedmont to join Big Hole River.

Just above the boundary of the national forest is a great accumulation of granite boulders, 1 to 10 ft in diameter, in the narrow gorge; about a mile above the boundary the boulders are piled in a low moraine and also lie on the lower side slopes. Apparently the glacier crowded a short distance into this very narrow part of the gorge and made its terminal deposit. Above this constricted part, the canyon is wider and its walls are less craggy. There are many granite boulders, and some appear to be aggregated in fans at the mouths of gulches cutting the steep side slopes of the gorge.

Two and a half to three miles above the forest boundary is a great moraine in front of Browns Lake. This is probably the terminal moraine of the Wisconsin stage. The glacier was thus about 8 miles long during the Wisconsin stage and about 2 miles longer during the earlier stage of glaciation.

From the outlet of the lake a trail ascends the steep wooded south side of the gorge. From this trail there are fine views of the U-shaped, glaciated gorge above Browns Lake to Granite Mountain and other high bare peaks. What appear to be several bouldery, south lateral moraines are crossed by this trail, the upper one being about 800 to 900 ft above the lake. The morainal drift extends westward along the slope and so blocks the mouth of a tributary gulch that it impounds Lake Agnes. The level of this lake is maintained in the hanging gulch, about 800 ft above Browns Lake, by an artificial dam.

WILLOW CREEK

About 3 miles west of the national forest boundary, Willow Creek enters a narrow craggy portal at an altitude of 6,250 ft. There is no road east of this narrow gap and the valley below was not examined. A branch road from Birch Creek extends northward across the smooth-topped intervening ridge and down into the rather broad basin of Willow Creek above the portal. The road ascends the valley on a bouldery gravel terrace from an old ranch near the portal. About half a mile above the ranch there is a natural rock tower composed of loosened blocks of disintegrating granite on the lower slope north of the road. This tower evidently was never overridden by a glacier. Half a mile farther west, near the confluence of Dubois and Willow Creeks, a great bouldery terminal moraine extends across the narrow bottom land at an altitude of 6,400 to 6,500 ft. This moraine probably marks the lower limit of confluent glaciers in the valleys of the two creeks during the Wisconsin stage of glaciation. As shown by the topographic map of Beaverhead National Forest, these glaciers headed on high platforms north and south of Tweedy Peak. Willow Creek glacier, the longer of the two, was about 8 miles long. It was joined by another branch glacier in the valley of Gorge Creek.

BIRCH CREEK

The mountain valley of Birch Creek within the Beaverhead National Forest is somewhat broader than the narrow craggy portal cut through upturned limestone strata near the forest boundary. Above the old mining town of Farlin the part of the valley examined by the writer has been cut mostly in granite. At higher levels, along bench tops of spurs and some interstream upland tracts there are indications of one or more older and broader valleys.

In this valley, as in those of Rock, Trapper, and Rattlesnake Creeks, there is some indication that during an earlier stage the glacier extended somewhat farther down the valley than during the Wisconsin stage. About three-quarters of a mile above the ranger station, near the place where the road branches, there is what appears to be a low, worn-down terminal moraine (6,500 to 6,600 ft above sea level). This low ridge is composed of fine material and of granite boulders 1 to 5 ft in diameter. A belt of boulders, some as much as 15 ft in diameter, extends a little west of north onto the edge of a smooth bench 100 to several hundred feet above the creek, like the remains of a lateral moraine. The boulder belt also curves and extends northward through a shallow depression in the crest of the ridge north of Rock Creek; a short distance down the north slope it loops around to the west, outlining a small lateral lobe of the glacier which crowded through the depression so its waters drained northward to Willow Creek. There are no boulders on the smooth grassy top.

West of the depression (in NE¼ sec. 5, T. 5 S., R. 10 W.) is the rough and very bouldery big moraine of the Wisconsin stage. It crosses the inner valley of Rock Creek at an altitude of 6,700 ft, and merges with a south lateral moraine that can be traced diagonally up the slope, curving southwestward around the flank of the big ridge between Rock Creek and Thief Creek.

The north lateral moraine extends northwestward and spreads out on the upland or broad old bench, 200 to 500 ft above the creek, as far as the south shore of Bond Lake. The uneven swale-and-swell surface of this moraine is thickly sprinkled with granite boulders, some 15 or 20 ft in diameter. The basin of Bond Lake is enclosed on the south by this big moraine, on the north shore by a granite ridge and a low granite spur at the lower or east end. The narrow outlet has been closed by a small artificial dam buttressed against a natural pillar of granite, which was not overridden by the glacier. Birch Creek glacier headed in great cirques on the flanks of Torrey and Tent Mountains, and the intervening high mountain crest, 9,500 to 11,000 ft above sea level; it had a length of about 9 miles. As shown on the topographic map of the Beaverhead National Forest, the southern part of Rock Creek basin is on a great platform or cirque floor north of Tent Mountain that is characterized by three or more steps several hundred feet high. On these steps are Tub, Anchor, Pear, and Boot Lakes—the last about 8,200 ft above sea level or 700 ft above Lily Lake, which occupies the head of the narrow inner gorge.

There probably was a separate glacier that headed on the north flank of the high cirque-scalloped crest at the head of Thief Creek. It probably did not reach Birch Creek valley.

RATTLESNAKE CREEK

The gorge of Rattlesnake Creek, which heads in the Pioneer Mountains east of the Grasshopper Creek basin, was glaciated down to a point about $1\frac{1}{2}$ miles above the old mining camp of Argenta, 6,000 ft above sea level. Much of the way above the village the road is on a narrow terrace of pebbles and boulders of quartzite, granite, and limestone. About 4 miles above the village (sec. 15, T. 6 S., R. 11 W.) this terrace heads about 6,500 ft above sea level at the front of a well-defined outer terminal moraine containing abundant 1- to 6-ft gray granite boulders and smaller fragments of quartzite and limestone. Through this moraine the creek has cut a notch. Above the notch granite boulders are scattered on the steep side slopes of talus and ledges, their upper limits increasing upstream. Judging from the manner in which denser parts of the granite boulders project, making their surfaces uneven, it is inferred that many of them have lost at least 2 or 3 in. in diameter in consequence of long weathering. This inference suggests that the outer moraine may be of pre-Wisconsin age. About a mile farther upstream, 7,000 ft above sea level and just below the reservoir, the canyon is blocked by another bouldery moraine which may mark the limit of Wisconsin glaciation.

GLACIERS OF GRASSHOPPER CREEK BASIN

There may have been small glaciers on the flanks of the range east and northeast of Polaris, but no moraines were seen from the highway within 3 miles north of Polaris. North of Polaris and below the mouth of Steele Creek canyon, which heads in cirques on the flanks of Highboy Mountain (10,300 ft above sea level), there is a big terminal moraine to which the tributary Dingley Creek glacier, heading farther north on the flank of Saddleback Mountain, may also have contributed.

AMES CREEK

There were several glaciers heading in the gorges of the Big Hole Divide between the south end of Big Hole Basin and the basin of Grasshopper Creek to the east. One extended northward down Ames Creek to a position on the slope about a mile southeast of the pass, or 11 or 12 miles east by south from Jackson forming a terminal moraine about half a mile up the piedmont slope, 7,100 to 7,200 ft above sea level. This moraine has been partly cut away by Ames Creek. Its surface is marked by gentle swells and swales and it has such a smoothed-down appearance and the pebbles and boulders (mostly of reddish quartzite) are so weathered as to suggest that the moraine is of pre-Wisconsin age. There may be a moraine of Wisconsin age (which was not examined) behind this outer moraine. The moraine is 700 to 800 ft above Grasshopper Creek at the Tash ranch, 3 to 4 miles to the northeast.

HARRISON CREEK

Nearly 2 miles west of Grasshopper Creek at the Harrison ranch (6,325 ft above sea level), the terminal moraine of Harrison Creek glacier lies on a pebble-strewn, partly dissected piedmont slope about 7,200 ft above sea level. Outside this terminal moraine some low gravelly swells and swales suggest the presence of a pre-Wisconsin moraine. There is, however, a possibility that this swell-and-swale topography is due to creep on underlying west deposits of Tertiary sand or clay from which water is seeping in places. The terminal and lateral moraines of Harrison Creek glacier are very well defined. The outer, grassed, front slope is steep and regular and increases in height from 25 to 100 ft where the terminal loop joins the wooded south later moraine. The surface of the moraine is strewn with angular to subangular cobbles and fragments of pink and reddish quartzite. The north and south lateral moraines rise southwestward along the sides of a glaciated trough, cut 100 to 200 ft deep through the upper part of the piedmont terrace, and they join the steep mountain front at either side of the canyon portal, at altitudes of 7,700 to 7,800 ft.

The highest part of the piedmont, adjacent to the moraines on the north and south have similar altitudes and are probably remnants of the highest set of terraces, which are of Pliocene or early Pleistocene age. There is some suggestion of a pre-Wisconsin moraine on the high terrace outside the Wisconsin north lateral and separated from it by a gulch. From the terminal moraine the slope, all the way to the hay fields on the gravelly flat nearly 600 ft lower to the east, is strewn with cobbles and 1- to 2-ft boulders, mostly of quartzite.

SWAMP CREEK

From Harrison Creek the somewhat dissected piedmont terrace extends southward to Swamp Creek. This creek heads in a deep glaciated canyon, and from the mouth of the canyon it flows through a glaciated trough transecting the high piedmont terrace. There appears to be a terminal moraine near the national forest boundary near Grasshopper ranger station (sec. 11, T. 7 S., R. 13 W.). There is also a suggestion of a pre-Wisconsin north lateral moraine on the edge of the high terrace (altitude 7,500 ft), similar to that on Harrison Creek. Judging from a distant view, Brays Canyon, 3 miles farther south, was also occupied by a glacier.

The trail leading south from Wise River basin across the pass (altitude 8,300 ft) to the north end of the Grasshopper basin is over a smooth, partly wooded, upland west of Elkhorn Creek. Judging from the topographic maps, there were glaciers heading in big cirques southeast of this pass which drained to Grasshopper Creek north of Polaris.

BLOODY DICK CREEK

There is a large, partly wooded, uneven-topped terminal moraine about 7,000 to 7,100 ft above sea level about 25 miles northwest of Grant. It nearly blocks the upper valley of Bloody Dick Creek, one of the tributaries of Horse Prairie Creek. This moraine was evidently formed by a glacier heading at the Continental Divide in the Beaverhead Range, 12 to 15 miles north of the Lemhi Pass. On this moraine are many cobbles and boulders, mostly or wholly of gray quartzite. For a mile or less in front of the moraine, which is probably of Wisconsin age, there are low gravelly swells suggesting remains of an older, worn-down moraine. When the glacier front stood at this outer moraine it probably blocked the mouth of Selway Creek on the north and diverted the creek temporarily along the foot of the hills, where it cut a small gorge behind a sharp cut-off ridge of fragmental quartzite. An outwash gravel terrace extends some distance down the valley below the moraine. Above the reservoir, 2 to 3 miles farther up the valley, the road follows the crest of a narrow esker-like ridge for some distance. This may be a lateral moraine.

GLACIERS ON GARFIELD MOUNTAIN AND THE SNOWCREST RANGE

Small glaciers appear to have headed in cirques on the north and east flanks of the mountain group about 6 miles south of Lima. One was at the head of Dutch Hollow. As seen with glasses from a distance of 2 to 3 miles, the high, bare, reddish cirque wall appears to be composed of stratified rocks dipping steeply into the mountain wall. Lateral moraines extend eastward to an altitude of about 7,500 ft and there merge into a strongly defined terminal moraine which has been cut through by a creek. Most of the pebbles and boulders seen are of light-colored sandstone and some are of limestone. Some distance downstream, on a remnant of the dissected gravelly benchland, are deeply etched boulders of sandstone suggesting remnants of an outer, pre-Wisconsin moraine.

The eastern flank of the Snowcrest Range is scalloped by several cirques at the head of the Ruby River valley. One of the glaciers heading in these cirques extended down the valley of Divide Creek to a point about a mile above the national forest ranger station. Its morainal loop is rather narrow where seen (7,700 to 7,800 ft above sea level), but the terminal moraine and the north and south lateral moraines are well-defined bouldery ridges. The valley appears to have been so blocked with drift that the postglacial creek has cut a new outlet through the south lateral moraine; a ditch now diverts water across the divide near the ranger station to the head of Long Creek. There may have been glaciers also at the heads of the creeks 1 to 2 miles to the north and to the south.

GLACIERS OF THE CENTENNIAL MOUNTAINS

The high and rugged mountains of the Centennial Mountains bore several glaciers on their north flanks. South and southeast of Upper Red Rock Lake (T. 14 S., R. 1 W.), is a series of terminal moraines apparently representing two distinct stages of glaciation. Four to five miles east of Lakeview, in secs. 27 and 28, the writer climbed to the top of the abrupt 300-ft margin of one of these great terminal moraines, directly in front of a great glaciated trough and cirque, the latter hanging high above the valley flat. The surface of the moraine is very uneven and contains abundant angular fragments of limestone, together with some dark-green crystalline rock. The remains of this moraine though bulky, are rather narrow. When, or after, the glacier forming this first moraine was melted away, the waters from the glaciated gorge shifted to the east side of the moraine and cut a rather narrow trough. During the Wisconsin stage, the glacier re-advanced down the new trough and was shifted laterally by it, laying a new set of morainal ridges whose tops are about 100 ft lower than, and at one side of, the older moraine, which is about 6,750 ft above sea level.

East of the old moraine are several terminal moraines. The third glaciated trough to the east is larger and deeper than the others and appears to head farther back in the mountains, perhaps in a multichambered cirque; on the plain below is spread a great maze of bouldery ridges, knobs, and kettles. Here also the highest part of the moraine is at the west side and appears to have been formed during the earlier of two distinct ice advances which were separated by an interglacial stage of stream erosion. These strongly developed and wooded moraines are in marked contrast to the broad, smooth gravel terrace that borders their abrupt fronts and slopes thence gently down to the shore of the lake.

The east lateral of the fifth moraine loop, counting from the west, was notched in five different places, suggesting Recent faulting. Some of these notches, however, are probably temporary stream spillways. At the east side there is an east-west morainelike ridge, behind which there is no glaciated gulch. Its relations are not clear, unless it is a remnant of a pre-Wisconsin moraine. Its top at the eastern end is 7,250 ft above sea level. There is also a short, higher spur at each side of the mouth of the fifth glaciated gulch. These spurs were not examined but they may be remnants of still older moraines, or of a high-level, preglacial piedmont terrace.

Most of the pebbles and boulders on the moraines are of limestone, with many of dark-green contorted schist and some of granodiorite (?), which have probably been derived from the dark-colored rock exposed below the limestone at the mouth of the gulch. The moraines of the sixth group slope steeply down from the mouth of a high-hanging gulch to the gravelly flat about 6,950 ft above sea level, behind the ranch buildings in sec. 25, T. 14 S., R. 2 W. The outer side of the east lateral moraine is very abrupt and overlooks a broad, gravelly flat that merges with the smooth piedmont terrace in Centennial Valley. Apparently in this basin there has not been sufficient erosion to develop late Pleistocene terraces at levels lower than the earlier Pleistocene piedmont flat. Red Rock River was beginning to erode an inner valley below a belt of low sand dunes in adjacent parts of Tps. 13 and 14 S., R. 3 W., near Brundage bridge, before the Lima Reservoir dam was built, obstructing the flow.

In the edge of the woods south of the road at Red Rock Pass there is a kettle-pitted deposit, apparently the terminal moraine of a glacier heading in the mountains to the south. At the north edge of this deposit there is an abrupt slope 30 to 50 ft high, suggesting a west-trending Recent fault scarp, such as cuts the moraines to the east in Idaho.

LANDSLIDES NEAR LAKEVIEW

For several miles south of Lower Red Rock Lake and west of Lakeview (T. 14 S., R. 2 W.) the lower north slope of the Centennial Mountains is characterized by conspicuous landslides, some ending in abrupt marginal fronts. Northwest of Lakeview the highway crosses the lower end of one of the lobate slides. This slide and the lower part of the one next west head on the northeast flanks below peaks southwest of Lakeview where, according to Condit, Finch and Pardee (1928, pls. 10–12), lava caps the Centennial Mountains and extends down the north slope.

As seen from the highway and also west of Lakeview, the uneven stony surface and the abrupt margin of the lobate deposit looks like that of a glacial moraine. The deposit, however, has not the concentric ridging that characterizes the moraine 5 to 9 miles east of Lakeview; neither does it appear to head in such definite cirques and glaciated gorges. A traverse of the wooded slope southwest of Lakeview to a height of 1,000 ft above the village (7,700 ft above sea level) did not reveal any evidence of glaciation. The surface is partly uneven, with characteristic landslide topography. Most of the loose rocks are fragments of lava, and some are of buff to gray sandstone. One sharp knob is composed of or covered with smoothly rounded cobblestones of white, gray, and red quartzite similar to the cobblestone gravel seen in lower places near the highway, north of Centennial Valley, and 7 to 8 miles west of the lower lake. At one place dull red and gray shale was exposed. The ensemble suggests the sliding of lava blocks over water-saturated Cretaceous or Tertiary clay or sandy clay.

Traverse of the lower part of the next slide to the west, between Duff and Shambo Creeks, shows similar conditions. Other similar deposits farther west were not examined. It is possible that these deposits are, in part, the result of oversteepening of slopes by late Pleistocene glaciers.

GLACIERS NEAR HENRYS LAKE, IDAHO

East of Red Rock Pass at the head of the Centennial Valley and south of the Continental Divide is the basin of Henrys Lake, Idaho, at the head of Henrys Fork of Snake River. Between Sawtelle Peak and the lowland bordering the south end of Henrys Lake, (in the southern part of T. 14, N., Rs. 42 and 43 E.) is a high, wooded lava bench or foothill tract. Its western part appears to have been cut down somewhat and later transected by streams heading in the mountains, so that the lower or piedmont part of the glaciated gulch that heads west of Sawtelle Peak is now flanked by two rather high, narrow-crested rock ridges or spurs.

The relations of these spurs are similar to those found at the mouths of some of the gulches at the western foot of the Madison Range to the north in western Montana and suggest that the rock spurs are erosion remnants of an older piedmont terrace of late Tertiary or early Pleistocene age. The abrupt cut-off north ends of these spurs, which are several hundred feet high (7,200 to 7,500 ft above sea level), were examined by the writer, but their crests were not traversed all the way back to their junctions with the steep and high mountain slope. On the narrow spur crests are large and small boulders of lava, gneiss, schist, green quartzite, and reddish-gray sandstone. These boulders are possibly remnants of early Pleistocene drift, as they are high above the well-defined terminal and lateral moraines.

During the Wisconsin stage of glaciation, and perhaps also during a somewhat earlier advance, a large glacier occupied the trough between the two rock spurs and spread out somewhat broader beyond their ends in a terminal lobe (about 6,600 ft above sea level). There are strongly defined lateral moraines 100 to 200 ft high, that curve inward to merge in a terminal loop. A somewhat later ice tongue seems to have crowded in between these great curved laterals. An interpretation of difference in age is, however, not at all certain; the moraines may all be of Wisconsin age. From the terminal moraine front a great gravel fan, very bouldery near the head, spreads broadly as it slopes down to the southwest shore of Henrys Lake.

Near the north end, the crest and side slopes of the east rock spur show a shallow transverse notch or trench suggesting faulting. On a line trending about N. 87° W. from this notch, several of the morainal ridges are either notched or cut off by a scarp and dropped on the north side, as though displaced by a Recent fault, similar to that which borders the west foot of the Madison Range to the north. In nearly direct line between this possible fault and Red Rock Pass are the notches in the moraines of the glacier next farther west.

The writer also examined some of the moraines 1 to 2 miles farther west near Red Rock Pass. The top of one outer ridge, a left-hand lateral moraine, is about 7,300 ft above sea level and boulder laden. Both inner and outer faces are very abrupt and the former is 100 ft or more high. This ridge is so bulky and its southwesterly trend, oblique to the mountain front, is so marked as to suggest either that it is a pre-Wisconsin moraine, subsequent to whose formation the drainage was shifted eastward, or that there is here a moraine-covered erosion remnant of an old high-level piedmont terrace. The pebbles and boulders on this moraine are mostly mottled, green, gray, yellow, and red quartzite, and diorite; some are of limestone. Near the mountain front this big ridge is cut by a gap through which a small sublobe appears to have extended and deposited a low moraine just to the west.

From the northeast end of this bulky ridge a lower sharp moraine crest extends northeastward and recurves in a big terminal loop. At a point E. 10° S. of Red Rock Pass this outer moraine is cut through by a sharp notch. A similar notch on the same line cuts the moraine on the southeast side of the loop. The conditions here and farther east suggest that these notches are on the line of a postglacial fault. Nothing suggesting faulting, however, was noted inside the moraine loop on a line between the two notches. This sharp-crested morainal loop is probably the moraine formed during the Wisconsin stage of glaciation and deposited on top of an older moraine. Outside this loop there are two small remnants of a lower, smoother, and older moraine, possibly of Iowan or Illinoian age, with an intervening gap through which a gravelly outwash terrace extends northward to the creek. The glacier that formed these moraines extended from a hanging cirque out onto the piedmont. It is probable that the outwash from the earlier moraines between Red Rock Pass and Henrys Lake lies buried beneath that from the later moraines.

GLACIERS OF THE UPPER MADISON RIVER

MORAINES NEAR WEST YELLOWSTONE, MONTANA

In and near the western part of Yellowstone Park, the Madison Valley contains possible evidence of a stage of glaciation somewhat older than the Wisconsin stage. About 19 miles north of West Yellowstone, Grayling Creek turns southward near the Montana-Wyoming State line after descending the west flank of the Gallatin Range. The writer climbed the steep lava slope north of this bend to a bench 300 or 400 ft above the creek. On and above this bench, up to an altitude of about 7,600 ft, there are granitic pebbles and boulders probably in glacial drift. Eastward up Grayling Creek from this point an older and broader high-level valley can be seen in which a newer and narrower gorge 300 to 400 ft deep is cut. It seems probable that the granitic pebbles were transported down the high-level valley from the rocks of Archean type to the east at a time before the inner gorge was cut. About 2 miles farther south the old road crossed a rock spur through which the creek has cut a narrow gorge about 200 ft deep. The relations here suggest stream diversion in interglacial time, for there is a broad sag east of the high point of the cut-off spur and in the woods on either side of the road there are big blocks of lava and granitic pebbles and boulders. East of the road are morainelike humps and hollows; one hollow contains a small pond. These may constitute a landslide, but it is quite as probable that the deposit is of pre-Wisconsin glacial drift lying in an abandoned part of the older valley. Either with this or the later stage of glaciation is probably to be correlated a deposit of bouldery drift that was exposed a short distance to the north where the new and old roads join west of Grayling Creek. There are also many large and small boulders of granite and gneiss on the wooded slope above the new road. About 8 miles farther south Grayling Creek leaves its narrow gorge and flows out across the gravel flat to Hebgen Lake in Madison Valley.

For about a mile west of the bridge across the lower gorge of Grayling Creek (secs. 7 and 8, T, 12 S., R. 5 E.) there is an uneven hummocky deposit that appears to be a glacial moraine. It lies partly on a bench above the lower cliff of rhyolite. Farther west it is lower and is crossed by the main highway north of Hebgen Lake. Here there are many large and small transported blocks of granitic rock, quartzite, and lava. This deposit is probably a remnant of a north lateral moraine deposited by ice that moved westward from the plateau in Yellowstone National Park and spread over the basin of Madison River as far west as Horse Butte. This butte or ridge, which stands in the angle between the two arms of the Hebgen Lake, rises 400 to 500 ft above the broad gravelly flat to the east. Examination showed this ridge to consist of pre-Cambrian gneiss cut by quartz veins. Scattered over its crest are pebbles and boulders of gneiss, rhyolite, and basalt—some of them large blocks perched in such positions as to suggest that they were left there by melting glacier ice. It is possible also that the lower north spur of the ridge is partly glacial moraine. There is glacial drift also on the low hills between the reservoir and the highway to the south, on the east and west sides of Denny Creek, 7 or 8 miles west of West Yellowstone. For 5 to 10 miles east of Horse Butte a smooth, flat terrace slopes gently westward from the western edge of the rhyolite plateau of the Yellowstone National Park. This great terrace is underlain by fine, loose, stratified, rhyolitic (obsidian) sand and gravel where observed, and does not show evidence of having been overridden by a glacier. These relations suggest that the glacier extended westward to Horse Butte before the sand and gravel underlying the broad flat was deposited; that is, the great lobe of ice advanced perhaps at the time of either the Iowan or the Illinoian glaciation. This ice may have extended nearly or quite to Targhee Pass and have discharged water across the Pass. Such an outflow, together with wash down Targhee Creek from the mountains to the north, would account for the great gravel fan that spreads west to south from the mouth of the gorge and incloses Henrys Lake basin on the east.

There is no evidence in hand to show that this part of the Madison River valley was glaciated below the west boundary of Yellowstone National Park during the Wisconsin stage. It is probable that the west limit of the ice during this stage lay across Madison River at the bend just below the mouth of the Upper Madison Canyon, that is, at the bend between 5 and 7 miles east of the Park boundary. Excavations for road grading in a moraine here expose 5 to 30 ft of coarse, gray, unsorted, bouldery material. The stones are mostly subangular and some show glacial striae. The largest are as much as 5 ft in diameter. West of the point where the rock cliff north of the river ends, the drift spreads out northwestward as a bouldery, humpy moraine, apparently filling an older channel of the river. The surface becomes smoother as it lowers and merges with the broad terrace to the west. South of the river the surface configuration is not so definitely morainal. In cutting through the deposit the river swung to the north side of its valley, but west of the morainal deposit it returns to the south; thence westward it appears to be out of its former course, for in two places it is now cutting into basalt. Probably the river formerly flowed more directly northwestward toward the point where it now crosses the park boundary 4 miles north of West Yellowstone. The position of the terminal moraine (6,800 to 6,900 ft above sea level) corresponds with a possible moraine on Grayling Creek, where that stream first reaches the Montana-Wyoming State line after descending the west flank of the Gallatin Range. There are also morainal deposits in similar positions near the place where the upper Gallatin River first approaches the State line (7,100 to 7,300 ft above sea level). One deposit forms the low divide near the pond between Grayling Creek and Gallatin River.

For 8 miles below the Hebgen dam, Madison River flows in a southwesterly direction through a deep narrow gorge known as Upper Madison Canyon, cutting directly across the mountain range which here is composed of pre-Cambrian rocks. In this canyon, 1 to 3 miles below the Hebgen dam and near the line between Madison and Gallatin Counties, Mont., Madison River has cut through a ridge of bouldery glacial drift about 200 ft high. Some boulders of gneiss and schist are 10 or 15 ft in diameter, and one depression in the deposit contains a pond. This great deposit of glacial drift, covering 1 to 2 sq mi, is transected by the narrow, lower gorge of Beaver Creek, which heads in the Madison Range on the north. Evidently this deposit is the terminal moraine of a glacier that advanced down the canyon of Beaver Creek and crowded Madison River over against the south wall of its canyon. The glacier may have entirely blocked the river for a while and after it melted away its moraine may have served some time longer as a dam that ponded Madison River as far as the western part of Yellowstone National Park. Into this ponded water may have been washed the fine, stratified, rhyolitic sand and gravel that now floor the West Yellowstone basin. The Beaver Creek moraine is probably of Wisconsin age. After the river had cut through the drift dam at Beaver Creek it eroded a lower terrace which is about 50 ft below the upper big flat near the park boundary; the terrace was later trenched by an inner channel. The building of Hebgen dam has ponded the water again nearly to the level of the lower terrace below the boundary of the park.

Extending southwestward down the Upper Madison Canyon from the moraine at Beaver Creek is a narrow but well-defined terrace of bouldery gravel, which the river has cut to depths of 15 to 30 ft. Near the national forest boundary at the mouth of the canyon this low terrace, which is either of Wisconsin or post-Wisconsin age, is cut across by a Recent fault scarp, so that the part to the west of the fault has dropped abruptly about 20 ft. For a short distance to the west the old road (which is above the present road) north of the river, appears to have been graded along the narrow bench below the northwest-trending fault scarp. Apparently the mountains to the east of this fault line have been uplifted relative to the basin on the west. So recent is the movement on this fault that the scarp is not yet worn down, even where it is in loose gravelly material, and the Madison River has not yet obliterated the rapids due to the movement.

GLACIERS SOUTH OF THE UPPER MADISON CANYON

The flanks of Coffin Mountain and adjacent peaks in the high range known as the Henrys Lake Mountains, south of the Upper Madison Canyon, have been glaciated and contain well-developed moraines at the mouths of the U-shaped gorges in T. 12 S., R. 2 E., north of Reynolds Pass on Mile Creek and other creeks. These moraines are cut across by the Recent fault scarp described on page 189. The road to the asbestos mine west of Sheep Mountain is graded across the fault scarp, whose altitude is about 7,300 ft at the mouth of a gulch cutting the west slope of the mountains. The fault scarp here is 30 to 50 ft high, and cuts across a torrential fan of unsorted bouldery material. It makes a waterfall in the small creek. There may be a terminal moraine farther up the gulch.

There are indications that the first gulch north of the asbestos mine (T. 12 S., R. 2 E.) was glaciated at least twice. There is an enormous deposit of bouldery drift which occupies the lower part of the gorge and spreads out for a mile or more below the canyon mouth in and near sec. 23, where the ice formed a piedmont lobe. Cutting across this moraine at the canyon mouth is a transverse, nearly bare Recent fault scarp, 50 to 60 ft high, on the face of which are some trees about 100 yr old. The top of the moraine, especially east of the fault scarp, is covered by large and small angular blocks of hard, gray siliceous rock and smaller fragments of schist. It looks as though much fragmental rock that had fallen from the canyon cliffs onto the glacier was carried by the ice down the gorge and in part out beyond the canyon mouth, where it composes the outer moraine on the piedmont. This outer moraine may have been formed at the time of either the Iowan or the Illinoian glaciation. What may be the terminal moraine of the Wisconsin stage is a transverse ridge about 7,300 ft above sea level, the site of prospector cabins. Behind (east of) this moraine is a small meadow or old lake bed. When the front of the glacier stood at this moraine the ice may not have been thick enough to reach up to the erosional towers and pinnacles that adorn the canyon walls above the glacially scoured cliffs. At the head of the gulch is a high-level hanging cirque. Some of the blocks in the gorge may have been shaken from the cliffs by an earthquake which accompanied the faulting after the ice disappeared.

CLIFF LAKE

South of the ranch of L. A. Hutchins, near the mouth of the West Fork of Madison River, the lava plateau is cut south to north by a remarkable gorge with vertical cliffs of lava forming the upper part of the walls. In this gorge, and above its junction with the West Fork (T. 12 S., R. 1 E.), are Wade Lake, Cliff Lake (about 6,200 ft above sea level) and Antelope Creek. Mansfield (1910, p. 764) states that the lakes are retained by glacial morainal dams. Where seen by the present writer conditions between the two lakes indicate that here, at least, the blocking of the gorge was the result of the slumping of the lava, probably over unconsolidated Tertiary beds. This slump is similar to those that have occurred in Madison Valley farther north.

GLACIERS OF THE WEST FLANK OF MADISON RANGE

PAPOOSE CREEK

On the piedmont upland east of the Madison River, in and near the eastern part of Tps. 10 and 11 S., R. 1 E., there are well-defined moraines of glaciers that protruded from the mouths of canyons on the west flank of the Madison Range. A narrow spur lying obliquely in front of the canyon mouth of Papoose Creek (see p. 36) deflected the later glacier ice somewhat to the north of a direct course. The ice nearly overtopped the spur and left boulders on it. The terminal moraine extends westward around the lower (west) end of this spur and curves northward and eastward, outlining a piedmont lobe a square mile or more in extent. This moraine is 900 to 1,000 ft above the river to the west and extends down into a broad old valley; between the valley and the river is the upland covered with old drift(?) boulders.

Near the boundary of the national forest the narrow crest of the high spur is partly separated from the mountain slope south of the gorge by a broad depression into which a small sublobe of the glacier seems to have protruded at an altitude of about 7,300 ft (fig. 4). In this depression morainal deposits are cut by a steep, 30-ft scarp of the Recent fault. A short distance farther east ledges of gneiss are exposed at an altitude of about 7,400 ft in the south face of the drift-covered ridge, showing that there, at least, the ridge has a rock core.

In one of the nearby gulches cutting the mountain front north of the Madison River there are indications of glaciation, but the relations seem somewhat abnormal. As seen with glasses from an altitude of about 7,100 ft on the moraine ridge below, there is a great hopperlike cirque, at what appears to be the head of the gulch, with bare talus slopes, not a typical cliffed cirque wall. Extending down along the south side of the lower gulch is a great narrow-crested, boulder-strewn ridge. The ridge appears to be either a massive south lateral moraine or a drift-covered rock spur separated from the mountain slope on the south by a narrower gulch. The steep outer front of the ridge (between 6,500 and 6,800 ft above sea level) extends northwestward nearly parallel to the main front of the mountains and may have controlled the direction of flow of the ice. The presence of angular rock ledges at the north side of the mouth of the gulch suggests that the glacier did not extend as far down as this portal during the last advance or reach the head of the alluvial fan, which is strewn with boulders of granite and gneiss 1 to 10 ft in diameter. The trace of the Recent fault is plainly marked here by a low scarp extending northwestward at the foot of the range.

SQUAW CREEK

A fine view of the remarkable moraines formed by Moose Creek glacier, by Squaw Creek glacier and a tributary glacier, and by Papoose Creek glacier may be had from the upland northeast of Lyon. As seen by the writer from this and closer points of view, it is evident that there were glaciers in the canyons of Squaw Creek and one of its tributaries on the south. These two glaciers appear to have coalesced on the piedmont after issuing from the canyon mouths. A long spur extends westward from the south side of the more southerly **U**-shaped gorge; this spur may be wholly a south lateral moraine of the piedmont lobe, or it may be a drift-covered older spur like that south of Papoose Creek. Near the mountain front the spur may have a rock core that is an erosion remnant of an early Pleistocene or a late Tertiary piedmont terrace.

Another conspicuous lateral spur, 250 to 300 ft high, extends obliquely south-southwestward from the north side of the main gorge of Squaw Creek. Here also there may be a rock core, an erosion remnant of an older piedmont terrace. The two big lateral spurs converge like the arms of a **V** but do not join. Between their cut-off lower ends the short trunk glacier extended some distance down the slope between Squaw Creek and its tributary and there laid a hummocky terminal moraine. It looks as though the big north spur prevented the last Squaw Creek glacier from extending directly westward onto the piedmont in front of its canyon mouth, but deflected it southward so that it joined the ice from the next canyon. There is also a coalescent, or medial, morainal deposit between the mouths of the two glaciated gorges. All these spurs and moraines are cut across by the Recent fault scarp.

MOOSE CREEK

The next canyon north of Squaw Creek was occupied by Moose Creek glacier. Either a big west lateral moraine or a combined moraine and older spur, like those on Squaw and Papoose Creeks, extends southwestward diagonally from the mountain front at the north side of the canyon mouth. The west or outer front of the moraine is remarkably regular and rises abruptly for 150 to 250 ft or more above the broad, smoothly sloping, gravelly terrace. At the northeast end of this ridge is a cut-off remnant of a higher, benched spur. The relations suggest that the big ridge is not wholly the product of the Wisconsin stage of glaciation but largely a product of an earlier stage, and that it controlled the advancing glacier and diverted it southwestward at the later stage. Between this west ridge and the mountain front is a great irregular, bouldery, morainal deposit of the Wisconsin stage across which Moose Creek has cut a small gorge. From the north lateral moraine of Swamp Creek glacier the Recent fault scarp is clearly marked, extending northward along the lower part of the mountain slope across the moraines of the Moose Creek glacier.

WOLF CREEK

Two or three miles farther north a great morainal deposit below the canyon mouth was spread by the piedmont lobe of the Wolf Creek glacier, about 6,600 ft above sea level. Across this moraine field and the bordering smooth, sloping, gravelly terrace or outwash plain the creek has cut a small inner gorge. The west front of the moraine is abrupt and remarkably regular north of the creek. The clearly defined 20- to 30-ft scarp of the Recent fault extends northwestward along the foot of the mountains and across this moraine field.

INDIAN CREEK

There is a very interesting combination of glacial, stream and fault phenomena at the mouth of Indian Creek, T. 8 S., R. 1 E. South of Indian Creek, the long north spur of the pyramidal mountain known as The Wedge, 10,508 ft above sea level, is separated from the main mountain front on the east by the narrow valley of the South Fork of Indian Creek. The lower mile of this valley follows the line of the Recent fault. The South Fork flows in a channel about 500 ft below the narrow crest of the spur, and the height of the spur above the lower land on the west increases southward from a few hundred to more than 1,000 ft. The lower 3½ miles of this narrow spur is mapped and described by Peale (1896) as a great glacial moraine.

It is very probable that the body of this spur is not wholly composed of glacial drift, for rock ledges are reported as cropping out on the slopes at places not seen by the present writer. The spur, however, may be capped with early Pleistocene glacial drift. Its crest is about on a grade with a cirque hung high up on the west flank of The Wedge, and the crest and the abrupt west slope are strewn with boulders of granite and gneiss to 1 to 10 ft in diameter. Some of the drift on the steep east face and crest of the spur appears to be of later Pleistocene age, for a well-defined lateral moraine descends the north end of the spur, curves westward, and merges with a lobate hummocky, bouldery, morainal tract nearly a square mile in extent where the end of a South Fork glacier spreads out on the piedmont terrace south of Indian Creek. This moraine field is almost directly in front of the canyon mouth of Indian Creek to the east but it does not appear to have been made, even in part, by a glacier extending out of that canyon—at least, not during the last stage of glaciation. The sides of the gorge are marked by crags and pinnacles of rock, and a narrow rock spur 250 ft high projects from the south side of the portal, part way across the path such a glacier would have taken to reach the moraine. Some boulders perched upon this spur are possibly remnants of pre-Wisconsin glacial drift. The spur is cut through by the present lower gorge of the South Fork. The South Fork was evidently located in this lower course before the Recent fault, and it was probably so located as a marginal glacial stream while the South Fork glacier occupied the moraine field. The moraine lies on the piedmont part of the big second terrace, 150 to 200 ft above the lower terrace on Indian Creek.

The physiographic relations strongly suggest that the terminal moraine was formed at the time of either the Iowan or the Illinoian glacial advance, before the present 100- to 200-ft valley of Indian Creek was cut across the piedmont terrace; and that Indian Creek and South Fork glaciers during the Wisconsin stage were not so extensive. A long-distance view suggests that the late Pleistocene terminal moraine is farther up the valley of the South Fork. J. T. Pardee and Edward F. Richards both examined the lower canyon of Indian Creek but found no indication of late Pleistocene glaciation there; however, they found a terminal moraine in the canyon 2 to 3 miles east of the portal. This moraine was evidently formed by one or more glaciers heading on the north flank of Shedhorn Mountain. These conditions are in harmony with the evidence of two stages of glaciation in Taylor Creek canyon directly across the divide to the east. The glaciers there headed on the south and east flanks of Shedhorn Mountain.

Very coarse bouldery gravel is exposed in the bluffs below the big second terrace, and smoothly waterworn boulders 1 to 5 ft in diameter are abundant on the low terrace and in the bed of Indian Creek. Some of the boulders are as much as 10 ft long. This is probably a mixture of torrential deposit and reworked glacial drift.

What may have been the moraine mapped by Peale (1896) in Cedar Creek canyon was seen from a distance by the writer. The lower part of the canyon is marked by pinnacles of limestone and appears not to have been glaciated. The mouth of the canyon is about 1,000 ft above the level of Bear Creek 5 miles to the west. Cedar Creek has cut 30 to 50 ft into the head of the great alluvial fan.

LATE PLEISTOCENE TERRACES ON MADISON RIVER

In the part of Madison Valley between the upper and lower canyons there is generally a strip of flat bottom land ranging in width from a fraction of a mile to nearly 3 miles along the river. This bottom land comprises the flood plain and remnants of a low terrace 10 to 20 ft above the flood plain. The low terrace is probably of late Pleistocene age, corresponding to the "Lenore terrace" of Blackwelder in western Wyoming, and is to be correlated with the terminal moraines of Wisconsin age in the mountain gorges. The streams are, so far as seen, now cutting into the bottom land.

Northward down the Madison Valley at numerous places are several well-defined terrace steps with risers 10 to 20 ft high below the edge of the great second terrace. The precise meaning of this series of steps cannot now be stated; no detailed study of the steps or attempt at correlation has been made by the writer. The schoolhouse at Ennis is built on one of these steps. It is probable that much of the broadening of the bottom land, as well as much of the terrace development is due to retardation of down cutting in the Tertiary beds as a consequence of slow deepening of the lower canyon, which is mostly cut in pre-Cambrian gneiss. Some of the minor steps perhaps are to be correlated with movements along the Recent fault scarp that borders the west foot of the Madison Range.

GLACIERS OF THE TOBACCO ROOT MOUNTAINS

Nine or ten miles northwest of McAllister, North Meadow Creek leaves the Tobacco Root Mountains and cuts through a great terminal moraine. From a position 100 ft or more lower than the big second terrace, near McAllister, the third terrace rises upstream above the level of the earlier terrace and appears to merge with the terminal moraine front like an outwash terrace. Both terraces are floored with coarse, bouldery gravel. The great moraine nearly blocks the gorge and through it the stream has made a narrow postglacial cut. A sufficiently close examination was not made to determine whether or not an older moraine can be distinguished from the later one.

The last glacier that extended down the gorge of South Meadow Creek traversed a trough between two high spurs, possibly composed of pre-Wisconsin moraines, and continued down the valley some distance beyond their ends. Its terminal moraine is near the boundary of the Gallatin National Forest.

Five miles southwest of Three Forks, Jefferson River is joined by Willow Creek, which heads in the Tobacco Root Mountains. In the gorge of North Willow Creek, about 2 miles southwest of the village of Pony, is the front of a terminal moraine. The lower margin of this moraine is about 6,100 ft above sea level and about 1,500 ft below the edge of the high-level upland tract described on page 63. This moraine, the outermost, was probably formed during the Wisconsin stage by a glacier heading at the cirque-scalloped mountain crest near Mount Jefferson. The rough, boulder-strewn moraine extends northeastward down the gorge of North Willow Creek to the junction with the gorge of Cataract Creek, spreading northward clear across the mouth of the latter gorge and completely blocking it. Cataract Creek probably gets its name from the character of the narrow rocky channel through which it escaped across the moraine. Farther west the gorge of Cataract Creek, as seen from a distance, appears not to have been occupied by a glacier, but there may be a moraine farther up this creek.

About 6 miles northwest of Pony and 12 miles south of Jefferson Island sec. 32, T. 1 S., R. 3 W. (about 5,600 ft above sea level), South Boulder Creek cuts through a small moraine, which marks the terminus of a glacier that headed in the highest part of Tobacco Root Mountains south of Mount Jefferson. North and south of the moraine the stream occupies a deep canyon cut in Paleozoic and pre-Cambrian rocks. It may be that much of the bouldery deposit that extends down the canyon for 4 or 5 miles below the moraine is the remnant of an earlier moraine of a more extensive glacier. Some high benches on either side of this canyon may be indicative of earlier stages of erosion.

Some of the gorges cut in the west flank of the Tobacco Root Mountains north of Sheridan are reported to have been glaciated. This is true also of the valley of Fish Creek, which heads on Red Mountain and joins Jefferson River south of Whitehall.

MORAINES OF THE GALLATIN RIVER GLACIERS

About 20 miles north of West Yellowstone the road over the low pass in the through valley between Grayling Creek and Gallatin River crosses a pitted morainal deposit. It appears to be a terminal moraine, and its relations suggest that part of the ice of the Gallatin glacier, which descended the west flank of the Gallatin Range, crowded southward a mile or two when it reached the north-south through valley and deposited the terminal moraine. The rest of the ice continued down the Gallatin River valley and may have contributed to the terminal moraine at the mouths of the valleys of Bacon Rind Creek and Fan Creek west of the Wyoming State line. It may, however, have terminated at a poorly marked moraine 1 to 2 miles south of Fan Creek.

Two to three miles south of the northwest corner of Wyoming, the road in the Gallatin River valley crosses a low terminal moraine marked by swells and swales and bouldery drift, largely composed of pebbles and boulders of volcanic rock, granite, gneiss, schist, and limestone. This deposit occupies the lower mile of the gorge of Bacon Rind Creek, near the ranger station and extends thence northward and eastward across the Gallatin River valley, so blocking it as to crowd the river over against the foot of the steep slope on the east where it has cut a small postglacial gorge about 40 ft deep through the drift and into the limestone. This drift deposit is probably the terminal moraine of a glacier that occupied the steep-sided gorge of Bacon Rind Creek and headed to the southwest on the flanks of Tepee Point and White Peak (T. 10 S., Rs. 4 and 5 E.) in the Madison Range.

The moraine is also directly opposite the mouth of Fan Creek, which cuts across the extreme northwestern part of Wyoming. The valley of Fan Creek has not been examined by the writer. It may have been occupied by a glacier which contributed to the moraine in the Gallatin River valley, either during the Wisconsin stage or earlier. Beyond the outer north front of the moraine, on the west side of Bacon Rind Creek 7,050 ft above sea level, the buttresses and pinnacles that characterize the unglaciated limestone walls of Gallatin Canyon begin.

TAYLOR CREEK

The writer has not noted any evidence of glaciation in Gallatin Canyon or the wider parts of the valley below Bacon Rind Creek. So far as can be seen near the road, there is no evidence of glaciation in the gulches that gash the west flank of the Gallatin Range north of Yellowstone National Park. Glaciation evidently took place in some of the gorges cutting the east flank of the Madison Range, but the ice is not known to have extended as far as the Gallatin River. The lowest evidence of glaciation noted in this valley is where Taylor Creek is joined by the South Fork, at an altitude of about 7,000 ft and nearly 4 miles above its mouth. Below that place landslides have carried considerable masses of local debris down from the upper slopes on the south.

At the junction of Taylor Creek and the South Fork and for a mile or more on the east side, the shale slope is sprinkled with granitic boulders for 100 ft or more above the stream; on the west side a great dump of granitic drift projects northward into the valley of Taylor Creek. No granitic rocks are known to occur in situ on the South Fork; the valley is cut entirely in Cretaceous rocks. The head of Taylor Creek, however, is in a great cirque cut in granitic rocks south of Shedhorn Mountain, 8 to 10 miles farther west. Apparently here at the mouth of the South Fork is a deposit of drift brought from the west by Taylor Creek glacier, possibly during either the Iowan or the Illinoian stages of glaciation, and later subjected to erosion. From this drift deposit coarse bouldery gravel extends eastward to Gallatin River.

Six or seven miles west of Gallatin River on Taylor Creek, in T. 9 S., R. 3 E., there is a humpy deposit that looks much like a terminal moraine but may in reality be a landslide on Cretaceous shale. Through this dump Cache Creek has cut a narrow gorge. On the uneven slope in the woods about a mile to the southwest and about 7,200 ft above sea level, there are many 1- to 10-ft boulders of granite and gneiss that came from the mountains at the head of the valley 6 to 10 miles farther southwest. They seem to indicate the presence of glacial drift overlying the Cretaceous deposits. Directly west, across the Madison Range, are the moraines of two stages of glaciation on Indian Creek, described above.

Six miles north of the mouth of Taylor Creek and just south of Buck Creek a big deposit, about 30 ft thick, of stratified coarse gravel and 1- to 3-ft granitic boulders has been cut into for road grading. In it are some fragments of limestone, sandstone, and porphyry. The deposit is overlain by red clay and gravel, as exposed below the woods; and is underlain by limestone which is exposed in the road cut 15 to 20 ft above the river. It is somewhat strange to find so many 1- to 3-ft granitic boulders here, as neither Buck Creek nor Elkhorn Creek to the east is known to cut into granitic rocks. Apparently this bouldery gravel was swept from Taylor Creek into and down the Gallatin River valley perhaps during a pre-Wisconsin stage of glaciation; or it might be of Tertiary age.

Twenty-three miles farther north there is a great deposit of large boulders of gneiss and schist at the mouth of the canyon of Hell Roaring Creek (5,600 to 5,800 ft above sea level), which may perhaps be a glacial moraine, although it is not certainly such. This canyon, which is cut in gneiss and schist, heads on the cirque-scalloped flanks of Gallatin Peak in the Madison Range and it has probably been glaciated, although the lower part of the gorge where examined by the writer does not clearly show it.

On a traverse of about 6 miles over gravelly deposits on the lower West Fork of the Gallatin River no glacial deposits were seen.

SPANISH CREEK

Nine miles south of Gallatin Gateway, Spanish Creek comes down from the Madison Range to join the Gallatin River. As shown by A. C. Peale (1896), this creek and its tributaries head on the north flank of a long, high, northwest-trending ridge of pre-Cambrian gneiss and schist and cut across a synclinal belt of folded Paleozoic rocks, which are overlain by a few square miles of so-called Bozeman "lake beds" of Tertiary age. A few miles farther west Cherry Creek, which flows northwestward directly to Madison River, has somewhat similar relations. Peale mapped glacial deposits in both these creek basins, but only Spanish Creek Basin (S. ½ T. 4 S., R. 3 E.) has been examined by the writer.

On grassy slopes south of the Flying "D" ranch (in or near secs. 20 and 21) numerous 1- to 6-ft boulders of porphyry, granite, and gneiss lie on the eroded surface of the upturned Paleozoic limestone and sandstone, several hundred feet above the creeks, like remnants of an early Pleistocene glacial deposit. Southwest from this bouldery hill what appears to be a great wooded terminal moraine may be seen looped across the head of the flat bottom land. To the southeast and south a strongly defined knob-and-kettle moraine is strewn with granitic boulders 1 to 10 ft in diameter. This terminal moraine bordered the lobate end of a glacier of the Wisconsin stage, where it spread out in the small basin between the head of the lower limestone gorge and the point where it emerged from the mountain gorge to the south. Apparently this small basin, several hundred feet deep, and the lower gorge to the north were due to erosion between the time of deposition of the extra-morainal boulders on the foothills and the readvance of the glacier during the Wisconsin stage.

There are some indications that some of the bouldery deposits may have been deposited at the time of either the Iowan or the Illinoian glaciations and that the Wisconsin terminal moraine is somewhat farther southwest in the woods.

East of the Flying "D" ranch the creeks have cut their inner valleys 50 ft or more below a broad gravel terrace, possibly composed of pre-Wisconsin glacial outwash gravel or equivalent to the second terrace farther north.

The only gorges in the northern part of the Gallatin Range that have been examined by the writer are those of South Cottonwood Creek and Hyalite Creek south of Bozeman. In the lower 4 or 5 miles of South Cottonwood gorge no evidence of glaciation was observed. About 7 miles above the portal of the narrow rugged canyon of Hyalite Creek a terminal moraine was found 6,500 to 6,600 ft above sea level, just south of Lick Creek, overlying south-dipping gray shale. Evidently this moraine marks the lower limit of glacier ice heading in the great cirques east of Mount Blackmore.

Some gulches cutting the west flank of the Bridger Range north of Bozeman may have been glaciated but none has been examined.

LATE PLEISTOCENE TERRACE

The main floor of the great tract between Gallatin River and the East Gallatin west and south of Bozeman is a nearly flat, gently sloping terrace of the third stage, equivalent to the third terrace on Yellowstone River and to Blackwelder's "Lenore terrace" in western Wyoming (Blackwelder, 1915, pp. 310 and 319–321). There are a few small remnants of a higher terrace near the north foot of the mountains and a low gently undulating tract between South Cottonwood and Hyalite Creeks, which was not entirely reduced to the third terrace level. Very extensive planation by several streams was required to produce this great terrace, which is 5 to 6 miles wide west of Bozeman. On it black loamy soil overlies coarse gravel. Most of the terrace is irrigated and farmed. At the eroded margins the surface drops abruptly for 15 to 25 ft to the broad strips of bottom land bordering the streams. Farther north, near Central Park and Manhattan, much of the third terrace is cut away and the bottom lands broaden until they merge between the streams. The Montana Agricultural College, in the southwestern part of Bozeman, stands on the third, late Pleistocene, terrace. Most of the city is built on the lower flat. At Logan two railroads and the National Parks Highway (U S 10) extend through the narrow gorge, 100 to 200 ft deep, which the river has eroded since it began cutting below the second terrace in early to middle Pleistocene time. West of this gorge the flat broadens rapidly and merges with the third terrace bordering Madison and Jefferson Rivers. The railroads and highways extend on this broad terrace for many miles.

GLACIERS OF THE BOULDER RIVER REGION

THUNDERBOLT CREEK

Several glaciers headed on the flanks of Electric Peak and Thunderbolt Mountain along the Continental Divide in the region northwest of Boulder. One advanced southward in the valley of Thunderbolt Creek, and there was probably another in the valley of Red Rock Creek. Twenty to twenty-one miles west of Boulder a great morainal deposit crowds Boulder River against the steep bluff on the south. It is the terminal moraine of the Thunderbolt Creek glacier. The uneven surface of the moraine is sprinkled with boulders of lava 1 ft to 15 ft in diameter, together with some of granite. The creek cuts through this moraine near its junction with a short west lateral moraine about 6,045 ft above sea level. At one place friable lava is exposed beneath the boulder drift at the south front of the moraine.

Knopf (1913, p. 42) mentions the presence of glacial deposits along Red Rock Creek, north of Bernice, but does not describe them. This creek valley was not examined by the present writer.

ELKHORN MOUNTAINS

The writer visited the Elkhorn Mountains and drove up the valley of Elkhorn Creek, which joins Boulder River about 9 miles southeast of the town of Boulder. A brief examination was made of the bouldery deposits at and above the old mining town of Elkhorn. They have been described in a paper by Weed (1901, pp. 453–455), from which the following is quoted:

> In the Elkhorn district the effects of glacial action are seen at several places in conspicuous morainal heapings and accumulations of boulders. The most prominent moraine extends entirely across the valley of Elkhorn Creek above the town. * * * There is a widespread distribution of boulders in the mountain gorges that indent the side of Elkhorn Peak, but the district was never covered by a general ice sheet, the glaciation being purely local and of the Alpine type. The snows of each winter accumulate to considerable depths in the amphitheater of Elkhorn Peak and exist as snow banks late into the summer, and through the Glacial epoch these amphitheaters were undoubtedly filled to a depth of 1,000 feet or more. This snow must have formed small glaciers during the early Pleistocene period, which pushed down the principal gulches, the largest glacier coming down Elkhorn Creek a couple of miles and depositing the boulder material on which the town is built. * * * Rounded and ice-worn ledges of andesite are seen near the divide east of Elkhorn Peak. The amphitheater floors, however, show no rounded bosses, but are littered by boulders which conceal the underlying rock. * * *
>
> The glacier which flowed down Elkhorn Peak was formed by the confluence of two sheets, one coming from the marble cliff amphitheater between Elkhorn and Crow peaks. The two glaciers united below Icy Lakelet. * * * The western glacier was the larger and crowded the lesser one toward the east, and in its retreat left great boulders of granite scattered over the andesite slopes and upon the metamorphosed Mesozoic shales. The confluent ice sheet flowed down the valley to a point opposite the mouth of Alpreston Gulch, reaching an elevation of 6,300 feet. At a later period its front was about one-half mile above the town of Elkhorn, at which point the ice must have maintained a nearly constant position for a considerable length of time, as the terminal moraine at this point is unusually large for so small a glacier, being several hundred feet high and extending clear across the valley. * * * This moraine shows a step-like profile, and consists of granite boulders up to 10 feet in diameter, with smaller masses of andesite and hornstone, the whole forming mammillary hummocks with intervening kettle holes. This terminal moraine passes northward into a well-defined lateral moraine lying high up on the slopes west of the valley, while a much smaller lateral moraine is seen low down on the opposite eastern slopes. In the granite area at the head of Turnley Creek the moraine is less conspicuous, as the glacial boulders are all of granite and aplite, and rest upon a granite surface, where they closely resemble the ordinary boulders of disintegration common to the granite area. There is a strong contrast in the character of the glaciated and unglaciated areas. The valleys which have not been glaciated show steep sides and rounded bottoms, with firm soil and no swamps, while the glaciated parts of the same valley are paved with huge boulders and show a scanty dark soil covered with rank vegetation and occasional swampy areas. * * * It is evident that glaciation did not materially affect the topography of the region, though many of the picturesque aspects of the present scenery are due to its erosive action.

It is quite possible, as indicated in the above description, that the very bouldery deposit that extends from the moraine down to the mine-tailing dumps (at 6,300 ft above sea level), below the village, represents a pre-Wisconsin extension of the Elkhorn glacier.

There were probably glaciers also on the northeast flanks of Elkhorn and Crow Peaks (altitude 9,200 ft) on the headwater branches of Crow Creek. These glaciated gulches have not been seen by the present writer. Judging from the topographic map, there may also have been a small glacier in the upper valley of Muskrat Creek, which cuts the west flank of the Elkhorn Mountains, northeast of Boulder. An observer looking eastward from one of the benched spurs at the mountain front, sees a steep-sided, U-shaped trough; however, only residual granite boulders and no evidence of glaciation were seen as low down as the old forest nursery (altitude 5,350 ft).

OTHER GLACIERS

Probably there were also small glaciers in the Big Belt Mountains northeast of Townsend, but their relations are not very well known. About 25 miles northwest of Helena glaciers appear to have headed in several cirques that scallop the east flank of the Continental Divide on the headwaters of Little Prickly Pear Creek. The terminal moraines of these glaciers may be at altitudes of about 5,000 ft, but their positions were not determined. The next glacier to the north on the east side of the divide was probably the Dearborn. The relations of its moraines and those in the Castle and Crazy Mountains are described in Professional Paper 174 (Alden, 1932, pp. 121–124).

SUMMARY OF GLACIAL FEATURES IN THE UPPER MISSOURI RIVER BASIN

The character and relations of the terminal moraines of about 50 glaciers, which headed on the mountains flanking the several intermontane basins drained by the Missouri south of the Dearborn River, as described above, may be summarized as follows:

The range in latitude of the glaciers under consideration is from 44°30′ nearly to 47° N., or from T. 14 S. to T. 12 N., a distance south to north of about 150 miles.

Aside from such ice tongues as headed in Yellowstone National Park, the glaciers ranged from cliff glaciers a mile or less in length to mountain-valley glaciers 10 to 12 miles long, of which six or eight in the valleys of the Big Hole and Madison Rivers extended beyond their canyon mouths and terminated in lobes a mile or two wide on the local piedmonts.

The altitudes to which these glaciers descended during the Wisconsin stage of glaciation differ somewhat locally, depending on several factors, such as the number and size of the tributary ice streams, the height of the mountains in which they headed, and the orientation of the glaciated gorges. The altitudes of the terminals, in general, lower northward from 7,200 to 6,000 ft, with a few as low as 5,600 or even 5,100 ft above sea level. There is considerable local variation within these limits.

The relations of the moraines to the terraces are shown in only part of the localities visited. In some places the glaciers terminated at or near the heads of terraces whose correlations have been fairly well determined in this present study. In these places it appears that the moraines are younger than the second set of terraces and are correlatives, or near correlatives, of the third set of terraces; also, that the third terrace gravel is probably, in part at least, glacial outwash material. Although some of these outwash gravel flats extend down valleys transecting the second terraces to depths of 50 or even 100 ft, yet their heads near the moraines are built to higher levels. It is possible that some of this higher gravel was deposited in post-glacial times by torrential streams that cut through the terminal moraines and swept drift material out as alluvium. In places, however, where these third terraces extend down to and along the main streams, they are 10 to 30 ft or more above, and distinct from, the present flood plains.

In 10 or 15 places outside the well-defined terminal moraine of the Wisconsin stage, there are remnants of a somewhat older, partly eroded moraine which may have been deposited at a time corresponding to the deposition of either the Iowan or the Illinoian drift in the Mississippi Valley. In one or two places the relations suggest, but do not prove, that this eroded moraine is a near correlative of the second terrace. In some valleys the outer or older moraine is a few hundred feet lower in altitude than the inner moraine of Wisconsin age, but the difference on the whole is small.

For the most part these outer moraines are near or but a fraction of a mile outside of the Wisconsin terminals. On Wise River, however, the outer moraine is 2 or 3 miles farther down the valley than the moraine that appears to mark the terminus of the glacier during the Wisconsin stage, and the upper Madison Valley glacier appears to have been 12 to 14 miles longer when the outer moraine was deposited in the basin north and west of West Yellowstone, Mont.

One of the most clearly marked effects of weathering since the deposition of the outer moraines was seen on Rattlesnake Creek, 4 miles above Argenta. It was noted here that the granite composing many of the boulders on the slope above the outer moraine is of uneven texture, and that the surface of the coarser-grained parts has spalled off or crumbled away, apparently as the result of weathering, so as to leave the denser parts projecting 2 to 3 in. However, no definite inference can be drawn from this as to the length of the time of exposure.

GLACIAL DEPOSITS NORTH OF YELLOWSTONE NATIONAL PARK

THE YELLOWSTONE GLACIER

A great glacier heading in and adjacent to the Yellowstone National Park extended northward down the Yellowstone River valley from the vicinity of Gardiner, Mont., the northern entrance to the park, to the vicinity of Emigrant (formerly Fridley) and Pray, a distance of about 30 to 35 miles. In his description of this glacier, Weed (1893, pp. 14–41) says:

> In both the upper and the lower valleys north of the park this trunk glacier received tributary streams of ice. In the upper valley an ice sheet crept down the mountainous region to the east, coalescing with another stream of ice from the park that pushed northward between Sepulchre mountain and Electric peak and filled the valley of Reese Creek. In the lower valley the main glacier was reenforced by numerous tributary glaciers flowing westward down the great mountain valleys of Sixmile, Emigrant, and Mill creeks, whose united force deflected the northern end of the Yellowstone glacier westward against the foothills of the Gallatin range. The névé fields of these eastern tributary glaciers were on the broad and high mountain summits of the Snowy range, each of the larger mountain gorges penetrating this rugged region, having been the bed of a glacier. The evidence shows that the névé fields of these tributary glaciers were of considerable extent and were confluent with those forming the head of the Boulder glacier.

According to Weed, the upper limits of the glacier ice in Yellowstone River valley, north of Yellowstone National Park, are clearly indicated along the slope of the Gallatin Range on the west by the distribution of erratic boulders of granite and gneiss strewn over the surface of the Tertiary volcanic rocks. At and south of Big Creek these boulders are found at altitudes of 7,000 to 8,000 ft or more above sea level, showing that the ice in the constricted part of the gorge above Carbella, known as Yankee Jim Canyon, was about 3,000 ft thick.

From the vicinity of Dailey Lake and the flat, basalt-capped tableland at the White Cliffs a belt of morainal drift extends northeastward at the foot of Emigrant Peak and adjacent mountains. This moraine, an east lateral moraine of the Yellowstone glacier, is characterized by swale-and-swell topography and is generally strewn with boulders. It is transected by the terraced lower courses of Sixmile Creek and Emigrant Gulch and some other gaps. According to Weed, both Emigrant Gulch and the gorge of Sixmile Creek were occupied by tributaries of the Yellowstone glacier, as seemed also to be indicated by the contour lines on the old topographic map of the Livingston quadrangle. Neither of these gulches has been traversed by the present writer. The lower part of Emigrant Gulch is narrow, V-shaped and, as seen from the road, shows no definite evidence of glaciation.

From the mouth of Emigrant Gulch and Chico Hot Springs an abrupt boulder-strewn ridge extends northward about 4 miles to the east bluff of the inner valley of the river. The ridge may be the terminal moraine of the Yellowstone glacier formed during the Wisconsin stage of glaciation. There are some indications that the moraine is younger than the inner valley of the Yellowstone near Chicory. What appears to be a small morainal ridge extends westward from the road north of Emigrant to the top of the bench above the basalt ledges and there merges with the broad lateral belt of morainal swells and swales that extends southwestward along the piedmont. Southeast of the inner valley, in the space between the moraine and Mill Creek, is a broad gravelly flat crossed by the highway. This flat is either a Wisconsin outwash terrace or an old alluvial fan of Mill Creek. Across the piedmont slope south of the gravelly flat a belt of mild moranial swells and swales can be traced eastward to the mouth of the Mill Creek gorge. Extending northward 3 to 4 miles between Mill Creek and Elbow Creek to the highway (US 89) near the river bend, there is an outer belt of lower boulder-strewn swells and swales that appears to be a somewhat older terminal moraine of the Yellowstone glacier. It may have been formed at the time of either the Iowan or the Illinoian glaciation and may thus be a correlative of Blackwelder's "Bull Lake" moraines in western Wyoming. This moraine is transected by the inner valley of the Yellowstone, and its westward continuation is the moraine at the head of the broad gravelly terrace at the crest of the north bluff about 150 or 200 ft above the bottom land near Pray, Mont. The material exposed in the upper part of the bluff northeast of Pray, where seen by the writer, is coarse, well-rounded, cobblestone gravel with 1- to 2-ft boulders. In Professional Paper 174 (pp. 123 and 124) it was indicated that this terrace may be the third bench and that it may not be an outwash terrace. It is possible, however, that the coarse bouldery gravel capping the terrace is, in part, outwash from this moraine.

Horberg (1940, pp. 297–298), in his description of the glacial geology of this part of the Yellowstone River valley, refers this outer moraine to an "early Wisconsin (Bull Lake) substage." In discussing the relative ages of the outer and inner moraines, Horberg says:

> The differentiation of drift belonging to two substages is based in part upon the stronger morainal forms of the younger drift, but more largely upon the fact that the late Wisconsin terminal moraine descends into the inner post-early Wisconsin valley of the Yellowstone about 2 miles north of Emigrant [Alden, 1932, p. 123] * * *. An age difference is further supported by buried recessional outwash, which may be identified south as far as the mouth of Emigrant Creek, and by a humus zone separating the two drifts at one point. This horizon is exposed along the north bank of Emigrant Creek about a mile above its mouth. That a long time interval was not required for its formation is indicated by the unweathered aspect of constituent minerals when studied under the microscope. The relative ages of early Wisconsin moraines in the main valley and adjoining mountains is shown at the mouth of Elbow Creek canyon where ground moraine extending out from the canyon is overridden and completely obscured by the outer lateral moraine of the Yellowstone Glacier. However, it is believed that the early Wisconsin drift in the main valley represents essentially the same substage as the typical Bull Lake moraines formed by glaciers in tributary canyons.

The road for 8 or 9 miles up the Mill Creek gorge was traversed by the present writer between towering, craggy, and partly wooded steep rock slopes but no definite evidence of glaciation of the gorge was noted. It seems probable, however, that there were glaciers in the several headwater branches of the gorge at the later stage. Even if they did not then coalesce in a trunk glacier confluent with the Yellowstone glacier, they may have done so at the time of the earlier glaciation.

Concerning the glaciers in the canyons tributary to the Yellowstone, Horberg (1940, p. 289) says:

Adjoining mountains.—In the North Snowy block all the larger canyons were occupied by early Wisconsin valley glaciers which descended to elevations as low as 5,000 feet and built imposing moraines on the 'Short Hills' surface and on No. 3 bench * * *. The moraines are now preserved as prominent lateral ridges, which in the case of Strawberry Creek rises 700 feet above younger ground moraine in the central part of the valley. Terminal portions of the moraines have been effaced by subsequent stream erosion and late Wisconsin glaciation, although remnants may be recognized along Pine Creek. The original elevations of the terminal moraines and the height of the latter cannot be used as a measure of interglacial erosion. This is indicated by a decrease in height at the outer extremeties of the lateral ridges. Nevertheless, considerable erosion took place during this interval, as the interglacial channel cutting through the north lateral of the Pine Creek moraine is 400 feet below the crest of the moraine and has subsequently been occupied by late Wisconsin ice * * *. In the South Snowy block eroded remnants of correlative moraines have been identified along Mill Creek and Six Mile Creek. No early Wisconsin moraines were recognized in the Gallatin Range, although it seems probable that valley glaciers in the larger canyons, Big Creek and Tom Minor Creek, were tributary to the Yellowstone Glacier at this time.

The present topographic aspect and position of the Early Wisconsin moraines, especially along the North Snowy block, are similar to the Bull Lake moraines of western Wyoming.

PINE CREEK

About 12 miles south of Livingston are outer and an inner bouldery terminal moraines of the Pine Creek glacier. Near the north side of the canyon mouth there is a partly wooded, narrow, even-crested ridge which, as seen from a distance, looks like an erosion remnant of an old, high-level, piedmont bench. This ridge is cut off from the higher mountain slope by a gap which may have been at one time an outlet for water from this canyon. Tailing off from the west end of the benched spur is the great, uneven, bouldery, north lateral moraine like that south of the creek. These lateral moraines and the terminal loop appear to have been formed by the Pine Creek glacier of the Wisconsin stage. Through this great moraine Pine Creek has cut a narrow gorge 150 ft or more deep. The sides of this gorge, where not overgrown, expose very stony, dense, grayish till. South of the lower end of the gorge through the big moraine is a lower and smoother bouldery ridge that appears to be an older moraine (possibly of either Iowan or Illinoian age). From the foot of this moraine an abandoned channel of Pine Creek extends toward the river.

Horberg (1940, p. 298, figs. 3 and 7) regards the high ridge crests north and south of Pine Creek as "early Wisconsin (Bull Lake) moraines." The present writer suggests that the north ridge may be an erosion remnant of a Pliocene or early Pleistocene piedmont bench. It appears, (as seen from a distance) to be a correlative of the big south lateral spur bordering the South Fork of Deep Creek to the north, as described below. The ridge just north of Pine Creek is separated from the mountain front by a rather broad gap about 400 ft deep through which, as indicated by Horberg, a small lateral sublobe of the Pine Creek glacier later extended, during the Wisconsin stage.

DEEP CREEK

About 5 miles farther north along Deep Creek a well-defined bouldery terminal moraine of Wisconsin age is strewn with 1- to 5-ft boulders of granite, gneiss, and schist at the mouth of the gorge. From the foot of the moraine an outwash terrace slopes down to the terrace on which is the highway (US 89). Abundant 1- to 3-ft boulders have been gathered from the fields on this terrace where the thin soil upon the coarse gravel is cultivated. Between the moraine and Pine Creek there is a prominent narrow spur extending northwestward for about a mile from the south side of the mouth of the gorge of the South Fork Deep Creek. From its lower end at an altitude of 6,150 ft (barometer) to one of 6,450 ft the narrow boulder-strewn crest of the ridge was traversed by the writer. The spur continues its slope until it joins the higher mountain slope. This spur trends obliquely, transverse to the upper part of the mountain gorge, and its crest is 500 ft or more above the creek on the northeast. Horberg regards this as an "early Wisconsin" lateral moraine. Its similarity to the conspicuous drift-covered spurs bordering Indian Creek and Papoose Creek west of the Madison Range leads the writer to suggest that this drift-covered spur also may have a rock core and may therefore be a remnant of an old high-level piedmont terrace of Pliocene or early Pleistocene age.

During the Wisconsin stage a glacier heading on the flank of Mount Delano extended down the narrow trough between this narrow spur and the mountain slope on the northeast; below its end the ice spread out as a small piedmont lobe, the limits of which are shown by a bouldery moraine curving around the lower end of the spur and extending down the slope nearly to the forest ranger station, about 5,350 ft above sea level (barometer). If the tops of these spur remnants on Pine Creek and Deep Creek mark the approximate levels at which the creeks were issuing from their mountain gorges in late Tertiary or early Pleistocene time, it appears that the Yellowstone River may then have been flowing across the limestone ridge south of Livingston at an altitude of about 5,500 ft well up toward the top of the present inner notch which is about 1,000 ft above the river. This would be in harmony with inferences drawn from the high-level gravelly benches at the southwest foot of the Crazy Mountains, 15 to 20 miles northeast of Livingston, as described below and in Professional Paper 174 (p. 25).

MORAINES OF CRAZY AND CASTLE MOUNTAINS

The relations of the high-level spurs south of Livingston on Pine Creek and on the South Fork of Deep Creek to the Wisconsin drift are very similar to those exhibited in one place near the head of Shields River at the west side of the Crazy Mountains, about 30 miles north of Livingston. At this place, T. 5 N., R. 10 E., there is a conspicuous spur at the west side of the mouth of one of the glaciated canyons. From an altitude of about 6,200 ft at the cut-off north end of this spur, the smooth gravel-capped top of this grassy bench rises gradually southward to an altitude of 7,400 ft or more in a distance of 3 or 4 miles and there joins the steeper mountain front. The adjacent canyon, which heads southwest of Sunlight Peak, was occupied by a glacier during the Wisconsin stage of glaciation. It seems clear, however, that this massive spur is not wholly a lateral moraine of this glacier. For some distance south of the north end no boulders were seen on the broad smooth top of the benched spur. A little farther south, near the edge of the woods, a belt of boulders 1 to 10 ft in diameter extends southward diagonally up along the steep east or inner flank of the spur until it lies along the crest as a well-defined lateral moraine. For some distance still farther south the moraine lies along the steep side slope a little below the edge of the bench top, and on this part of the top, between altitudes of 7,000 and 7,200 ft, there are no boulders. Still farther south the bench top narrows and the bouldery lateral moraine again covers the crest. Some boulders appear to have slid or rolled from this part of the moraine down the west slope of the big spur. No evidence of pre-Wisconsin drift was noted on top of this spur. An irrigation ditch which crosses the lower north part of the bench exposes smooth, waterworn, cobblestone gravel. The wooded east slope of the spur is 400 to 500 ft above the bottom of the bordering glaciated gorge. It seems clear that this big benched spur is not a lateral moraine but an erosion remnant of an older piedmont terrace, like that east of the Crazy Mountains and south of the American Fork of the Musselshell River; also that it is probably of Pliocene or early Pleistocene age. The smooth gravel-capped top of this remnant of the first bench east of the mountains is narrow, but 10 miles or more in length, and the west end is separated from the east foot of the mountains by a gap about 6 miles wide through which the American Fork flows. The benched spur on Shields River is also a correlative of the long, high, piedmont bench between the southwest front of the Crazy Mountains and Shields River east of Clyde Park.

These benched spurs are very similar in character and topographic relations to those on the headwaters of the Musselshell River at the south side of the Castle Mountains near the old mining town of Castle, west of Lennep. One of the two benched spurs here, that north of Alabaugh Creek, is about 4 miles long and the other on the south side is about 6 miles long. Their smooth tops, which are several hundred feet above the intervening creeks, are beveled across strata of Cretaceous and Paleocene (Livingston) age and are capped with badly weathered gravel and abundant boulders, mostly 1 to 5 ft in diameter and some 10 to 20 ft long. This bouldery deposit was described by W. H. Weed as glacial drift much older than that which constitutes the terminal moraine within the gorge above the village. Whether or not this bouldery deposit is glacial drift, it seems clear that the benched spurs are of early Pleistocene age or older. The moraines of other glaciers of Crazy and Castle Mountains are described in Professional Paper 174, page 121.

LATER PLEISTOCENE AND RECENT TERRACES

Between the lines of the river bluffs, at whose tops are the eroded edges of the great piedmont terraces in western Montana, there are in many places remnants of one or more lower gravelly terraces of Wisconsin and post-Wisconsin age. In some places there are several steps at heights 10 to 50 ft apart. Such lower terraces are less extensive than the piedmont terraces and are generally confined between the main lines of the river bluffs, which are one to several miles apart. In places they are well developed in tributary gulches transecting the piedmonts. They seem to mark minor substages of downcutting and incipient lateral planation. Although well preserved, they do not generally show up well on the topographic maps. Some of the terrace gravels may be composed of outwash from mountain glaciers of the Wisconsin stage. On plate 1 in this paper these lower terraces are not differentiated from the later flood plain deposits or the broad valley bottom lands with which they merge in places. Generally distinct from these gravel terraces west and north of Missoula are terraces composed of laminated silt deposited in glacial Lake Missoula.

RECENT FAULTS

Reference has been made on preceding pages to well-defined fault scarps the locations of which are shown on the map, plate 1. The most conspicuous fault scarp bordering the west foot of the Madison Range for a distance of about 45 miles was mapped by J. T. Pardee. Where it is crossed by the Madison River at the mouth of the canyon below the Hebgen Lake, near the town of Cliff Lake, there are rapids in the channel which have not yet been cut down to grade. Nearby, the scarp, which crosses even the lowest terrace, is 20 ft or more in height. The scarp also cuts across the moraines of several late Pleistocene glaciers to the south and to the north. In places there are trees, 100 years or more old, on the fresh-looking face of the scarp. Just north of Indian Creek the scarp is remarkably well preserved where it cuts across the head of an alluvial fan at the mouth of a gulch.

At Red Rock Pass and eastward toward Henrys Lake, Idaho, moraines of two or three Pleistocene glaciers are cut across by a Recent fault.

A few miles southwest of Lima, Mont., a recent fault extends westward along the foot of the hills and across the heads of the alluvial fans of Birch Creek and Little Sheep Creek. There it curves northwestward and extends along the piedmont at the foot of conspicuous triangular facets—the cut-off ends of several benched spurs between which sharp gulches gash the abrupt mountain side. Farther north where the scarp crosses an alluvial fan, it is 50 to 100 ft high (fig. 39).

FIGURE 39.—Recent fault scarp across an alluvial piedmont slope northwest of Lima, Mont.

About 3 miles southwest of Dell the head of the great alluvial fan of Sheep Creek is cut, just below the mouth of the canyon, by an abrupt scarp 20 ft high (fig. 40). How much farther than this distance of 7 or 8 miles the Recent fault is traceable has not been determined. When the lights and shadows are just right, this fault scarp between Sheep Creek and Little Sheep Creek is visible from U. S. Highway No. 91, between Lima and Dell. On each of the Recent faults described above the downthrow is on the side toward the broad intermontane valley.

EARTHQUAKES

Among the geologic phenomena which have affected some localities in western Montana since the settlement of the country by white men are earthquakes that oc-

FIGURE 40.—Recent fault scarp across the alluvial terrace at the mouth of Sheep canyon, northwest of Lima, Mont. The trees are on the down-faulted terrace below the scarp; the man is on the terrace above the scarp.

curred in the Missouri River basin in 1925 and 1935. The one that occurred June 27, 1925 has been described by Pardee (1926, pp. 7–23) and others; those of 1935 are described by Scott (1936). The epicentrum of the 1925 shocks was in Clarkston valley near the Missouri River north of Three Forks. Buildings were damaged and one of the railroads was temporarily blocked by rock debris shaken from the limestone bluffs. These places are nearly in line with the Recent fault scarp that borders the Madison Range on the west and are only 40 to 50 miles from the visible north end of the scarp near Ennis. The writer, however, knows of no evidence that there was any movement along the line of the postglacial scarp in the Madison Valley in either 1925 or 1935. The epicentrum of the 1935 earthquakes was near Helena where considerable damage to buildings occurred during a succession of shocks. It is stated that several other less severe earthquakes have occurred in this region in the last 75 years.

EXISTING GLACIERS

As shown on the topographic maps, there are about 65 to 70 small glaciers in Glacier National Park (fig. 41 to 43). They lie in high cirques at altitudes between 6,500 and 10,000 ft above sea level. The largest, the Blackfoot Glacier, comprises 3 or 4 square miles of ice. There are two small glaciers on the Flathead Range south of Nyack, one or two on the Mission Range, and one on the Cabinet Mountains at altitudes about 6,500 ft. There are also two or three small glaciers on the Crazy Mountains (Mansfield, 1909, pp. 558–567) at altitudes of 9,000 to 10,000 ft and on the mountains east and northeast of Yellowstone National Park at altitudes above 10,000 ft. There are several small glaciers on the Bighorn Mountains in northern Wyoming at altitudes above 11,000 ft. Examinations of several of the glaciers in Glacier National Park at different times between the years 1900 and 1944 show a progressive

FIGURE 41.—Front of ice on inner terminal moraine of Sperry Glacier. When seen in 1927 and 1936 the ice front had receded some distance from this moraine. Photographed in August 1913.

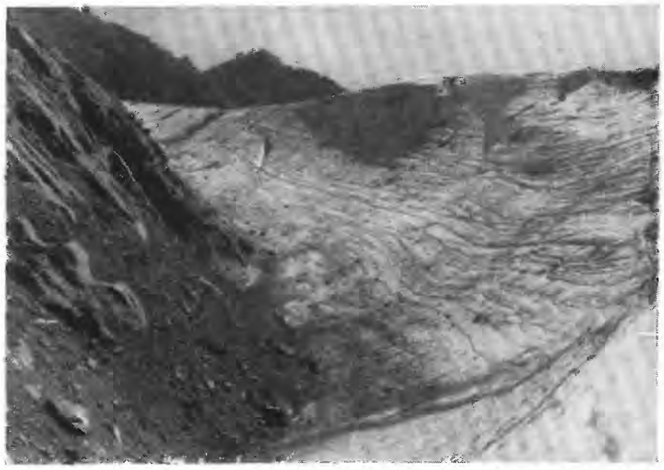

FIGURE 42.—Moat and cliff of stratified ice, about 150 ft high, at the northeast margin of Sperry Glacier; rock cliff at the left. Photographed in 1936.

FIGURE 43.—Glacial stairway at the head of Sprague Creek. The cliff below the lower lake is 500 ft high; similar cliff below bench on which is Sperry Chalet (lower right). Edwards Mountain is at the left; Gun sight Mountain at the right. The outcrop of the diorite sill shows as a dark band in the cliff beyond Sperry Glacier in the background. Photograph by the U. S. Army Air Corps.

decrease in the size of some of the glaciers (figs. 42 and 43). These glaciers have been described in other papers. (Alden, 1914, 1923; 1930: Campbell, 1914, 1921; Gibson and Dyson, 1939; Dyson, J. L., 1940, 1941.)

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