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THE MONTANA LOBE OF THE KEEWATIN ICE SHEET

BY

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THE MONTANA LOBE OF THE KEEWATIN ICE SHEET.

By Fred. H. H Calhoun.

INTRODUCTION.

Just south of the forty-ninth parallel and east of the Rocky Mountains is an area that is of much interest to glacialists It is the area which lay between the Keewatin ice sheet and the mountain glaciers coming from the west. Although it has been known for nearly twenty years that the bodies of drift deposited by the ice coming from opposite directions were closely associated, little detailed field work has been done in this region. As early as 1881 Sir James Geikie prophesied that a careful study of the region would clear up many important points in glaciology.[a] In 1885, Dr. T. C. Chamberlin and Prof R. D. Salisbury, in a reconnaissance of the region, determined roughly the course of the terminal moraine of the eastern ice sheet and obtained data concerning the character and extent of the mountain glaciation [b] In 1890 Mr. G. E. Culver, while a member of the military party under the command of Lieutenant Ahern, U. S. Army, gathered many data concerning the geology of the region, publishing the results of his investigations in the Transactions of the Wisconsin Academy of Sciences, in 1891.[c] Doctor Dawson and Mr McConnell, of the Canadian Survey, have worked out the geology of the region north of the boundary line.[d] Their reports are unusually complete, but the area to the south offers better opportunity for study, and somewhat different conclusions were reached from a study of that region.

The work on which the following discussion is based was done during the field seasons of 1901, 1902, and 1903. During the first season the writer was accompanied by Mr. Bruce McLeish, then a student at the University of Chicago. The second year Mr. Porter Graves, of the Kansas City High School, rendered valuable assistance The writer is most deeply indebted to Dr. T. C. Chamberlin and Prof. R. D. Salisbury, of the University of Chicago, for friendly interest shown while superintending the compiling of this manuscript. Professor Salisbury also personally directed a portion of the field work and made many practical suggestions. Thanks are also due Dr. G. K. Gilbert for careful criticism of the report.

[a] Am Naturalist, vol. 15, pp 1-7

[b] U S Geol Survey, Seventh Ann Rept, 1888, pp 147-248

[c] Trans Wis Acad Sci, vol 8, 1891, pp 187-205

[d] Geol Survey Canada, Rept of Progress, 1884, sec C, Geol Survey Canada, vol 1, n. s, 1885, sec. C; Bull. Geol. Soc. America, vol. 7, pp 31-66

GENERAL FEATURES OF THE AREA.

LOCATION

The area covered by this investigation lies along the eastern front of the Montana Rockies, between longitude 108° and 113° 40′, and latitude 47° 15′ and 49° 30′. Over the eastern and northern part of this area the ice from the northeast deposited its drift. Over the western part the ice from the Rockies pushed down the mountain valleys and, deploying on the plain, deposited large and well-defined terminal moraines. Extending from the Canadian line to the Missouri there is a strip of country, varying greatly in width, which the ice did not cover.

PROBLEMS PRESENTED.

In studying this region four important subjects present themselves—the eastern drift, the mountain drift, the deposits on the intervening area (which was not glaciated), and the relations of these three surface formations to one another. In order that these relations may be clearly understood the physiography and the general geology of the region must be briefly considered.

PHYSIOGRAPHY.

The region may be divided into three physiographic provinces—the great plains that cover the eastern part of Montana, the foothill belt, and the Rocky Mountains proper. The plains begin at the edge of the foothills and slope eastward with sharp descent. At Midvale, near the base of the mountains, the elevation is 4,788 feet above sea level; at Blackfoot, 20 miles distant, 4,145 feet, giving a slope of 30 feet per mile; at Shelby Junction, 52 miles from Blackfoot, 3,279 feet The fall between the last-named places is, therefore, 16 feet per mile

The foothill region separates the plains from the mountains This confused mass of hills and ridges narrows as it extends southward until, at the mouth of Sun River Canyon, it disappears altogether and the mountain walls rise abruptly from the plains. The height of the foothills averages 1,000 feet, though many individual peaks measure 1,500 feet.

As the foothills are distinct from the plain, so are the mountains distinct from the foothills Towering above the smaller hills at their base, these mountains raise their nearly vertical faces 4,000 to 5,000 feet above the plain.

The Rocky Mountain divide separates three drainage basins. A drop of water falling near the summit may be carried eastward by the tributaries of the Missouri to the Mississippi and the Gulf of Mexico, northward by St. Mary River or its tributaries into Hudson Bay, or westward by Flathead River into the Pacific. Of these three drainage basins this report is chiefly concerned with the first two. All the streams considered rise on the eastern slope of the Rockies, flow through deep mountain valleys with high, nearly vertical walls, across the foothills in deep, narrow canyons, and finally make their way across the plains in great U-shaped valleys whose forms suggest a long period of erosion.

The region shows at least three periods of erosion, when the land stood at different levels. Running out from the mountains in a general eastward direction are plateaus 900 to 1,000 feet above the present level of the streams. These plateaus have plane surfaces, except for dissection by valleys, and slope sharply eastward at about the same grade as that of the present streams. The plateau between South Fork of Milk River and Cutbank Creek, from a point near the mountains to Rocky Coulee, has a decline of 900 feet The fall of Milk River in the same distance is practically the same, while Cutbank Creek has a drop of 850 feet. Milk River Ridge, a plateau lying between Milk River and the valley of St. Mary River, has essentially the same slope. The distance is 33 miles and the decline about 28 feet per mile. Near the mountains these plateaus are from 1 to 3 miles broad. Toward the east they narrow to ridges, the ridges give place to buttes, and the buttes in turn yield to small piles of sandstone débris, rising but little above the lower surface of another erosion cycle. The ridges now forming the remnants of this old base-level are found between streams flowing from the mountains, their narrowness in places being due to the lateral cutting of the streams during succeeding periods of erosion. In some cases this lateral planation has been carried so far as to remove the ridge entirely. On Cutbank Ridge there is a low, flat butte, rising 200 feet above the plateau level, which represents a still older surface, possibly a still older plateau base-level.

South of Sun River are a number of great buttes, not capped with the gravels supposed to have been deposited during the time of the first base-level Possibly, at the time these gravels were being deposited, the buttes stood too high to receive them; they now stand 1,300 feet above the Sun River Flat. These flat-topped rock masses, while suggestive, are scarcely sufficient to determine the existence of an earlier base-level.

Between the first base-level and the third erosion level developed along the present stream courses, in which the streams are now cutting a fourth level, a well-developed second cycle is shown. This is found in nearly all the river valleys, but in some places the erosion in the third cycle was so long and vigorous as to destroy all traces of the second along the sides of the valleys. The second cycle was the least persistent of the series; the third cycle was the most complete. The great flats along Milk River and Cutbank Creek and those along the upper courses of Muddy and Teton rivers were formed at this time. In places the third cycle may be divided into two distinct cycles, and more detailed work may establish these in all the valleys. Taking the doubtful stages into account, six erosion levels can be differentiated.

STRUCTURE.

The present topography is the result of three physiographic processes, diastrophism, volcanism, and gradation. The Rocky Mountains were formed by a great

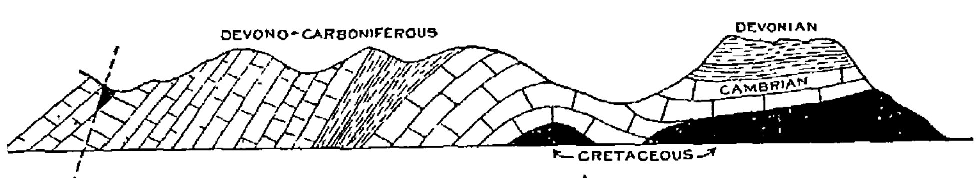


FIG. 1.—Section of frontal range of Canadian Rocky Mountains along South Fork of Ghost River, showing thrust-fault relations of Cretaceous to Algonkian and Cambrian After R G McConnell

fault which thrust 8,000 to 10,000 feet of Algonkian rocks obliquely up and over upper Cretaceous beds for a distance of 7 miles or more. This fault has been worked out by Willis[a] in the vicinity of Chief Mountain, near the international boundary line, but the same fault appears to extend both northward and southward.[b] It is seen in

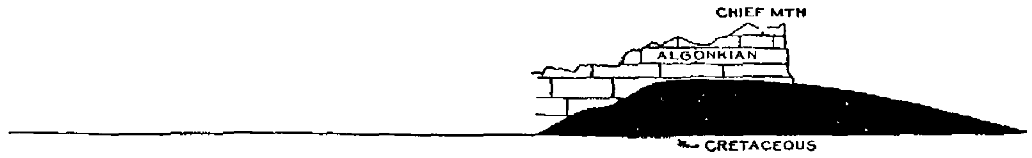


FIG 2—Section of frontal range of Rocky Mountains along the forty-ninth parallel, showing thrust-fault relations of Cretaceous to Algonkian and Cambrian. After Bailey Willis

Sun River and Teton River canyons, though there the Cretaceous appears to lie under a great thickness of limestone, which in this case is not Algonkian but Carboniferous.

GENERAL GEOLOGY

SEDIMENTARY ROCKS.

The rock material forming the mountains is varied. North of Summit Pass the basal member of the series is a hard buff limestone Above the limestone are argillites, quartzites, and conglomerates In some places the limestone has been metamorphosed. A fine exposure of the resulting marble is seen on the south side of Rising Wolf. The argillites are red, green, and black, and so hard as to withstand weathering to a remarkable degree The quartzites are commonly red and white, and are even more durable than the argillites Some of them contain flat pebbles of argillite, giving to the formations the appearance of a quartzite with interstratified layers of shale. The evidence of their shallow-water origin is seen throughout the series. Ripple marks and sun cracks are found even at the summit of Rising Wolf, nearly 10,000 feet above the sea Into this great sedimentary series there has been at least one igneous intrusion of diorite. Exposures of this intrusive rock occur in Swiftcurrent Canyon and at several other places on the west slope of the mountains.[c] This rock appears in the drift along the face of the mountain, being abundant in the St. Mary River Valley but gradually decreasing in amount toward the south.

The region lying at the foot of the mountains consists of a high plain sloping abruptly eastward. The beds forming the surface are upper Cretaceous; the lowest member of the system is referred to the Pierre formation of the Montana epoch; the upper member of the system is the Laramie. In the southeastern portion of the area the rocks of the Colorado formation are exposed along Missouri River This classification of the strata of the region is based wholly on Dawson's classification of the formations to the north The shales and sandstones of the Pierre formation are exposed at Midvale, in Two Medicine Valley on the Marias near its headwaters, on the Teton, and north of Shelby Junction on the line of the Great Falls and Canada Railroad. There are also outcrops in the disturbed region between the foot of the mountains and the area of horizontal beds.

Near the mountains the Pierre shales become sandy and in places conglomeratic, indicating proximity to an old shore line. The conglomeratic character

[a] Willis, Bailey, unpublished manuscript.
[b] Geol Survey Canada, 1886, vol 2, Rept. D.
[c] Culver, G E, Trans Wis. Acad. Sci., vol 8, 1891, p 195.

is well developed in Summit Pass and along the face of the mountains generally. The Fox Hills beds are regarded as deposits of a stage existing between the marine conditions of the Pierre and the fresh-water conditions at the time of the Laramie, and were not identified.

Concretions are found on the surface in great numbers, frequently arranged in belts extending uninterruptedly across the country (Pl. II, *A*).

These concretions are often found in the drift.

IGNEOUS ROCKS.

The continuity of the sedimentary series of the plain is interrupted by igneous outcrops in various parts of the region studied Chief among these are the Sweetgrass Hills, igneous intrusions south of Sun River on the headwaters of the Muddy, the Highwoods, the Bearpaws, the Little Rocky Mountains, and the Larb Hills.

The Sweetgrass Hills afford data for the solution of some of the glacial problems of the region, and therefore deserve especial mention. These hills or buttes are usually spoken of as outliers of the Montana Rockies, but they are not such in any proper sense of the term. The Rockies were formed by a series of faults, while the Sweetgrass Hills are the result of igneous intrusions, which lifted the sedimentary layers and left them dipping at high angles from the central igneous core. The hills are three in number, known as East, Middle, and West buttes. Of these, West Butte is the highest, its summit being about 6,800 feet (aneroid) above sea level. The East Butte is several hundred feet lower, while Middle Butte, the smallest of the three, is but 6,000 feet in height.

The igneous intrusions which formed these buttes may have belonged to the mountain-making period at the end of the Mesozoic, as volcanic activity was at this time great, or may be still younger Gold, silver, and copper are found to some extent in the buttes, occurring in veins, usually along the contact between the sedimentary series and the intrusive mass

The area of igneous rock found south of Sun River is some 30 miles from the base of the mountains. It caps some of the high buttes between Sun and Missouri rivers The easternmost outlier is found at Square Butte, in T. 20, R 2 W. The rock is pyroxene-porphyry, rather dense and roughly columnar It rests on a sandstone formation, which contains oyster shells and fine examples of the straight baculite shell. These fossils lie within a few inches of the contact and are perfectly preserved The sandstone shows scarcely a sign of metamorphism, even at the zone of contact The lava flowed over a very uneven surface. On Square Butte the contact is 400 feet above the level of the plain; on Crown Butte the bottom of the porphyry is but 100 feet above the plain.

The Highwood Mountains are the result of former extensive volcanic action. Early in the Eocene a great igneous mass pushed its way through the sedimentary layers to an unknown height above the plain. At the present time the mountains are much subdued by erosion and weathering, a number of peaks have been formed, and great buttes have been separated from the main mass of the flow. The mountains and the plains surrounding them have been cut by dikes, which radiate in all directions.[a]

[a] Weed, W. H., Description of the Fort Benton district Geologic Atlas U S, folio 55, U S Geol. Survey, 1899.

Just north of the Highwood Mountains lies a very peculiar valley, locally known as the Sag (Pl II, *B*), which extends from Highwood Creek Valley on the west to Arrow River Valley on the east The Sag is 80 miles long and in many places is very wide and deep. Near Steele it is over a mile wide, with valley walls 600 to 800 feet high Its great size and peculiar course have led some geologists to consider it a pre-Glacial channel of the Missouri, but its close association with the ice edge suggests another interpretation, which will be discussed later.

Directly northeast of Highwood Peak, the highest point of the Highwoods, and at a distance of some 70 miles, the Bearpaw Mountains rise above the plain. Like the Highwoods, these mountains are volcanic, being composed of lava flows resembling those which formed the Highwoods. Dike rock is less common, and as a whole the Bearpaws are older, being past their maturity. The range is made up of low rounded peaks separated from one another by wide fertile valleys The two ranges are connected by a system of dikes, but it seems evident from the topography that if volcanic activity began at the same geologic period, the Highwood center continued active long after flow in the Bearpaw group had ceased.

The Little Rockies, the most picturesque and interesting of the three mountain groups, are situated some 50 miles southeast of the Bearpaws In contrast to the Bearpaws these mountains appear young Mission Peak, the highest, stands 3,000 feet above the level of the plain. The valleys are narrow and canyons are not infrequent. The canyon through which the St. Paul's Mission–Landusky road passes is 5 miles long and often 500 feet deep. The central mass of the mountains is of porphyry, which is surrounded on all sides by limestone of Carboniferous age Cretaceous sandstone lies on the limestone and extends outside the limestone area, dipping away from it at a low angle The porphyry and the limestone are cut by dikes of gneiss and schist None of these dikes were observed to extend into the sandstone, but some doubtless intersect it also. The gneisses and schists are of many varieties and are not found in the other mountain groups. In the porphyry are pockets of crystalline limestone and quartzite, which appear to be part of the sedimentary series, inclosed in some way by the igneous mass. In places near the porphyry shaly parts of the limestone have been turned to phyllite

The metamorphic rocks that occur in the mountain group have been carried out by streams and deposited along their channels and on their flood plains These rocks are in no wise different from some of the bowlders of the Keewatin drift and occur in the same area. Where all morainic topography has been destroyed by erosion, and where that topography was never developed, the tracing of the former extent of the ice becomes a complex and difficult problem.

The Larb Hills seem to be the top of a dome through which the streams have eroded great valleys but have not yet cut sufficiently deep to reach the igneous center. These hills lie east of the Little Rockies and form the breaks of the Missouri. The highest point is some 3,500 feet above sea level and 1,200 feet above the level of the plain. Between these mountain groups lie broad plains, which had a marked influence on the edge of the ice.

SURFACE FORMATIONS.

QUARTZITE GRAVELS.

CHARACTER.

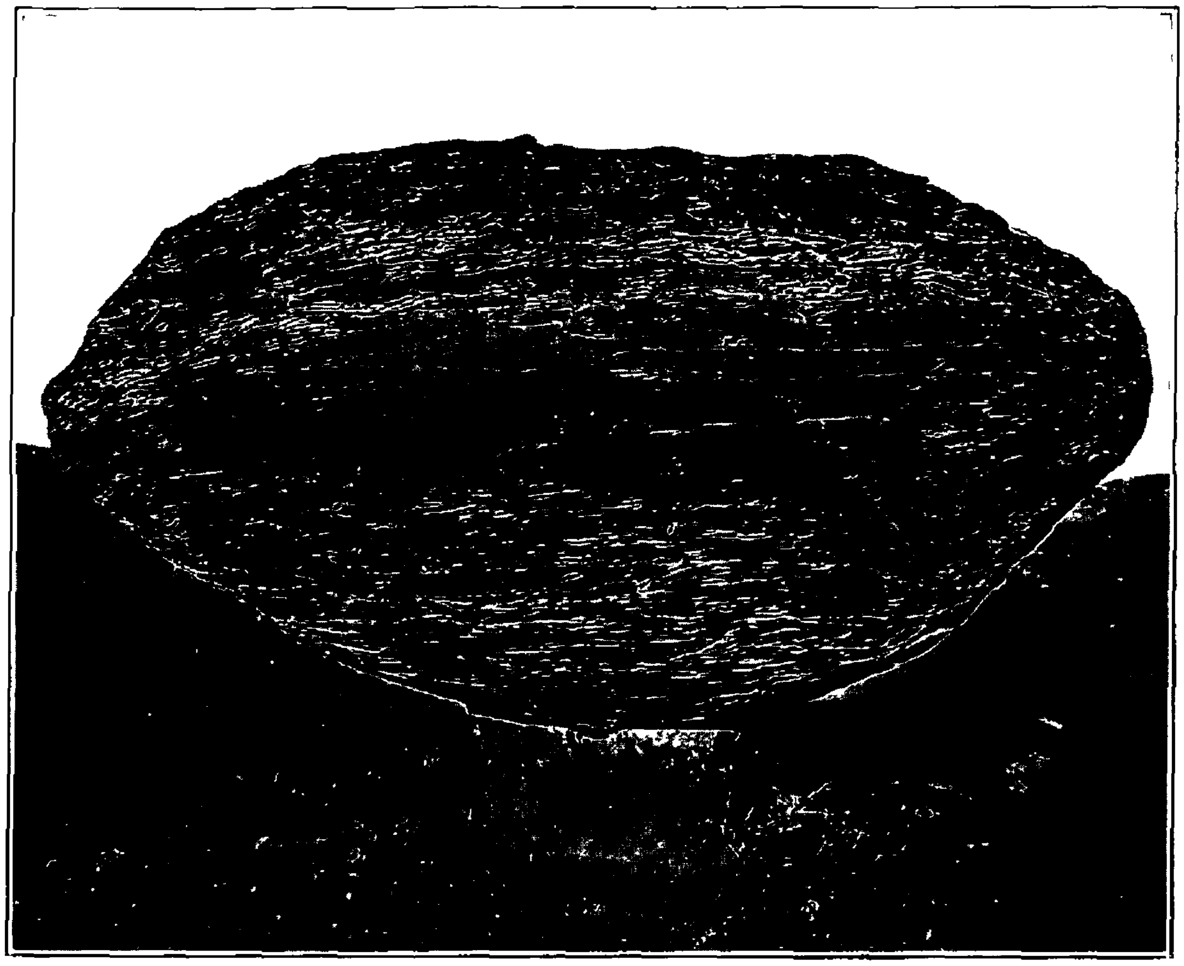
On the plateaus between the streams, on the terraces and slopes in the stream valleys, and in the present channels of the watercourses are found the surface formations with which this report deals. There are four such surface formations: (1) A gravel deposit, found in the driftless area; (2) morainic material brought in by the ice from the mountains; (3) morainic material deposited by the ice from the northeast; and (4) the present fluvial deposits. The last are of so little importance that they need not be considered.

Between the moraines deposited by the Keewatin ice sheet and the valley glaciers and on the surface of the strip of nonglaciated country lies a peculiar formation which will be spoken of as the quartzite gravels. These gravels are made up of argillite and quartzite formations of the mountains. Limestone is rarely present. The few fragments found show the result of long-continued weathering. In some cases all the calcium carbonate has disappeared, leaving nothing but irregular masses of chert. In general the quartzite and argillite pebbles making up the formation are well rounded, though some still show traces of angularity. The fact that these hard quartzites are generally smooth and round, taken together with the absence of any appreciable quantity of limestone or other nonresistant rock, shows conclusively that the constituents of the gravel were subjected to prolonged wear. In size the pebbles are rather uniform, being on the average 3 or 4 inches in diameter. Isolated specimens found near the mountains measure as much as 12 inches in diameter.

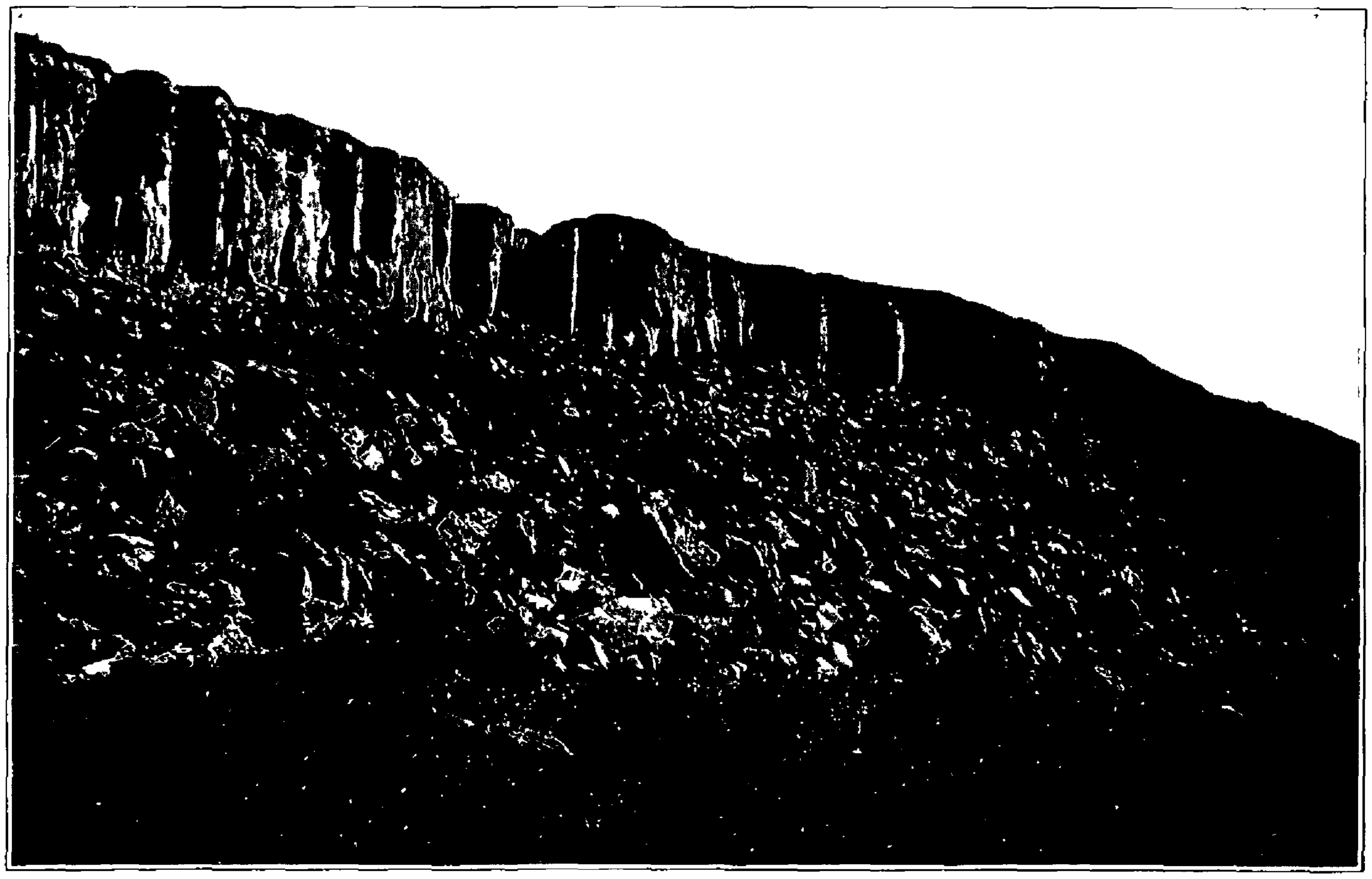
South of the forty-ninth parallel the character of the gravels changes with the character of the rocks forming the front of the mountains. South of Birch Creek the quartzites and argillites are less common. South of the Teton Ridge the gravels consist of small cherty pebbles, the residual material of the original cherty limestones.

DISTRIBUTION.

How far eastward the gravel extends is not known. East of latitude 112° the formation is buried by drift beds. Beneath the drift the gravels have been found on the Milk, Marias, Teton, and Missouri rivers. Dawson describes them as found 200 to 500 miles east of the mountains. They appear in the drift of the Keewatin ice sheet and make up a considerable per cent of its rock material. Their topographic positions are significant. The high divides between the watercourses are capped by them to a depth of from 1 to 10 feet, but they are absent from the divides near the mountains and from some of the high buttes south of Sun River, which, lava-capped and standing 1,000 feet above the plains, are covered only by the residual material from the lava itself. The gravels appear on the slopes descending from the higher to lower levels and for the most part covering them. On the flats adjacent to the present streams they are sometimes absent, and isolated areas in front of the moraine deposited by the Keewatin ice sheet are not covered by them. Taking the entire area into consideration, the gravels are very persistent. Their relation to the other surface formations, their origin, and their age will be considered later.



A PERCHED CONCRETION WEATHERED FROM CRETACEOUS SANDSTONE



B THE SHONKIN SAG

The sag at this point is about 600 feet deep

DRIFT OF THE MOUNTAIN ICE.

DISTRIBUTION OF THE MOUNTAIN GLACIERS.

In the distribution of glaciers, living and extinct, in the western mountains, one feature which stands out above all others is their greater extent on the western slopes In the Sierra Nevada in Glacial time the western slope was one continuous ice sheet,[a] while on the eastern side of the range the glaciation was confined to a few narrow gorges. In Colorado the heaviest glaciation was on the west side of the mountain ranges; the La Plata Mountains, which are the first to catch the moist winds from the Pacific, were heavily glaciated on the west side; in the San Juan Mountains there was not only a much greater thickness of ice on the west slope, but the territory covered by the ice was much larger.[b] In Washington the western sides of the ranges suffered severe glaciation, and the Wasatch Mountains were more heavily glaciated on the west than on the east.

The reason for this is evident. The prevailing winds over the western mountains were from the west and carried with them moisture gathered from the Pacific. This in part was deposited on the first mountain slope, because here the currents were forced to ascend and therefore precipitated their moisture. The larger part of what was carried over was deposited, not on the eastern slope of the same range, where the air currents were descending and where instead of precipitation there would be, to some extent, drying winds, but on the western side of the next. Glaciation in the mountains of Montana should follow the same law, and the western slope should be more heavily glaciated than the east. During the work in the field evidence was found to show that practically all the mountain valleys between the Waterton and the Missouri on the east side of the range were once filled with glacial ice. The western slope, though not studied in detail, appears to have been more nearly covered. Large glaciers occupied South and Middle forks of Flathead River, and into these main valleys there flowed small ice tributaries from the sides. Into the valley now occupied by Flathead Lake these ice streams poured and united to form a great piedmont glacier.[c] This glacier was augmented by an ice lobe coming from the north, for striations have been found running north and south on the west side of the Kootenai Mountains and on the low mountains north of Kalispel The moraines along the southern edge of Flathead Lake appear to have been deposited by the piedmont glacier thus formed.[d] Whether the lobe from the north was a part of the Cordilleran ice sheet or a great glacier formed in the valley north of Kalispel is yet to be determined.

The main divide of the Rockies formed the collecting ground for the glaciers. Those which made their way down the west side were of great extent, and in some cases covered the ridges between the streams. Those on the east slope were confined to the mountain valleys, and appear to have had no connection with each other until the separate glaciers reached the plain and, deploying, united to form a piedmont glacier extending along the foot of the range. During Glacial time all the great valleys and many of the minor ones in the area studied contained

[a] Kneeland, Samuel, Glaciers of the Yosemite Valley Proc Boston Soc Nat Hist, vol 15, p 37
[b] Stone, George H, Glacial gravels of Maine Mon U S Geol Survey, vol 34, 1899, pp 338-355
[c] Garrey, George, unpublished manuscript
[d] Chamberlin, T C. Seventh Ann Rept U S Geol Survey, 1888, p 78

A. PERCHED CONCRETION WEATHERED FROM CRETACEOUS SANDSTONE.

B. THE SHONKIN SAG.

The sag at this point is about 600 feet deep.

glaciers. From 14 mountain valleys the ice reached beyond the mouth of the canyon and deployed upon the plains. In other valleys the ice did not reach the plain, but deposited its moraines across the canyon somewhere above the point of debouchure.

DETAILED DESCRIPTIONS OF THE MOUNTAIN GLACIERS.

Sun River Glacier.—The area comprised in the Sun River system is that which lies between Dearborn River on the south, Missouri River on the east, and Teton River on the north. For the first 50 miles of its course North Fork of Sun River (the main branch) flows nearly due south, parallel to the main divide of the Rockies. It receives numerous tributaries from the west which have their heads at the very top of the divide. The course of the river abruptly changes in T. 22, R. 9 W., whence it flows eastward through a deep, narrow canyon in the mountains and, emerging on the plain, continues in the same direction to its junction with the Missouri, 75 miles distant.

The glacier which occupied the valley of Sun River was the largest one south of Summit Pass. At the present time Sun River drains a considerable area of mountain territory, and in the past it was well situated for collecting the glaciers which made their way down the eastern slope through its tributary valleys. For a distance of 50 miles Sun River received those tributary ice tongues which, had the drainage been to the east, would have been carried in independent valleys directly to the plains. The result of this concentration of the ice into one valley was a glacier of considerable size.

The mouth of Sun River Canyon is narrow, but it was through this restricted opening that the ice pushed, tearing great blocks from the sides, cutting deep grooves in the valley walls, and smoothing and polishing the rock to a greater extent than in any other canyon along this part of the range. (Pl. III, *B*.)

The sides of the canyon are glaciated to a height of over 1,600 feet, the change from the glaciated to the nonglaciated surface being easily made out by the rather abrupt change in the topography. From the upper limit of glaciation at the mouth of the canyon to the terminal moraine, a distance of 18 miles, the fall of the upper surface of the ice was about 2,200 feet, giving an average decline of about 130 feet per mile. This glacier at its maximum extent reached to a point northeast of Augusta, where its moraine now crosses Sun River in a north-south direction. On the south side of the river and about 1 mile from it, the moraine turns S. 70° W. and continues in that direction for some distance. Beyond this the moraine on this side of the river was not traced, but it probably joins that deposited by the glacier which occupied South Fork of Sun River.

On the north side of Sun River the ice pushed eastward on the south side of a high ridge which forms the divide between Sun River and Deep Creek. For a distance of about 3 miles the moraine lies along the south side of this ridge, but at a point 3 miles north of Willow Creek it reaches the top of the ridge and swings to the north. Near the mountains the moraine of the Sun River Glacier joins that of the Deep Creek Glacier.

The outer moraine of the Sun River Glacier is well marked. In places it is about one-half mile wide and bears many basins which contain water in spring but are dry in summer This moraine, in sharp contrast to those farther north, is strewn with great numbers of large limestone bowlders, the largest noted being 18 by 12 by 12 feet. Part of this bowlder is buried and the numerous large fragments scattered around its base show that it was once much larger

Three miles west of the outer moraine there is a well-marked recessional moraine. A second recessional moraine is found just west of Willow Creek This is not so well defined as the first, though it is of sufficient size to indicate that the ice front remained stationary here for a considerable period of time The topography of these two recessional moraines is not so characteristic as that of the terminal ridge. There are no well-defined basins, and the bowlders are not so large nor so numerous. The third recessional moraine is of a very different type It is marked by a series of sharp ridges inclosing lake basins The bowlders are again numerous and large, and bear marks of severe glaciation, some of them showing grooves 3 feet across The bowlders in this recessional moraine appear to have suffered considerably less from weathering than those in the outer moraines As will be pointed out later, this same difference in the character of the recessional moraines is found in other valleys, and it is possible that this better-developed moraine is the result of a rather distinct ice stage

Between the third recessional moraine and the mountains there is an extensive lake flat, now drained by Willow Creek Over this old lake bed are scattered a number of alkali lakelets, in which so much alkaline deposition has taken place that, at a distance, they look like ice surfaces.

The bowlders deposited by the Sun River Glacier are chiefly of limestone. Sandstone of all varieties and colors, a peculiar flinty rock, and both red and black slates are also found. Besides these sedimentary rocks there are several varieties of diorite

At the mouth of Sun River Canyon there is no rock but limestone exposed. The sandstone, slate, and diorite must have been derived from the upper portion of the river basin. The valley trains reached at least to the town of Sun River, where the river runs onto a plain with a fall of but 2½ feet per mile. Because of the sudden check in the velocity of the stream, the gravels, if they extend farther, are covered by later fluvial deposits.

Deep Creek Glacier.—Deep Creek, one of the most important branches of Teton River, issues from the mountains through a very narrow canyon. This stream does not extend far back into the mountains, and the area at the head of the creek was too small to gather any great accumulation of snow during Glacial time. The north and south course of Sun River for so many miles enables it to gather most of the precipitation on the east side of the divide In Glacial time the same was true. Most of the ice which gathered along the present valley of Sun River was tributary to the glacier which formed in that valley, and little got into the streams to the north. For this reason the Deep Creek Glacier was small and moved but a short distance out from the foot of the mountains, its terminal moraine being found in sec 32, T 23, R. 8 W The local character of the drift is evident from the absence of diorite, quartzite, and sandstone bowlders, showing that the glacier could have moved only over limestone rocks and could not have extended far back into the mountains. The ice which issued from the mountains appears to have been confined entirely to South Fork of Deep Creek, for the valley of North Fork is not glaciated. The moraine from South Fork does not cross North Fork, though at some places it lies so near it as to suggest that the ice filled the old channel and pushed the stream to the north. South of Deep Creek the ice was continuous with that of the Sun River Glacier, but to the north the plain at the base of the mountains is not glaciated for a distance of 8 miles. In this direction the mountains rise abruptly from the plain, and there is no opening through which a glacier could have come till Teton River is reached

Teton River Glacier.—Two streams but half a mile apart issue from deep, narrow gaps in the mountains, and, joining a mile or two below the mouth of the canyon, form Teton River Like Sun River the course of the Teton in the mountains is north and south, and though much of the ice which collected near its headwaters was diverted into the Sun River basin, enough was left to form two good-sized glaciers The ice issuing from these narrow passes immediately joined and deployed upon an unusually flat plain. The glacier thus formed, though extending but a few miles east of the mountains, gives evidence of having been very powerful and active. The terminal moraine on the north side of the river consists of a series of sharp ridges, which form a belt over a mile wide. They are so steep and are covered with so many limestone bowlders that the moraine is difficult to cross on horseback. The terminal moraine is covered with a growth of stunted pine trees, which are found neither on the ground moraine nor on the plain to the east The north and south edges of the ice formed two moraines which extend parallel to each other for a distance of 6 miles from the mouth of the canyon. They are about 3 miles apart and are well developed throughout their entire extent. This development of the moraines along the side of the glacier is in sharp contrast to that formed at the end of the ice. There the moraine is low and of weak relief. Either the ice did not form a strong terminal moraine or the river has since eroded a considerable portion of it. The amount of ice coming from the north gap was greater than that which came from the south one. This is shown by the great amount of ice erosion in the north valley, the higher level to which the canyon walls were glaciated, and by the fact that the ice spread north from the mouth of the canyon of North Fork for a greater distance than it spread south of South Fork. The bowlders of the Teton Glacier till sheet consist of limestones and sandstones, no diorite being found.

Muddy Creek glaciers—Muddy Creek is formed by the union of many small streams, but two of which issue from the mountains. Most of the tributaries have their source in springs on the sides of the mountains and are intermittent, contributing to the main stream only while the mountain snows are melting. The two main branches issue from what are known as Black Leaf and Muddy canyons. Of these, Black Leaf Canyon lies to the south and contained a glacier which extended somewhat more than a mile beyond the mouth of the canyon The material making up the moraine of this glacier is a heavy bowlder clay, containing many limestone bowlders and few of sandstone The moraine, which reaches a height of 200 feet and has the form of a sharp ridge, is the highest seen in this region The glacier from Black Leaf Canyon was not connected with any other glacier either north or south The canyon of the Muddy also contained a glacier which pushed out on the plain a mile from the mouth of the canyon, and resembled in many ways the glacier which issued from Black Leaf Valley

Dupuyer Creek Glacier.—The next glaciated canyon to the north is the one now occupied by Dupuyer Creek. This stream heads in the mountains just north of the sources of Teton and Sun rivers and contained a glacier which extended 3 miles eastward from the mouth of the canyon and formed a well-defined moraine, dotted with many small lakes and ponds Lakes in the moraines south of Dupuyer Creek are common. Bowlders, which are numerous in the till of the other moraines, are not abundant here. The height to which the ice reached is shown on the surface of the canyon walls, and from these we may determine its slope. At the mouth of the canyon the walls are glaciated to a height of about 1,000 feet. Beyond the canyon for the first three-fourths mile the decline of the ice as shown by the slope of the moraine was 750 feet, in the next 2¼ miles to the terminal moraine it was but 450 feet, making 1,200 feet for the 3 miles, or an average of 400 feet per mile. As soon as the ice left the confines of the canyon it deployed rapidly

Sheep Canyon Glacier—There was a small glacier in Sheep Canyon, but its moraines show no striking peculiarities.

Blackfoot Glacier—Properly speaking, the Blackfoot Glacier consisted of a group of glaciers which, reaching the plain, joined and spread to the east. At least 5 such ice lobes were concerned in the formation of a large piedmont glacier which extended about 50 miles from the main divide, and which, in its widest part, was over 30 miles across

The main collecting ground for the snow which furnished the ice was in the low pass now crossed by the Great Northern Railway (Pl III, *A*) From this pass the ice moved both eastward and westward The center of accumulation may have been west of the top of the pass, for the rocks for nearly 2,000 feet above Summit station are smoothed and polished, and well-marked glacial bowlders are found at a height of 1,000 feet above the 5,205-foot bench mark at the summit. Along the side of the mountains north of the track and east of Summit station there is a terrace 1,800 feet above the valley level, which seems to coincide with the upper limit of glaciation and to represent the thickness of the ice near the point of origin. Thence the front of the ice descended to an altitude of 3,800 feet This would give a slope to the surface of 65 feet per mile, a low slope for a mountain glacier.

The southernmost glacier that was tributary to the Blackfoot Glacier came from the valley of Birch Creek. It extended southward as far as the divide between Birch and Sheep creeks, but in no place did it meet the ice which issued from Dupuyer Creek Canyon The eastern edge of the ice swung across the river due north and south at a point in sec. 30, T. 29, R 8 W, but on the flat on each side of the river the ice front curved to the west North of Birch Creek is a high ridge, which forms the divide between that stream and Blacktail Creek so high as to prevent the ice of the piedmont glacier from extending far into the narrow Blacktail Valley The bowlders in the Birch Creek drift are for the most part limestone; the most common variety being a dull noncrystalline limestone. A light-colored crystalline type and a cherty variety are also common. There are sandstone bowlders, but they are not abundant. The glacier in Birch Creek Valley formed several recessional moraines, but they are not so sharply defined as those in the valleys farther south.

A. SUMMIT PASS AND ADJACENT VALLEYS.

The main valley was completely filled with glacial ice. The one at the left contained a glacier tributary to the main stream.

B. SUN RIVER CANYON.

This photograph shows the glaciated surfaces in the background and the amount of post-Glacial cutting

The valleys of Blacktail and Whitetail creeks furnished great glaciers to the ice mass at the foot of the mountains, causing a bulge in the ice front, which carried the edge of the ice nearly to Fourhorn Lake The moraine deposited was of the same character as that in Birch Creek Valley, and contains the same sorts of rock Within the moraine of the Blacktail Glacier the country is rolling, and there are a few shallow lakes, the topography being essentially that of a ground moraine The bowlders south of Badger Creek consist of dull-colored limestones and sandstones of the same character as those found in the till of each valley glacier north of Sun River

North of Badger Creek, near the Little Badger, the character of the drift suddenly changes The dull rocks give place to the red, green, white, black, and mottled quartzites and argillites that are characteristic of the drift from this point north. Diorites and a peculiar conglomerate also appear This conglomerate is formed of siliceous material, varying in size from pebbles an inch in diameter to the finest grains, the entire mass being cemented by silica and hard as quartzite The limit of the two sorts of bowlders is marked approximately by the line where the ice from Badger Creek and the valleys south of it joined the ice which issued from Summit Pass

The influence of the Two Medicine Glacier upon the confluent piedmont glacier is seen by the great extension of the ice to the east in this latitude The terminal moraine of the piedmont glacier just west of Fourhorn Lake suddenly swings to the east and crosses the Piegan-Robare trail about 4 miles south of the Old Stockade. Here its direction is N 40° E, and its edge lies along the foot of a cliff about 250 feet high In some places the ice carried its moraine to within a hundred yards of the foot of the plateau In Glacial time the drainage may have lain between the moraine and the cliff, where it formed coulees, which left small valley trains beyond the edge of the ice These coulees appear to have contained but little water since the ice left. The moraine extending from this point northeastward is sharply defined Shallow basins, which are filled with water in spring and dry in late summer, dot its surface at frequent intervals The country is very rough, and the hummocky topography is common The surface slopes abruptly toward Two Medicine River, but post-Glacial erosion has made but little headway The moraine crosses Two Medicine River 8 miles west of the point where that stream joins the Marias, and 5 miles east of its junction with the Badger On the north side of the river the moraine is finely developed Lakes are numerous, fine outwash plains are common, and valley trains occur at many places along the front of the moraine The valley train of Two Medicine Valley is now covered by later deposits

Within the terminal moraine several recessional moraines are found, one of which lies just east of Kipp A second forms the site of the village of Browning. Between Browning and Kipp there is a flat plain, which at one time was covered by a lake, which persisted until Willow Creek cut through the terminal moraine at Carlow and drained it The third recessional moraine is found near the mountains on the plain just east of the North Fork of Two Medicine River This moraine appears to be much younger than the moraines at Browning and Kipp. The lakes in it are so numerous and so close together and the topography is so sharply defined that it is a trying undertaking to cross it. There has been little erosion of the drift, though the moraine is on a slope, and the average rainfall 30 inches. This moraine corresponds with the better-developed recessional ridge found in Sun River Valley. There are other recessional moraines in the valleys of North and South forks of Two Medicine River. Lower and middle Two Medicine lakes were formed by the deposition of a ridge or ridges of till across the valley, while the upper lake basin was formed by the gouging out of the rock by the ice and by deposition.

The ice in the vicinity of lower Two Medicine Lake was somewhat over 1,500 feet thick. Along South Fork of Two Medicine Valley there are also several recessional moraines. One well-defined ridge with lakes and kettles occurs 7 miles east of Summit station, while another, not so well defined, is found at Summit.

The ice which filled the valleys of the various branches of the Two Medicine River formed the northern part of the piedmont glacier. The northern edge of the ice lay along the south bank of Cutbank Creek from the junction of the two forks to a point north of Blackfoot. The relation existing between the streams and the moraine is such as to suggest a considerable change in drainage.

Cutbank Creek Glacier.—North of the great glacier just described the ice from the valleys of the North and South forks of Cutbank Creek joined and pushed eastward as far as the junction of the two streams The outer moraine is well marked, and is about three-fourths of a mile wide. On ascending the valley of the North Fork, which is the larger of the two tributaries, four recessional moraines are crossed. There is no appreciable difference in the appearance of these moraines, though some of those found within the outer moraine are better developed than the outermost ridge itself

Between the two outer moraines are drumloidal hills, small but perfectly formed. Esker-like ridges were seen in a number of places, but in no case was a ridge over 100 yards in length found. Several of the recessional moraines in this valley show themselves as terraces on the sides of the bluffs, and as spurs from these terraces. The moraine between the spurs, if ever continuous, appears to have been removed by erosion. The valley floor back of the last complete recessional moraine is composed of stratified gravels, in places 40 feet deep. There was not only a great amount of water associated with the glacier, but it was concentrated into a comparatively narrow channel. A gravel train extends for miles down the valley east of the outermost moraine.

The ice which came down North Fork of Cutbank Creek completely filled the valley, though this, at the mouth of the canyon, is more than 1,200 feet deep, but did not spread over the plateau to the north To the south the ice partly covered the ridge between the North and South forks of Cutbank Creek. The slope of the ice from the mouth of the canyon to the terminal moraine was about 200 feet per mile.

Milk River Glacier.—The valley of South Fork of Milk River contained a glacier which was developed in Cutbank Valley and not in Milk Valley itself. South Fork of Milk River heads back on the slopes of Wolf Calf Mountain, and has cut but a very small valley, far too small to give rise to a glacier of such proportions as those of the glacier which deposited moraines along Milk River east as far as Antelope ranch The divide which extends between the headwaters of North Fork of Cutbank Creek and South Fork of Milk River contains a depression through which the ice from the former valley spread into the latter. The moraine formed by this lobe is well defined and extends about 4 miles down the valley.

The country between the Milk River lobe and Milk River Ridge, a notable eminence that runs in a northerly direction from Divide Mountain, is not glaciated. This ridge, which, near the mountains, is more than 1,500 feet high, prevented the ice occupying St. Mary Valley from flowing directly east and diverted it to the north. At the foot of the lower St. Mary Lake the ridge becomes lower and the ice from the St. Mary Valley, crossing it, spread to the east in the valley now occupied by Duck Lake. The area between Duck Lake and South Fork of Milk River is the largest driftless area along the face of the mountains between the forty-ninth parallel and Sun River.

St. Mary River Glacier.—A glacier of great size occupied the valley of St. Mary River and extended northward over the Canadian plains for an unknown distance. The valley of the St. Mary is somewhat typical of the glacial valleys along the east face of the Rockies and for that reason will be described in detail, the data concerning it having been collected for the most part by Mr. Bruce McLeish.

St. Mary River rises at the very foot of the main divide of the Rockies, and after flowing eastward through a most picturesque valley suddenly bends to the north and crosses the forty-ninth parallel in longitude 113° 20′. In two places in its course the river widens into lakes of great beauty. The lower St Mary Lake is about 7 miles in length, the upper about 10 miles Both lakes are narrow, neither exceeding 1½ miles in width. St. Mary River below the lakes is a wide, shallow, rapid stream, which carries in the course of a year an immense volume of water

At the present time there are a number of glaciers found at the headwaters of St. Mary River and its tributaries Some of them, such as the Blackfoot and the Grinnell glaciers, are several square miles in extent. These glaciers may be the last remnants of a great ice mass which formerly filled the basin of the St. Mary River. In following this stream to its source many recessional moraines are found, deposited as the ice retreated up the valley. The last moraines are those now forming at the very edge of the glaciers Some 60 miles intervene between the accumulations of material at the edge of the ice and those deposited when the glacier had its greatest known extension to the northward. The numerous recessional moraines show plainly where the ice rallied in the unequal contest with adverse climatic conditions. The different stages in the retreat are also indicated by a dozen or more terraces which rise in succession on the western slope of Milk River Ridge to a height of 1,000 feet. It was suggested by Culver[a] that these terraces were the result of lake action; but as they slope sharply to the east at about the angle that the surface of the ice should have maintained they are clearly not the work of lake water. The numerous lakes, the sharp ridges, and the great number of bowlders that occur on these terraces indicate glacial action and they fall into the class of morainal terraces. As these terraces are traced eastward it is found that they develop below Duck Lake into terminal and recessional moraines. The ice below Duck Lake turned westward and again crossed Milk River Ridge in a north-south direction and spread east and west in St Mary River Valley. The outer moraine was deposited as a terrace on the

[a] Trans Wis Acad Sci, vol 8, 1891

north slope of the ridge. This terrace descended 1,200 feet in 4 miles, giving the ice an average slope of 300 feet per mile in this valley.

The St. Mary Glacier proper received a number of large tributary ice streams, the largest of which was formed in Swiftcurrent Valley and was but little inferior in size to the St. Mary Glacier. Its thickness where it joined the main ice mass must have been over 1,300 feet. Both the north and south forks of Kennedy Creek contained glaciers, which, however, were smaller than those found in the other valleys. That they were local is shown by the great abundance of limestone bowlders in the drift they deposited and the absence of any other variety of rock. The region occupied by these glaciers was surrounded by the Algonkian limestone.

The valleys of Waterton and Belly rivers and of Lees Creek were also glaciated. Whether the tongues of ice from these valleys joined one another north of the boundary line and formed a piedmont glacier similar to that south of the forty-ninth parallel has not been determined, but from their size such a conclusion seems tenable.

DRIFT OF THE KEEWATIN ICE SHEET.

TERMINAL MORAINE.

During the Glacial period as many as five ice sheets, it is believed, covered the northern part of the United States. The bodies of drift deposited by the successive ice sheets have never been found one above another in a single locailty, but from their interrelations the following order of deposition has been established. (1) Sub-Aftonian, (2) Kansan, (3) Illinoian, (4) Iowan, (5) Wisconsin. Between these drift sheets interglacial deposits occur which indicate modifications of the climate, sometimes very important, between the successive advances of the ice.

In the region just north of the area under consideration Dawson found three drift sheets. The earliest he named the Albertan. The drift sheet resting on the Albertan is correlated with the Kansan and the upper bowlder clay with the Iowan. Between the two upper drift sheets are interglacial deposits which are best developed along Belly River. This classification of Dawson's[a] was merely tentative, and it is a question whether it can be held. The following detailed description of the terminal moraine and the subsequent discussion of the relations of the Keewatin drift to the drift deposited by the mountain glaciers in the various river valleys will throw some light on the age of the various drift sheets found in this region.

During the season of 1901 the moraine of the northeastern ice sheet was traced from the Missouri below Great Falls westward to Choteau, and thence northward to the international boundary line in longitude 112° 20′ From this point it bends westward until it reaches Waterton River, where it turns to the north, following a course nearly parallel to the mountains[b] During the seasons of 1902 and 1903 the moraine was traced from Great Falls to a point east of the Little Rocky Mountains Its course is very irregular, being influenced in great measure by the three groups of mountains and the great valleys between them. The moraine was followed for a distance of about 510 miles, in which distance it exhibits many phases of moraine topography. While to trace it in detail throughout its length and to describe every

[a] Bull Geol Soc America, vol 7, pp 65-66

[b] Map accompanying report on Bow and Belly rivers. Geol. Survey Canada, 1882-1884.

turn and twist and lobe would be a profitless repetition of what is better shown on the map, some of its features deserve special mention.

Doctor Dawson traced and mapped its western limit from a point some hundreds of miles north of Calgary to Waterton River, finding it at different heights and at varying distances from the mountains. The remainder of the drift, comprising the part south and east of the Waterton, will be considered here.

The terminal moraine of the continental ice sheet crosses Belly River about 10 miles north of the line. It consists of a sharp ridge, in front of which there is no outwash or valley train Within the terminal ridge there is a well-defined ground moraine, which, at this point, is 4,163 feet above sea level.[a] Between the Belly and St Mary rivers the edge of the drift is in places attenuated. The ice sheet pushed in from the northeast and surrounded but did not cover an irregular series of foothills which trend in an irregular line between the two rivers. These hills are about 800 feet above St. Mary River. Their tops and slopes for about 400 feet from the summit are covered with quartzite gravels, below which appear the crystalline bowlders characteristic of the drift of the Keewatin ice sheet Small lakes dot the surface and the topography is hummocky and irregular.

From the top of one of these hills at the edge of the drift the country covered by the northeastern drift can easily be distinguished from that covered by the mountain drift by the number of its lakes and ponds. To the north many small bodies of water may be seen, while to the south, nearer the mountains, there are but few The local mountain glaciers were eroding and not depositing, and as a result but few morainal depressions were formed, so that the line of abundant lakes marks approximately the edge of the northeastern drift. The moraine between Belly River and Lees Creek shows well developed kettles.

In the St. Mary basin the ice pushed farther south than on either Belly River or Lees Creek. The moraine crosses the St. Mary just north of the line. One-half mile east of the river it swings south of the forty-ninth parallel, and for a distance of 3 or 4 miles lies in the United States. The boundary monument on the ridge just east of St. Mary River is built of the crystalline bowlders of the moraine. The ridge south of this point was not glaciated, a fact strikingly shown by the contrasting topography of the two portions of the ridge. The region within the moraine at this point might well be called the "lake country." One standing on the northern edge of the ridge just mentioned may count 120 lakes and ponds without stirring from one position. These bodies of water vary in extent from a few square yards to several acres. Many more may exist in this area, though invisible from this position on account of the numerous glacial hills and hummocks. In Willow Creek Coulee, east of the ridge just referred to, the ice pushed as far west as Galbraith's ranch and as far south as Milk River Ridge, which rises 400 to 500 feet above the valley of Willow Creek. At this point the ice did not push south over Milk River Ridge but deposited its moraine along the northern slope. In places the ridge was dissected by pre-Glacial streams, and into these valleys the ice pushed to the very banks of Milk River This happened in McCloud Pass and in the pass farther northeast, known as Whiskey Gap. West of the McCloud-Fort Benton trail the moraine assumes a ridge-like form 60 to 80 feet high and 100 yards wide at the base At this place there are splendid examples

[a] Bench mark Canadian Survey

of kettle configuration. The bowlders are numerous and of the crystalline type, though large bowlders of mountain origin are plentiful This moraine resembles more than any other seen during the summer that formed by the Green Bay lobe, especially the portion of it developed in the vicinity of Baraboo, Wis. Northeast of this point the ice reached the flat top of Milk River Ridge and spread over it to the south, forming a wide moraine characterized by lakes, undrained depressions, and hummocky topography of strong relief, the difference between the tops of the knolls and the bottom of the kettles in many cases being 120 feet At the point where the moraine swings to the top of the ridge it has an altitude of about 4,720 feet, and at a point 6 miles to the west of about 4,300 feet; this gives a slope of 70 feet per mile to the edge of the ice of the northeastern ice sheet

Although the ice reached the summit of Milk River Ridge it did not move for any considerable distance across its plateau-like top. The ridge separated the ice into two parts, one lobe entering St. Mary Valley while the main sheet was forced farther east, causing a great reentrant to be formed If Milk River Ridge had not been present, the ice would undoubtedly have extended much farther into the United States The ice crossed the forty-ninth parallel again in longitude 120° 20′, having a general northwest and southeast direction.

From the boundary line to the Great Northern Railway in the vicinity of Baltic the relief of the moraine is pronounced, the difference in height between the hills and hollows being often 100 feet and sometimes more The edge of the drift north of the railroad is associated with outwash plains and valley trains. In the valleys considered up to this time the slope has been toward the direction from which the ice was moving; that is, the ice moved up the valleys. Under such conditions valley-train deposits were impossible, but here the slope was south and west into the Cutbank Creek and away from the ice edge.

Just north of Baltic the moraine is not so well developed as nearer the Canadian line The lakes are shallower, and the topography more of the swell and saucer type. At Baltic the moraine is interrupted; the gap continuing to a point south of Two Medicine River. In this interval bowlders and till are present, but the edge of the drift is not in the form of a ridge. Instead it is spread out in a great sheet, with occasionally a very shallow basin and rolling topography It is entirely possible that back from the edge of this drift sheet a ridged moraine will be found, as is the case on the banks of the Missouri. The edge of the drift crosses Cutbank Creek 5 miles below the railroad bridge at Cutbank and Two Medicine River about 7 miles west of its mouth. Along Cutbank Creek and Two Medicine River bowlders not associated with till line both banks of these streams and their tributary coulees. The till once present has been removed by the action of wind and wash.

The moraine south of Two Medicine River consists of a broad, undulating till sheet which is much more moraine-like than that to the north of the river, but far inferior to that north of the railroad. A well-defined moraine of pronounced topography is not found again until the Pondera basin is reached, this basin being a large reentrant in the plateau between Dry Fork of Marias and Muddy rivers. Between the ridges facing the north and south sides of the basin the ice is pushed to the west, and the moraine becomes once more well defined The lakes are as numerous as in the moraine near the forty-ninth parallel, while the general roughness of the surface is even more pronounced. At its greatest westward extension the ice is pushed sharply against the bluff which limits the basin on the west, at its southern edge it did not reach the ridge but left its material piled in the form of a high moraine one-fourth of a mile north. The drainage during the time the ice was present was between the moraine and the plateau to the southeast along the edge of the ice. The habit of the ice of pushing for miles into a valley and of not occupying the ridges, though they are but 100 to 150 feet above the level of the moraines, is characteristic. In the Pondera basin the ice extended for 5 miles between ridges 150 feet high, but not once in the distance did it reach their tops. Reasoning from these data the slope of the surface could not have been more than 30 feet per mile. The tendency also of the edge of the ice to move around buttes, leaving deposits on all their sides but not covering their tops, is also characteristic.

Five miles east of the western edge of this basin the ice reached the top of the ridge north of North Fork of Muddy River, and extended across it in a general north-south direction. While not so well defined as the edge of the drift in the Pondera basin, the moraine on the higher level is distinct, consisting of a broad, flat ridge with many shallow depressions containing water. At the southern edge of the flat the moraine turns abruptly to the southwest and runs along the north bank of the Muddy. In this valley is seen one of the best examples in Montana of a striking terminal moraine. There is no well-marked terminal ridge, but the valley north of the creek is one great expanse of hummocks and kettles. The topography is so rough that wagons could cross this section of the country only with the greatest difficulty, while without a compass one not familiar with the region might easily be lost A mile south of the Kropps ranch, in T. 26, R. 3 W., the ice edge turned abruptly toward the west and filled the valleys of the Muddy and the Teton with a drift sheet of considerable thickness. The western edge of the ice lay across the valley a few miles west of the one hundred and twelfth meridian, and crossed Teton River a few miles east of Choteau. Here its farther southern progress was checked by the Teton Ridge, which is about 500 feet high and extends in a general northeast-southwest direction, and which held in the ice as far east as the Great Falls and Canada Railroad. The ice crossed Teton River in T 24, R. 3 E., and on the slope south of that river deposited morainic material to the height of 220 feet. Above this level, which is the upper limit of the crystalline bowlders, and on the top and the slope of Teton River Ridge there is gravel composed of limestone, sandstone, and quartzite pebbles. These gravels are not glaciated, and belong to the quartzite gravel formation.

Eight miles due south of Brighton there is a break in Teton Ridge, through which the Great Falls and Canada Railroad passes At this point the ice pushed through and for the first time deposited material on the south slope of this ridge. Not only did it push into the pass, but it also covered the ridge east of the railroad, a fact easily seen by the difference in topography between the east and west portions of the ridge.

The character of the moraine changes abruptly after it passes over Teton Ridge. There is no longer a well-defined ridge-like edge, but more often a low, broad rise, usually too slight to be noticeable. The drift in the pre-Glacial valleys south of the Missouri and east of Great Falls is 100 to 200 feet thick. Near its edge the drift is usually thin, but along Belt Creek, in sec. 30, T. 21, R. 7, it is 250 feet thick. In many places in the valley of Belt Creek and in the valleys of the neighboring streams there are cuttings of over 100 feet into the drift which do not reach the underlying sandstone.

The moraine swings southeastward from Great Falls to a point north of Belt. Here the Highwood Mountains caused the ice to turn to the north, hence the moraine from Belt Creek runs in that direction for 15 miles Turning then to the east, it crosses both Belt and Highwood creeks and follows in general the north bank of the Sag to Arrow River In this part of its course the moraine, where found at all, is low, broad, and of the swell-and-saucer variety, with shallow lakes The drift is in most places less than 30 feet deep. The same type of moraine continues as it swings along the west bank of the Arrow, but for some distance east of the Missouri there is no ridge of any kind and only here and there a thin ground moraine

On the southwest side of the Bearpaws, a bowldery ridge with many lakes is again encountered. From this place the moraine swings around the Bearpaws, nearly encircling them (Pl. IV, *A*) and exhibiting at every point a moraine as well defined as that seen along the north slope of Teton Ridge. On the northern slope of the mountains the ice pushed into the foothills and reached an altitude of 4,250 feet. Here, also, the edge of the ice developed many irregularities, due to the great number of valleys. This is shown by the irregular contour of the moraine.

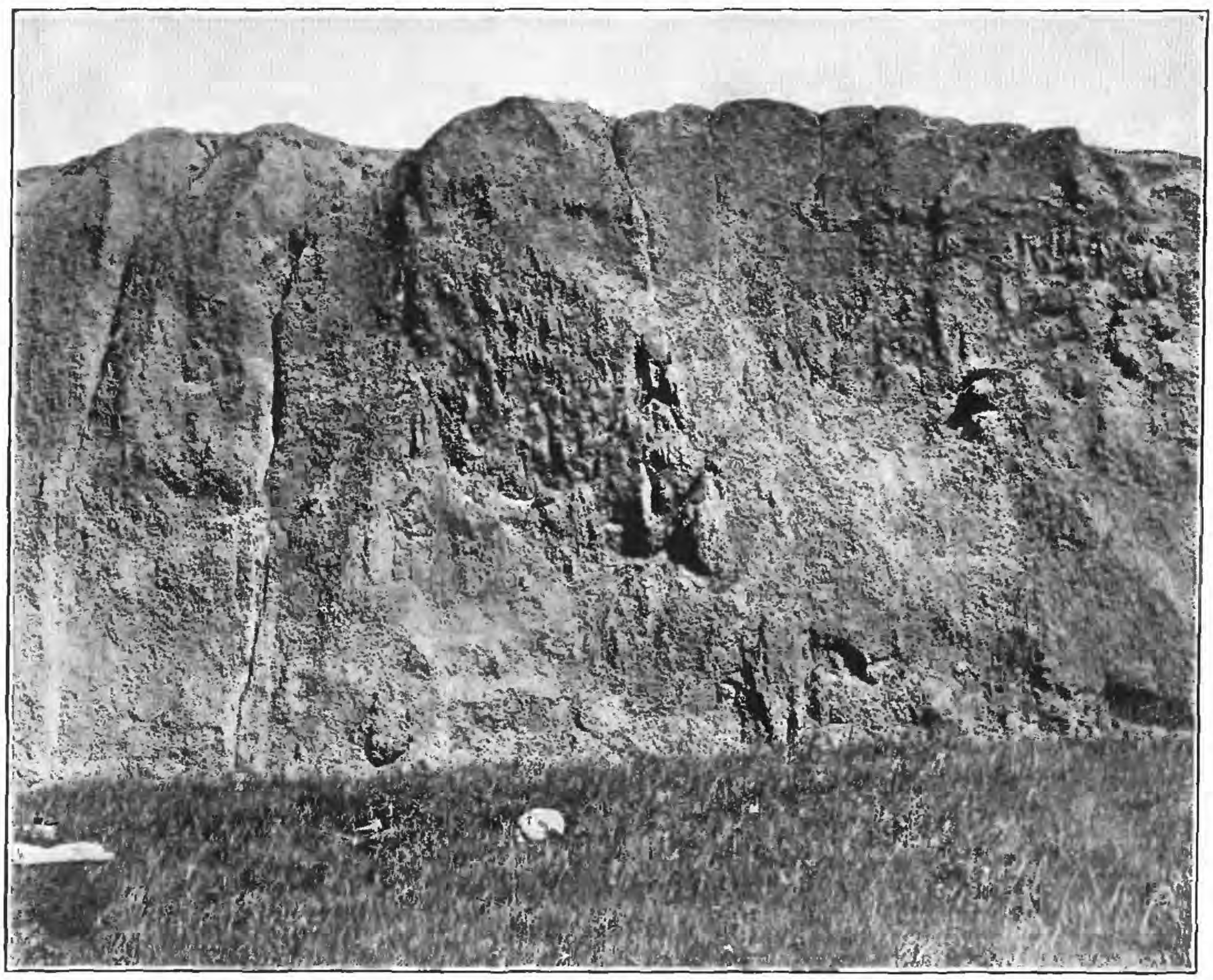
A lobe of ice pushed south between the Bearpaws and the Little Rockies into the valley of Little Rocky Fork Creek The moraine north of the latter group of mountains does not approach as close to the foothills as it does in the case of the Bearpaws. It lies about 7 miles north of St Paul's Mission and runs directly east until T 26, R. 26 is reached, where it turns abruptly southeast and continues in that general direction until all morainic form is lost in the breaks of the Missouri South of the Missouri, in the valley of the Big Dry, the edge of the drift sheet was traced for 60 miles, but no moraine was found

LATER MORAINES

On the east bank of the Missouri south of Floweree a later moraine, rather well defined, may be made out In front of the moraine the relation of the stratified drift (till and lacustrine clay) is so complex as to suggest an oscillatory ice edge and much water.

North of the Great Northern Railway and near the divide between Teton and Missouri rivers occurs a second later moraine, which exhibits some unusual features. The edge of the ice advanced into pre-Glacial valleys leading north to the Teton and filled them with drift The post-Glacial drainage has established itself along these old drainage lines, and the moraine appears to be the divide between the Teton and the Missouri, just as the ridge which it now caps was the divide between the pre-Glacial Teton and the pre-Glacial Missouri. Along this ridge the moraine contains many soft and friable sandstone erratics, which were doubtless plucked from Teton Ridge, lying to the north Bowlders of local origin are not common in the drift The soft sandstone over which the ice moved during the last hundred miles of its course yielded but little material, and even this is not so sandy as might be expected. From all indications the ice sheet was not only

A. EAGLE BUTTE NEARLY ENCIRCLED BY MORAINE OF NORTHEASTERN ICE SHEET.



B. TILL SECTION 100 FEET HIGH ON MUDDY CREEK.

Note tne absence of bowlders.

incapable of any considerable amount of erosion at its edge, but it deposited material over such formations as the quartzite gravels without disturbing them

This moraine may be traced, with few breaks, directly across the country from Teton Ridge to the Bearpaws It is better developed than the terminal moraine, which, while having the essential elements of the kettle moraine, often shows them in a feeble state of development South of Tunis the moraine is between 3 and 4 miles wide and is covered with lakes and lake basins, some of which extend 50 feet below the general level. This moraine is again seen, though not so clearly defined, along the north bank of the Missouri, near the mouth of the Teton Between the headwaters of Big and Little Sandy creeks there is another excellent example of morainic topography, continuing to the foot of the west slope of the Bearpaws. North on the ground moraine there are occasionally ridges, never more than a few miles in length These were doubtless caused by the halting of the ice for a short period, but they are not sufficiently continuous to be mapped as moraines.

CHARACTER OF THE DRIFT.

The material carried by the ice was of four kinds—crystalline erratics, small pebbles of mountain origin, sedimentary rocks derived from the plains over which the ice passed, and a matrix composed of sand and clay The crystalline erratics are of such variety as to furnish specimens of the whole rock series In a small area, not over 5 square yards in extent, the following rocks were found Limestone, sandstone, shale, coal, granites (both fine and coarse grained, and with different percentages of quartz and feldspar), syenites, diorites, basalts, and hornblende, mica, and garnetiferous schist, and all gradations between these and gneissic rocks

The granite and the syenitic rocks predominate Basalts and rocks containing a large proportion of the ferromagnesian minerals are not so common. There seems to be very little change in the variety and the nature of these bowlders throughout the length of the moraine. Limestone is more common in the northern part and sandstone occurs more frequently in the southern part. The character of the crystalline bowlders remains the same. The ice must have passed over a wide extent of country, for the nearest outcrop of crystalline rock is 700 miles distant.

To these rocks may be added those which are of mountain origin and which make up from 5 to 25 per cent of the bowlders of the drift. Originally they belonged to the quartzite-gravel formation, and were picked up by the ice from the northeast and incorporated in its drift.

The crystalline bowlders are common on the surface of the drift, occasionally occurring in such numbers as to cover the ground. In some post-Glacial cuts, bowlders from 1 to 4 feet in diameter are accumulated in the bottom of the channel to a depth of 5 to 10 feet. In the body of the drift a large crystalline bowlder is seldom seen. Small crystalline fragments and quartzite pebbles are found, but even these are uncommon. The explanation of the position of these bowlders on the surface of the drift has been given by Prof. R. D. Salisbury.[a]

The great body of the drift is a hard, sandy clay, which as a rule is unstratified and stands in vertical faces where trenched by streams (Pl. IV, *B*). Its thickness

[a] Jour Geology, vol 8, pp 426–432

is variable. On Belly River an exposure of till 120 feet thick was measured; near Baltic, north of the railroad, post-Glacial drainage has cut 100 feet into the drift without reaching the underlying sandstone, on Two Medicine River exposures 50 to 75 feet thick are seen, and on the Teton drift banks 150 feet high border the river. In the ground-moraine belt the drift is not only thin, but in places is entirely absent. Between the moraine and the Sweetgrass Hills the drift is frequently wanting.

ICE SURFACE

Height —The edge of the ice stood at various levels during the time of its greatest extent, a few of the more prominent elevations being as follows, aneroid determination:

Approximate height of edge of ice

	Feet		Feet
Milk River Ridge	4,720	Bearpaw Mountains	4,250
Baltic	3,900	Muddy Creek	3,500
Ridge south of Baltic	4,000	Teton Ridge	3,800
Two Medicine River	3,800	Highwood Mountains	4,200

Slope.—As has been noticed, the slope of the surface of the Keewatin ice sheet was not great. In the Pondera basin the slope was about 30 feet to the mile; on Teton Ridge the slope, much less exactly determined by the slope of the moraine, was about 40 feet per mile, and on the slope of Milk River Ridge it was 50 feet per mile. The most satisfactory determination was made between the Sweetgrass Hills and the edge of the ice to the west. A careful examination of these buttes showed conclusively that they were not covered by the ice sheet, but that they stood as great nunataks about 2,000 feet above its general level. Not only were they not covered by the ice of the Keewatin ice sheet, but there is no evidence that they were locally glaciated. The ice from the northeast, when it reached them, was near the end of its long journey, and was a depositing rather than an active body. On the west, north, and east sides of West Butte a well-defined terminal moraine is banked against the slope. On the south side there is no such terminal moraine, and for some distance south the country is driftless The ice, divided by the butte, did not come together till it reached a point about 2 miles south of its foot. The moraines left by these two ice edges as they circled the butte and pushed south over the plain are well defined. The moraine on the west slope of the butte is 1,200 feet above the plain; along Milk River on the north side it is 1,500 feet, and on the southeast side it is 1,300 feet. This, then, would make the average thickness of the ice about 25 miles from its edge. In this distance the slope of the upper surface of the ice averaged about 50 feet per mile On the southeast side of West Butte the slope of the ice, as determined by the slope of the moraine, was 70 feet per mile. Thus it is seen that along the edge of the ice the slope was low, due in great measure to the level plain over which the ice traveled.

DRAINAGE.

LAKES

Character of the lakes.—The relation of the ice to the river valleys was such that the formation of lakes in front of the ice was inevitable. These lakes may be divided into two classes—those dependent on the ice as a barrier and those dependent on a moraine as a barrier. Those of the first class existed while the ice was present and gradually lowered as the edge melted back. Those of the second class were more enduring bodies of water, which were formed in front of the terminal moraine. Yet even these were short lived, for the swift mountain streams soon trenched the moraine and drained the lakes. The former existence of the lakes is not made known by degradational phenomena but by aggregational The extent of the first and more extensive lakes is shown by the presence of crystalline erratics deposited by floating ice The limits of the more restricted lakes are marked by the deposition of a peculiar lacustrine clay in and on which there are but few bowlders.

Location of the lakes.—Nearly every river valley in the area studied contained a body of water, and in some cases this water extended over the divides between the rivers and formed long, narrow lakes in front of the ice. The water forming these lakes was that which gathered at the margin of the ice as the result of the damming of the mountain streams and the melting of the ice itself There were probably four such lakes; the first in the basin of the St. Mary River, the second in that of Two Medicine River, the third in the basin of the Teton, and the fourth, the largest of all, in the basin of the Missouri.

Lake in St. Mary Valley—The lake in St. Mary River Valley reached a point about 8 miles south of the forty-ninth parallel The edge of the crystalline bowlder area, which marks approximately the extent of the old lake, is found along the slope of Milk River Ridge and on both sides of the ridge which runs north of St. Mary River. The southern limit of these erratics crosses St. Mary River just north of the mouth of Kennedys Creek, but it is not at all well defined. A few scattered crystalline bowlders, most of them small, lie along the banks of the river, but south of the creek even these fail The extent of the lake was doubtless somewhat greater than the bowlders indicate, for these may have been covered by later deposits or washed away by the river or may have failed to reach the extreme limit of the lake.

Lake in Two Medicine River Valley—From the forty-ninth parallel to the vicinity of Cutbank Creek no lake existed along the edge of the ice. The slope of the land here is to the southeast, and the waters formed by the melting ice flowed to the south in many channels instead of collecting into a lake. These streams were tributary to a lake that existed in the valleys of Two Medicine River and Cutbank Creek, a considerable portion of this water finding its way through the Rocky Coulee. Granite and other crystalline bowlders are found along the present bottom of the coulee, though not to such an extent as might be expected The lake in the basin of Two Medicine River was of irregular shape—one great arm extended up the present Cutbank Valley, another into the flat coulee several miles south of the railroad, and a third into Two Medicine Valley as far as Robare. This last bay was much larger than any of the others along the west side of the lake. Into the valley of the Dupuyer Creek the lake advanced as far west as sec. 31, T. 28, R. 6 W., and a small arm extended up the valley of Dry Fork of Marias River.

Lake in Teton River basin.—The next lake to the south was in the basin of the Teton The great plateau between the Dry Fork of the Marias and Muddy Creek was not covered by water and served as a divide between Two Medicine and Teton lakes The western edge of Teton Lake was near Bynum and Choteau, in Muddy and Teton valleys, respectively, and its southern edge was against Teton Ridge.

Lake in Missouri River Valley.—Between the Teton and the Missouri River basins a lake of large size existed, its waters extending into the valleys of Missouri and Sun rivers and covering the lowland between the two. Square and Round buttes were islands situated at the extreme western edge of the lake; around them, as around all the other hills and buttes in the neighborhood, are found crystalline bowlders at approximately the same elevation. Some of these are large; the exposed part of one found near Ulm on the Ulm-Great Falls road measured 8 by 4 by 4 feet.

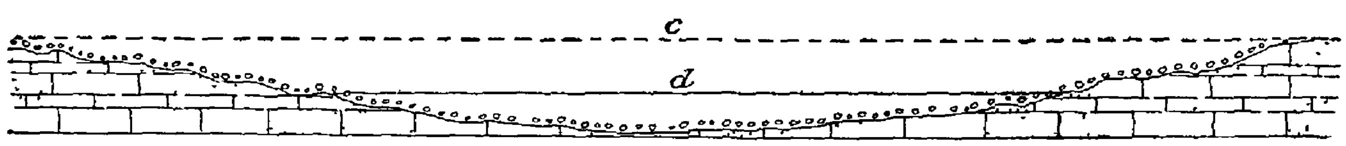


FIG. 3.—Ideal cross section showing relations between the two lake deposits in the Missouri Valley west of Great Falls. c, Level of the more extended lake; d, level of the more restricted lake.

As will be seen from the topographic map of the Great Falls and Fort Benton areas (Pl. V), this lake had a very irregular extent. The level of the water during the maximum stage of lake development was between the 3,800 and 3,900 foot contour lines. At this level bowlders characteristic only of the northeastern drift are found, few in numbers in the smaller and more distant coulees, but numerous in the valleys in which floating ice could easily enter and be carried about by the wind and currents. The waters of this lake extended for a considerable distance up both Smith and Missouri rivers, but the upper valleys of the two streams are canyon-like, with high walls that afford no resting place for bowlders even if the ice could have made headway against the swift current of the mountain streams.

The bowlders are not found on all parts of the area mapped as covered by water, for they do not appear on the flood plain that extends along both sides of

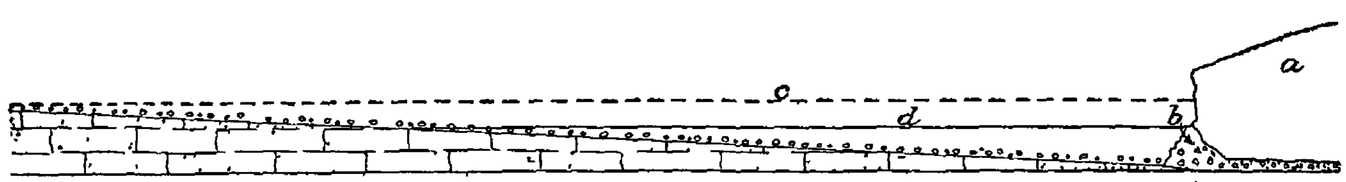


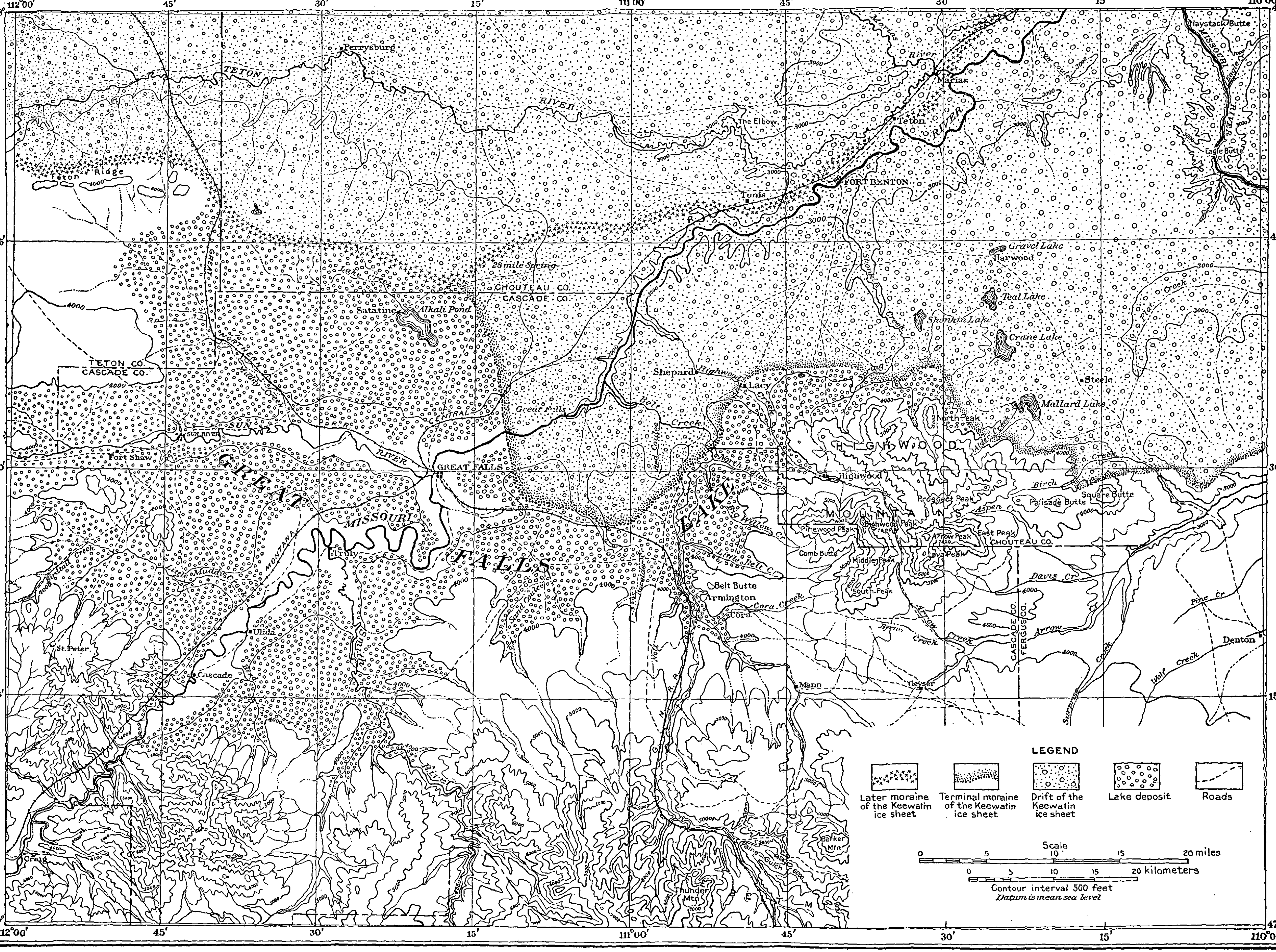
FIG. 4.—Ideal longitudinal section showing relation of the two lake deposits to the drift dam and the ice dam. a, Ice edge; b, moraine; c, level of the more extended lake; d, level of the restricted lake.

the Missouri. This plain was formed when the waters were held back by the morainic dam, forming a restricted lake, the area of which is essentially that along the Missouri and its tributaries below the 3,400-foot contour line.[a]

The relations between the deposits of the two lakes are shown in figs. 3 and 4.

The deposits of the more restricted lake consist of a finely laminated clay, which when dry is hard and cleaves like shale. When wet it becomes soft and pliable and would make an excellent molding clay. Interstratified with the clay are smal crystalline pebbles one-fourth to one-half inch in thickness. They usually consist of quartz or feldspar crystals, or of small fragments containing several minerals, showing that the rock from which they were derived was granite,

[a] Shown on Pl. V by unshaded area along Sun and Missouri rivers.



MAP SHOWING AREA COVERED BY THE GREAT FALLS LAKE AND THE POSITION OF THE TERMINAL AND LATER MORAINES.

syenite, or basalt. Very seldom a large crystalline bowlder is found embedded in the clay. These bowlders and pebbles connect the formation with the Keewatin ice sheet. This formation is found in each of the old lake basins, though in St. Mary Valley but one section of the clay was seen. In Two Medicine Valley exposures of it 10 to 20 feet thick are common. The best development of this formation is found in the Teton River basin, this being due in part to the relation that the terminal moraine bears to the underlying topography Fig. 5 shows a section of the moraine, the clay, and the underlying formations

The relations of the various formations shown in the above diagram have given rise to the conditions for artesian wells. The limestone gravels from the mountains washed over the old pre-Glacial surface collect the water and carry it under the clay, which acts as an impervious cover layer. At *a*, fig. 5, a well 80 feet deep has been drilled, from which the water comes out of an 8-inch pipe with considerable force At *b*, fig. 5, nearer the mountains, the limestone gravel is reached by an artesian well 60 feet deep, while at *c* the wells are between 10 and 20 feet in depth. The water obtained is used for irrigation.

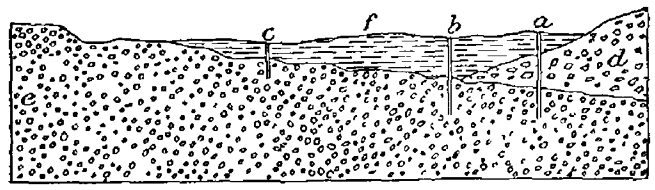


FIG 5.—Section showing the relation of lacustrine clay to gravels and till of northeastern ice sheet *d*, Terminal moraine of the Keewatin ice sheet, *e*, gravels washed out from the mountains, *f*, lacustrine clay, *a*, *b*, *c*, artesian wells

Along the Missouri the clay is found about 10 miles west of Great Falls near Ulm. Here it is about 40 feet thick and contains the small crystalline pebbles characteristic of it farther north.

The clay is not always found lying in front of the moraine In some places the lacustrine deposit lies upon the moraine itself, and in some places under the till. The edge of the ice appears to have oscillated, retreating first and allowing the deposition of lake sediment and then advancing and covering the deposits of the lake (fig. 6).

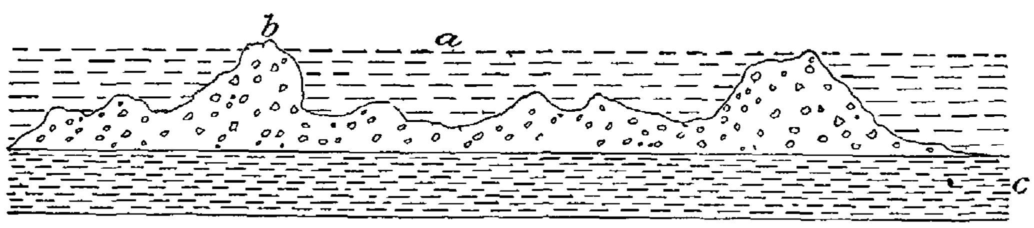


FIG. 6.—Section on Belt Creek, showing the moraine covered by lake deposit *a*, Lake deposit, 50 feet, *b*, drift, 70 feet; *c*, shale, 80 feet

The drainage of the lakes north of the Teton Ridge was eastward under the ice. The waters of these lakes could not have escaped into the lake that existed in the valley of the Missouri except by some subglacial passage The latter lake was drained by an outlet through the Sag into the Arrow and to the eastward, following tributaries of the streams that flowed north. It was through the erosive action of the waters that poured out from this lake that the Sag was formed and the present course of the Missouri determined.

RIVERS.

EFFECT OF MOUNTAIN GLACIERS.

The ice deploying from the mountain valleys had but little effect upon the pre-Glacial courses of the more important streams. Small valleys that were tributary to the main watercourses were blotted out, and after the retreat of the ice the change in topography forced the drainage ways to follow new courses In some parts of its upper course Cutbank Creek was crowded northward by the ice, and its valley was partly filled with valley trains, in which the present streams have cut their channels, though the cutting has in no case been great.

EFFECT OF NORTHEASTERN ICE SHEET.

In contrast to the effect of mountain glaciation the coming of the ice sheet from the northeast changed the character of the drainage markedly. Every river flowing north and east from the mountains was obstructed by the drift, had its waters expanded into a lake, and then, cutting through the morainic dam, found itself superimposed, perhaps some distance from its old bed, upon a body of drift.

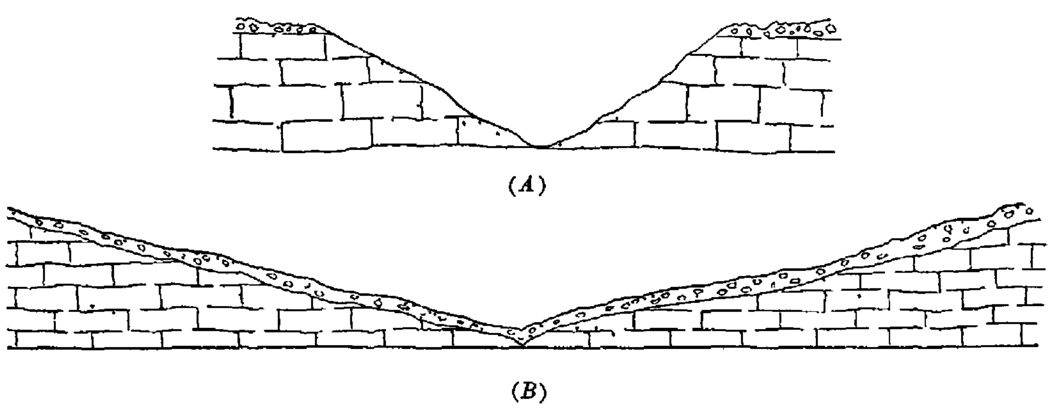


FIG. 7.—Relative size of post-Glacial and pre-Glacial valleys of Two Medicine River A, Post-Glacial valley of Two Medicine River, B, pre-Glacial valley of Two Medicine River In "A" the bluffs are covered with till from the Keewatin Glacier, in "B" the valley itself is covered by a deposit of till laid down by the Summit Glacier

In most cases the displacement of the stream channel was not great, the post-Glacial streams generally occupying the same valley, though not the same channel.

St. Mary River.—About a mile north of the international boundary line St. Mary River was superimposed upon a sandstone ledge, its old channel being filled with drift. At this place it has cut a narrow gorge over 100 feet deep. The post-Glacial cutting in the drift near this place has been from 20 to 60 feet In a number of other places along St. Mary and Belly rivers the streams have been forced to cut into sandstone. In no case near the boundary line was the change in drainage more than a slight shifting of the stream channel.

Milk River.—In pre-Glacial time Milk River flowed in a deep, wide valley, and for this reason was little affected by the drift in the area studied.

Two Medicine River.—West of the place where it is crossed by the terminal moraine of the northeastern ice sheet, Two Medicine River flows in a broad U-shaped valley, which was once filled by the ice from Summit Pass. East of the moraine the stream flows in a post-Glacial valley. It is no longer broad, with gently sloping sides, but is narrow and gorge-like (fig 7). The walls are nearly vertical sandstone bluffs capped by northeastern drift The pre-Glacial course of the Two Medicine appears to have entered that of the Marias 5 miles below its mouth in post-Glacial time.

The following cross sections show the width of the Two Medicine at its mouth compared with the cross sections of the valley of the Cutbank above and that of the Marias below (fig. 8). The fact that much more water flows through the valley of the Two Medicine than through that of the Cutbank and that this water has a greater velocity renders the difference in width much more striking Fig. 7 shows the width of the Two Medicine above and below the terminal moraine.

Birch Creek.—North of the big bend Birch Creek flows between sandstone walls capped with drift. In some sections of the drift the capping is 80 feet in thickness, but usually 10 to 40 feet. The pre-Glacial channel of Birch Creek was not determined. It doubtless led to the Two Medicine or the Marias much farther east than at present.

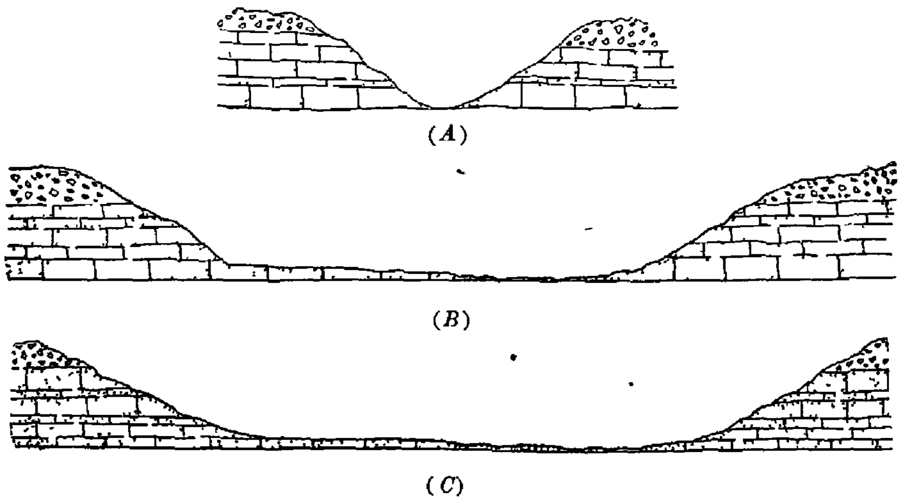


FIG 8.—Cross sections showing relative size of Two Medicine, Cutbank Creek, and Marias valleys. *A*, Two Medicine Valley just above its mouth, *B*, Cutbank Valley above its mouth, *C*, Marias Valley below junction of the Cutbank and the Two Medicine

Muddy Creek.—East of the terminal moraine of the Keewatin ice sheet the valley of Muddy Creek is post-Glacial This part of its valley is 80 to 100 feet deep. Locally the stream has cut through the drift into the sandstone beneath The old pre-Glacial valley of Muddy Creek is completely hidden, but the general topography of the region shows that its course was not very different from that of the present stream.

Teton River.—In Teton Valley a similar condition exists, and the present channel follows somewhat closely that of the pre-Glacial stream. The Teton has in places cut a valley 150 feet deep in the drift Lower in its course the Teton has been subjected to more important changes. North of Fort Benton, above the elbow (Pl. III), the Teton flows in a drift-filled valley. The present stream has cut into the modified pre-Glacial valley from 200 to 250 feet. At the north end of the elbow the river turns suddenly to the south and, after flowing for 2 miles in a narrow valley between rock walls, again finds itself in the drift-filled valley of the pre-Glacial Missouri Here post-Glacial erosion has formed a valley 200 feet deep and a mile wide, similar to that above the elbow. The Teton appears to have been forced into the valley of the Missouri by the drift filling the eastern end of its old channel This extends from the north end of the elbow through the valley now occupied by Sheep Creek into the Marias. East of Fort Benton the Great Northern Railway has tunneled through the ridge between the Teton and the Missouri. Here the two streams are but half a mile apart, and are separated by a divide 200 feet high, at least 120 feet of which is drift

Other streams in the area studied were turned from their pre-Glacial courses by the ice, but as in each case the change was closely associated with the change in the Missouri, they will be considered in connection with the pre-Glacial and post-Glacial history of that stream

Missouri River.—Of all streams in northern Montana, the Missouri was the one most affected by the ice sheet, to which is doubtless due the fact that it is a tributary of the Mississippi and not of the Saskatchewan or the Red River of the North.

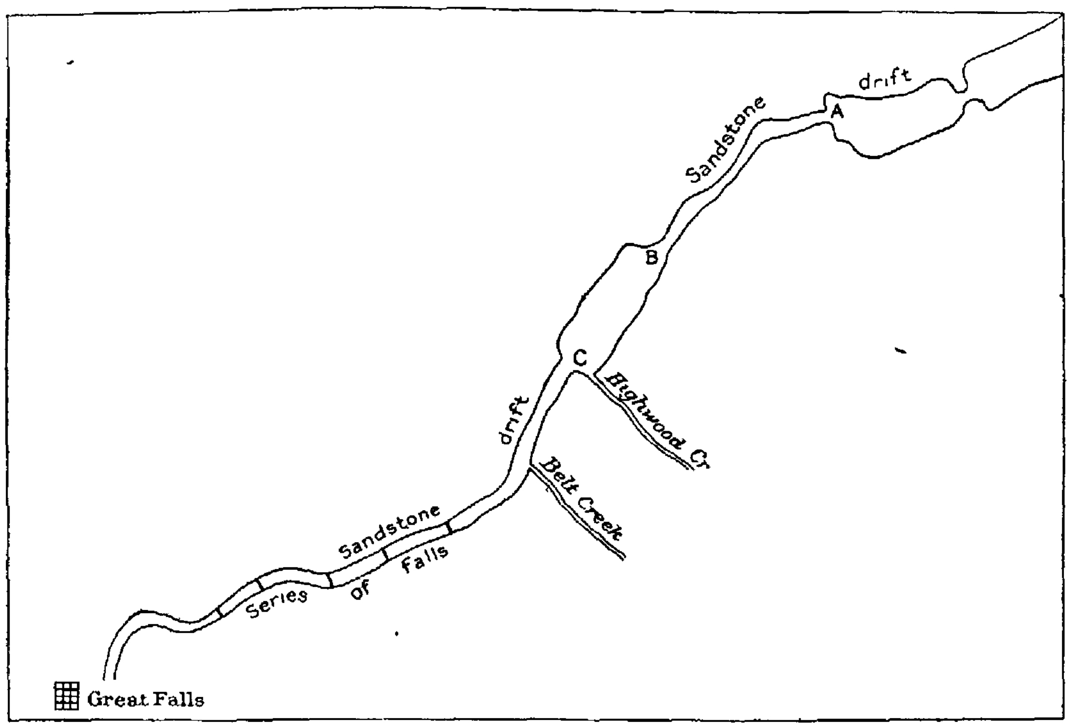
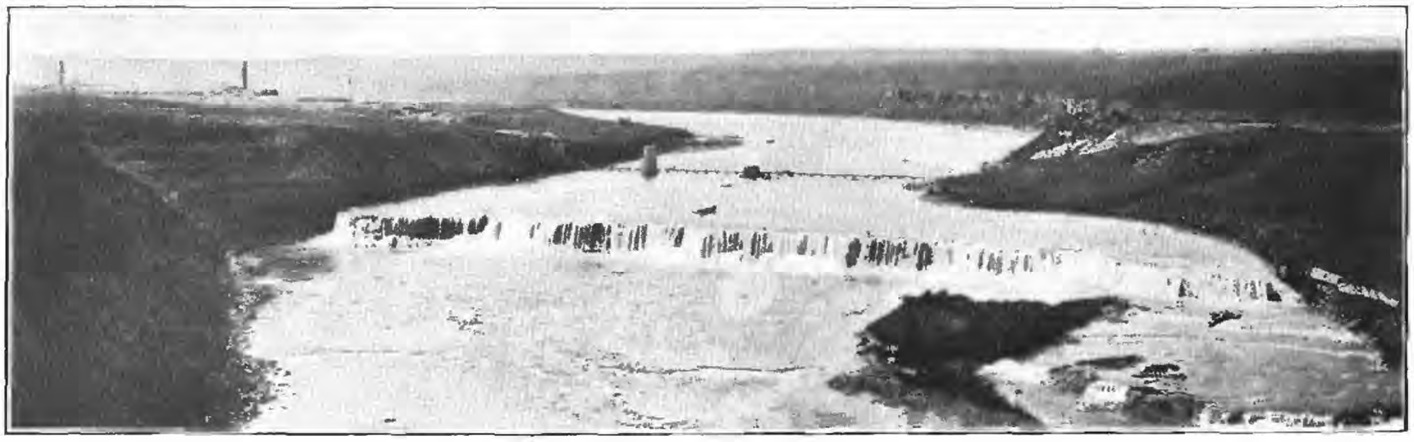


FIG 9 —Valley of the Missouri, showing post-Glacial cutting in sandstone and drift

When the old channel of the Missouri became filled with drift, the river was turned from its former course and forced to find a new channel for itself south of the edge of the ice sheet In some places the post-Glacial stream followed the old valley for some distance until at last, turned aside by some barrier, it was forced to follow a tributary stream across a col into the valley of another river The changes in the course of the Missouri have been varied and are given in detail.

The river rises in the extreme southwestern portion of the State and flows northeastward. For the first 300 miles it is confined by mountains, but after passing between the main range of the Rockies and the Little Belt Mountains it escapes to the plain From this place to Great Falls the river meanders over a wide flood plain, flowing 75 miles with a fall of but 85 feet At Great Falls an abrupt change in the character of the stream takes place. Leaving the plain it flows through a canyon with high sandstone walls and falls 512 feet in 12 miles.



A. FALLS OF THE MISSOURI

B. ONE OF THE FALLS OF THE MISSOURI, SHOWING AMOUNT OF POST-GLACIAL EROSION.

In this part of its course the river runs in a sandstone valley, in which cataracts have developed (Pl VI, *A*, *B*) because of the harder ferruginous layers found in it The unequal rate at which the falls have retreated is due to the varying hardness of these layers It is not known exactly at what point the falls originated, but it was doubtless where the superimposed Missouri found its way over the side of an old valley wall, either into its own pre-Glacial channel or into that of one of its tributaries This, so far as now known, may have happened at any one of a number of places. At a point near the mouth of Belt Creek the valley suddenly broadens and at the same time turns abruptly to the north (Pl VII, *A*) Here the river flows through an old drift-filled pre-Glacial valley (fig 9). The post-Glacial river does not everywhere flow in the old channel but crosses it at all angles. This unconformity of the old channel to the present one is shown in the sections forming fig 10

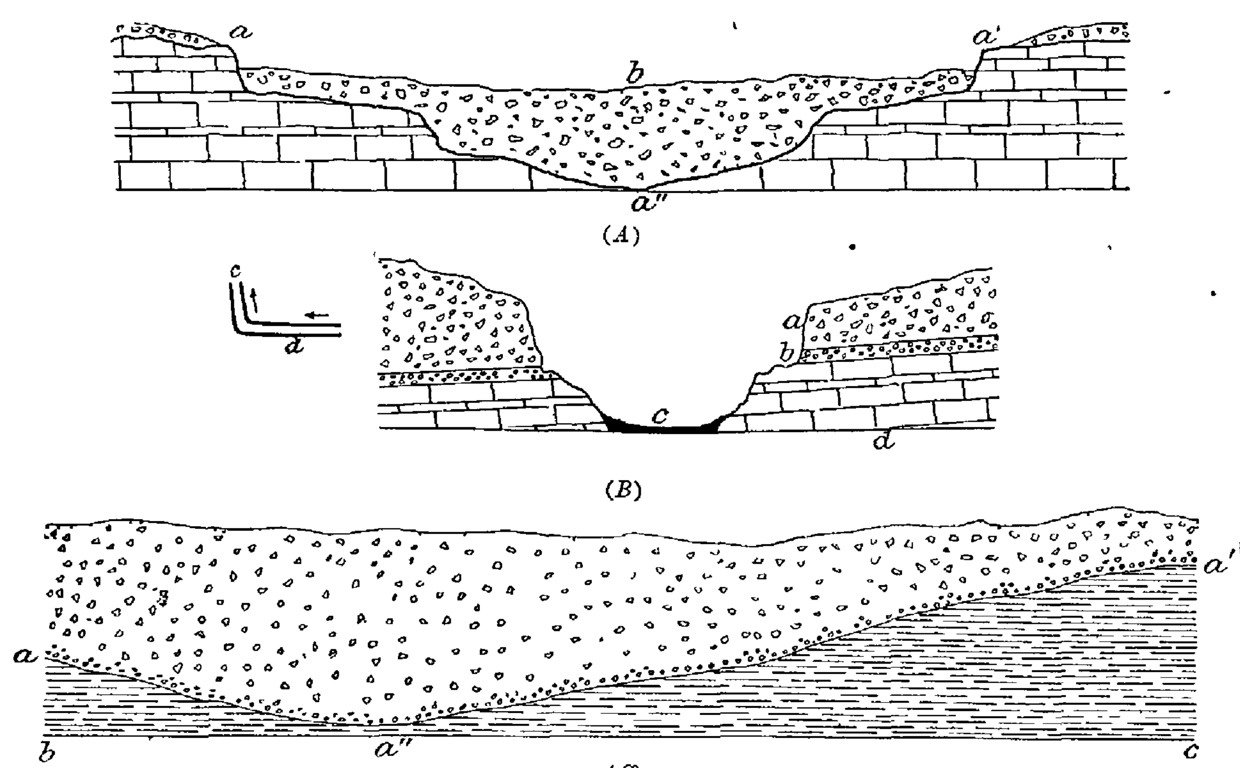


FIG 10—Sections showing the pre-Glacial valley of the Missouri *A*, Old valley of the Missouri, 12 miles wide, *a* and *a'* represent the exposed sandstone bluffs of the pre-Glacial valley, *b* is the drift filling *B*, Slope of the old valley, *b* is a layer of old river gravels and *a* the drift deposit, the small diagram to the left shows the relation of the river and the exposures Through these deposits the post-Glacial stream has cut into the underlying rock *C*, Present course of the Missouri, *b*, *a''*, *c*, cutting across the pre-Glacial channel at a right angle

At the big bend of the Missouri, at the mouth of Little Sandy Creek, there is another abrupt change in the character and direction of the valley. The river, which has been flowing northeastward, turns abruptly to the southeast. The valley narrows, becomes more canyon-like, and loses its drift walls. The bench on both sides of the stream slopes to the north while the river flows south At the mouth of Arrow River there is a sudden turn to the east, though the character of the valley does not change. The river continues to flow between high rock walls, with little bottom land, and in a valley which narrows and widens without apparent cause. From the mouth of the Musselshell to that of Milk River the valley is narrow, with walls 600 to 1,000 feet high. Beyond Milk River it takes on the broad, shallow character of that stream and becomes wide, the banks being very low At Williston, N Dak, it appears to have been turned to the south by a great moraine (fig 14, p. 39), which crosses the Great Northern tracks west of Tioca. Beyond this place the valley is much deeper and narrower

It is evident that the river near Great Falls is not in its old valley Between the meandering stream west of the town and the river in its great drift-filled valley east of the mouth of the Highwood, extends a canyon-like valley with a series of rapids and falls. Well borings along the river southwest of the town show that the stream is now flowing at the top of a flood plain about 270 feet above the bottom of the pre-Glacial valley. A well at Ulm, drilled by the Great Northern Railway Company about 1888, went down some 270 feet through sand and clay into a gravel layer.[a] A well located on the Odell ranch on the Missouri south of Great Falls went through the following material

Record of well on Missouri River south of Great Falls, Mont

	Feet		Feet
Soil	20	Gravel	7
Quicksand	125		
Clay	60		212

These two well sections show conclusively that the valley of the Missouri was formerly much deeper and that it has been filled with deposit. The problem that presented itself in the field was to find the old channel extending from the valley above the falls to the drift-filled valley below them This pre-Glacial valley must have had the general altitude of 3,050 feet, or 270 feet below the present surface, and must reenter the post-Glacial valley of the Missouri at an elevation sufficiently below this level to allow for the fall of the river Such a valley is found in what is known as Sand Coulee, now occupied by a small mountain stream.

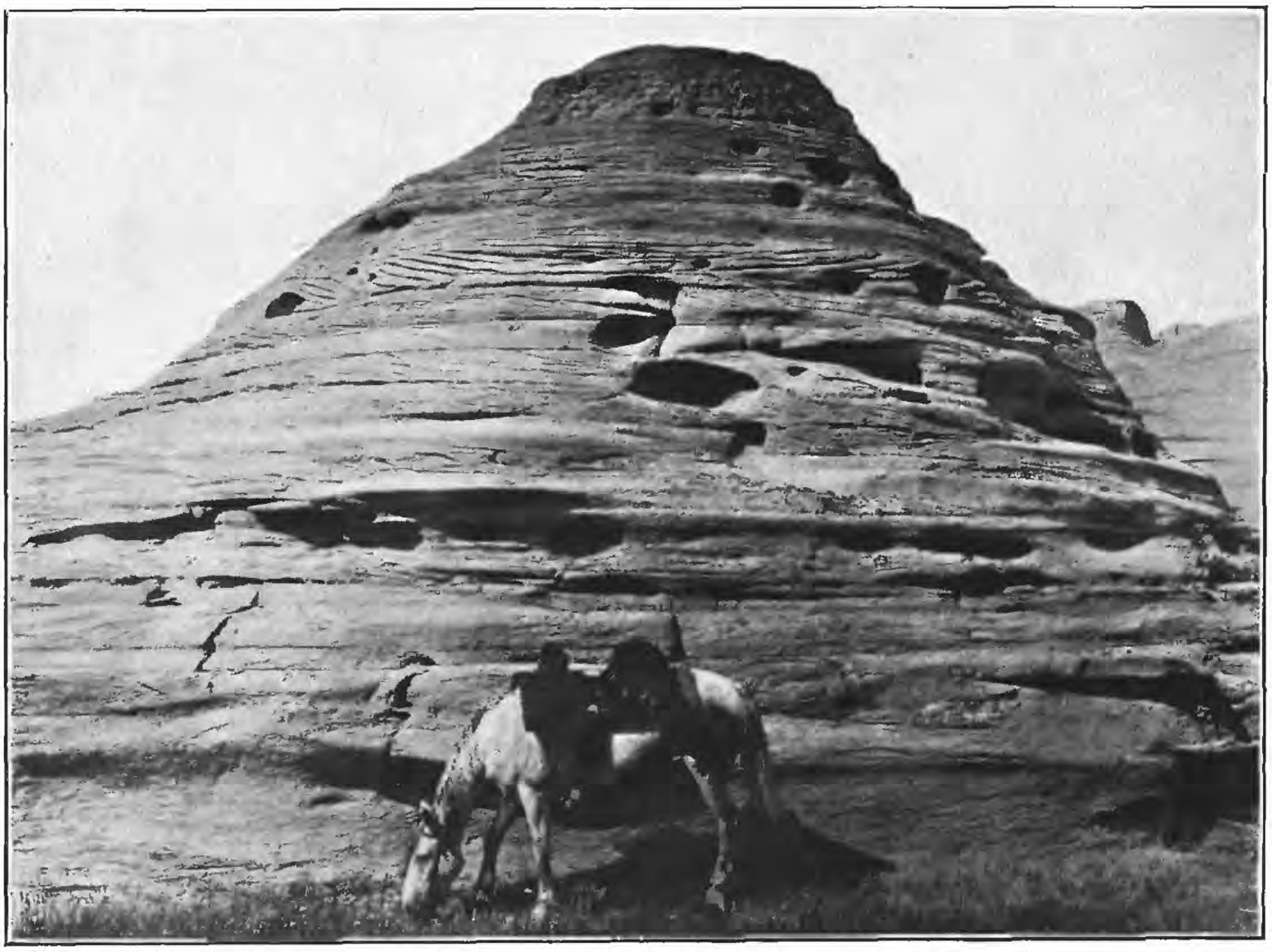
This little creek, which during most of the year is dry, occupies a valley over half a mile broad, with sandstone banks 150 to 200 feet high The reasons for thinking that Sand Coulee Creek now occupies the old channel of the Missouri are as follows: (1) The topographic relations are such that a broad valley like that now occupied by Sand Coulee Creek could not have been formed by that stream or by any stream flowing westward; (2) the cross section of Sand Coulee Valley, while not quite as large as that of the Missouri, is of the same general shape, (3) Sand Coulee Valley contains great meanders, and if the Missouri could be turned into it the resemblance to the Missouri from Ulm to the junction of Sand Coulee Creek would be striking; (4) the tributary valleys which now join Sand Coulee Valley have their acute angles downstream, and therefore appear to have been formed when the water in the valley flowed in the other direction; (5) at the lower end of Sand Coulee Valley there is a deposit of lacustrine clay and at the upper end a deposit of bowlder clay, which appears to block the old channel at this point

East of Senator Gibson's ranch Sand Coulee runs into a broad plain, the southern edge of which marks the limit of the drift Here the old valley had been filled by a drift dam to such a height that drainage from the water ponded in front of the moraine was to the north over Cretaceous sandstone The waters of the diverted

[a] This information was given me by Mr P W Bradford, of Great Falls No record was kept of the depth and of the material by the railway company, but his figures agree essentially with those of Mr Chaffie, a well digger of Great Falls, who has sunk other wells in the vicinity

A. WATER GAP FORMED BY MISSOURI RIVER.

The wide valley has been reexcavated from one filled with drift. The narrows are found at a point where the stream was superimposed on the top of a pre-Glacial sandstone ridge.



B. WIND EROSION NEAR DRY FORK OF MARIAS RIVER.

stream entered the old valley near the mouth of the Highwood, and it was doubtless at this point that the falls originated (fig 11).

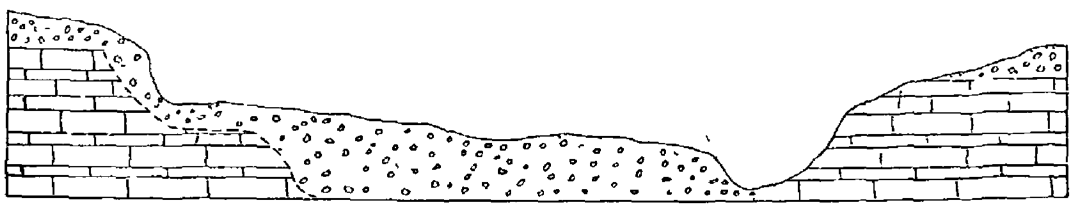


FIG 11—Cross section showing the drift in the valley through which Highwood Creek now flows Looking north downstream

Into this pre-Glacial valley, situated south of the present stream, flowed Belt and Highwood creeks When the major stream was diverted to the north these streams were obliged to cut through miles of sandstone to find an outlet.

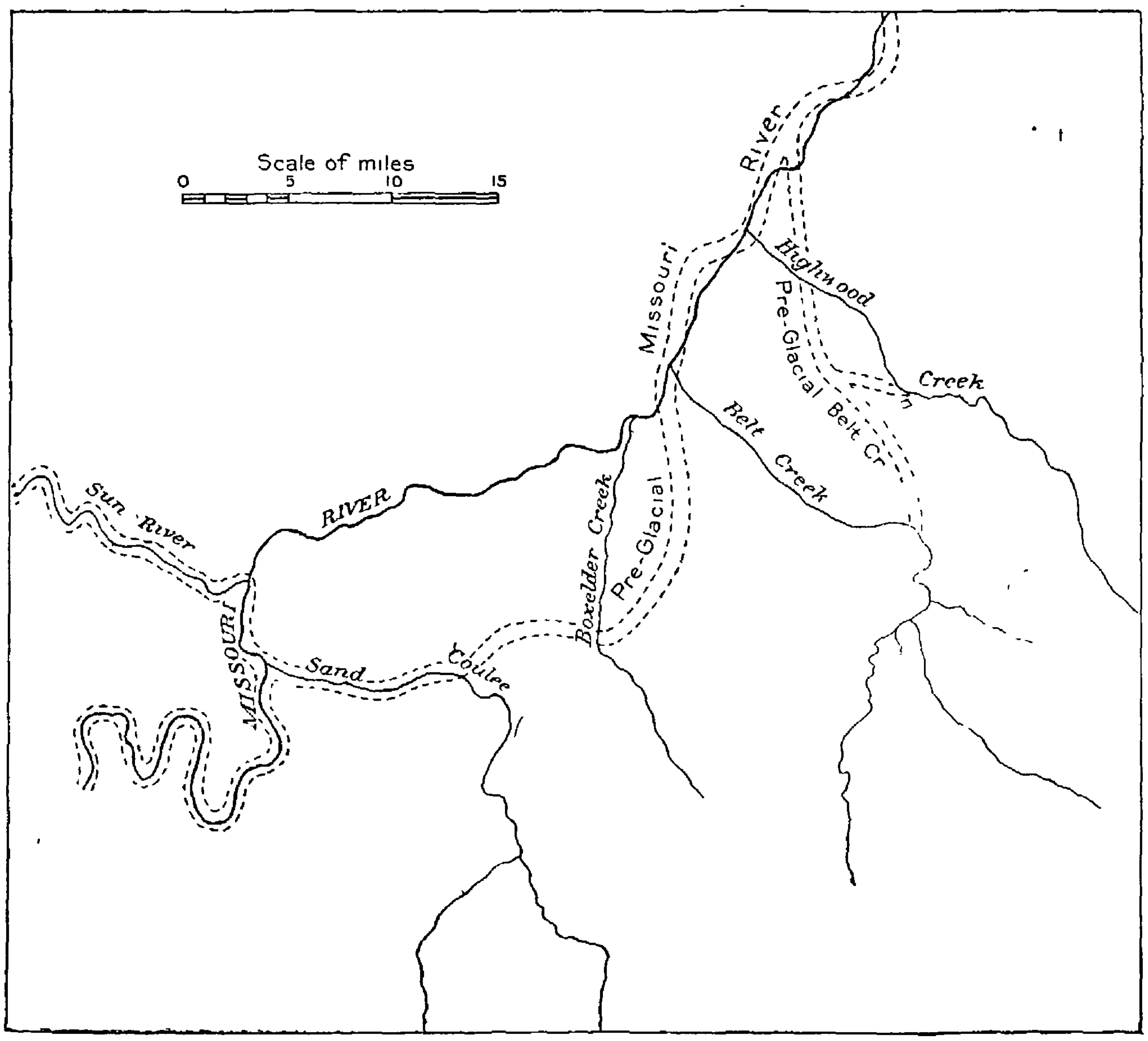


FIG 12—Map showing the pre-Glacial course of the Missouri between Sand Coulee and the mouth of Highwood Creek.

The map (fig. 12) shows the relation of these streams to the pre-Glacial Missouri and to the present river

Into the old valley, now filled with drift, the post-Glacial stream cut its channel, meeting no more serious obstructions than are usually encountered by a superimposed stream Fig. 13 gives some idea of how the new channel cut across the meanders of the old

At the mouth of the Little Sandy, the sudden turn to the south, the narrow valley with its rock walls, and the great, wide, drift-filled valley stretching off to the northeast to the Milk River, all suggest that the river has again been diverted This valley is 35 miles long and is occupied by two streams—the Big Sandy flowing north into Milk River and the Little Sandy flowing into the Missouri The two streams rise in the same vicinity but are separated from each other by a morainic dam that stretches across the valley 8 miles north of the Missouri (fig. 14)

The thickness of the drift deposit in Big Sandy Valley is not easy to estimate. Near the Missouri, where the river makes its sudden turn, there appears to be

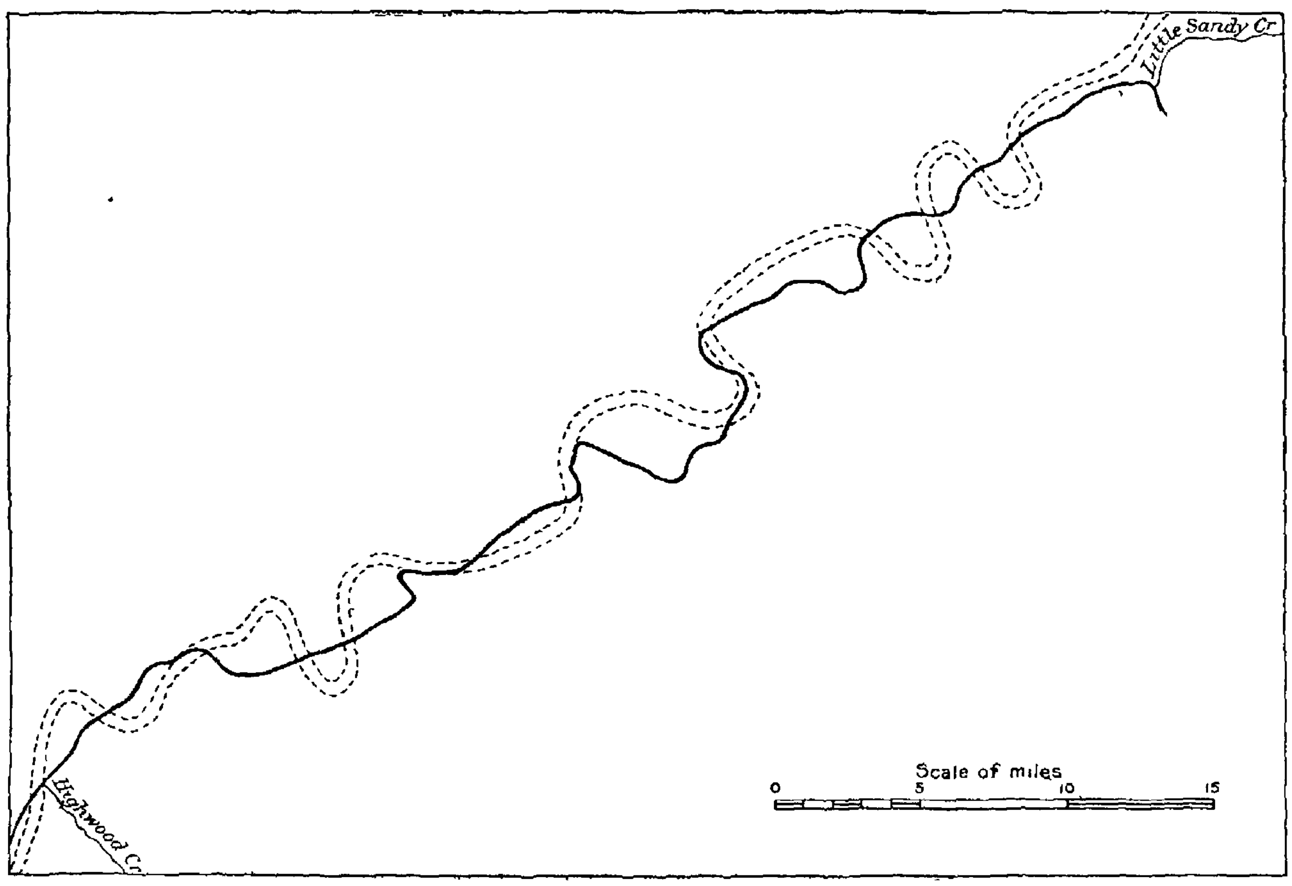


FIG 13—Relations of the post-Glacial and pre-Glacial channels of the Missouri between mouth of Highwood Creek and mouth of Little Sandy Creek

200 feet of till, but this at lower levels may be talus-covered rock Forty feet above the present level of the river near Blankenbaker's ranch is a bed of river gravels covered by cross-bedded sand These gravels are found on the top of the sandstone at many other places and consist of smoothed and rounded pebbles of both Rocky Mountain and northeastern origin The thickness of the drift deposit in this valley north of the Missouri could not be determined The Little Sandy has cut a channel 60 feet into the drift without reaching rock From this point to Havre there is no cut of more than 20 feet

This valley joins that of Milk River east of Havre South of the town there is a drift filling 140 feet thick The map gives the relations of the present valleys to the old valley (fig 15)

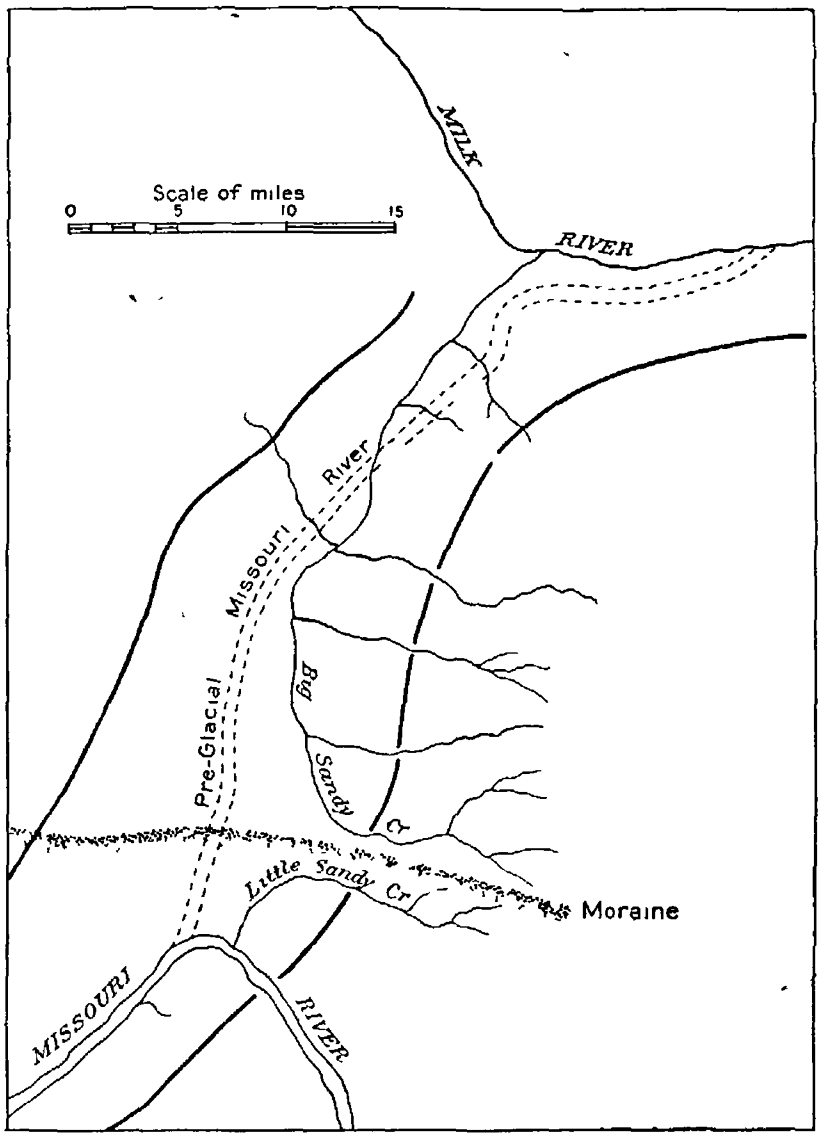


FIG 14—Map showing outlines of the great pre-Glacial valley between Missouri and Milk rivers The map also shows the moraine that forced the river south

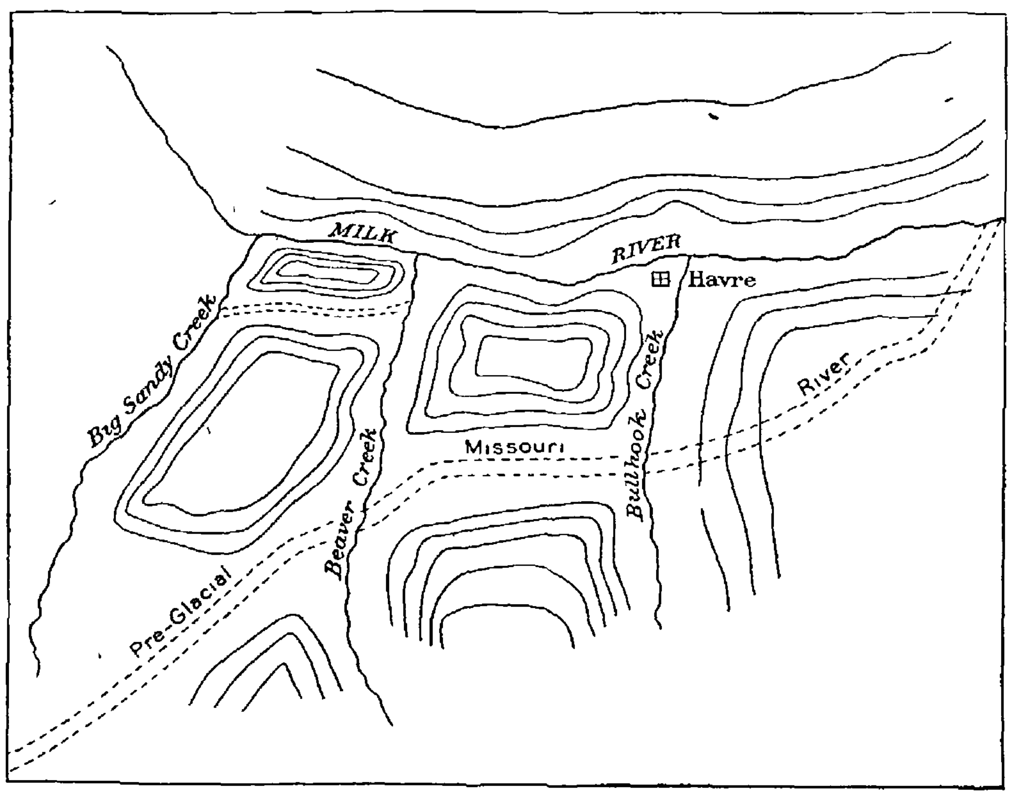


FIG 15—Map of the vicinity of Havre, showing the relation of the pre-Glacial Missouri to the valleys of the post-Glacial streams

The valley of Milk River above its junction with the pre-Glacial valley of the Missouri varies in width from one-fourth to one-half mile, but below the junction becomes much broader, being 2 to 3 miles wide.

South from the turn at the mouth of the Little Sandy the Missouri flows between high rock walls. The bottoms are few and small and the current rapid. The Arrow, the Judith, the Musselshell, and the Dog are tributaries in this part of its course, and each one has been affected by the change in the direction of the trunk stream

In order to illustrate the conditions under which these various changes took place and the reason for each change figs 16, 17, 18, and 19 have been prepared.

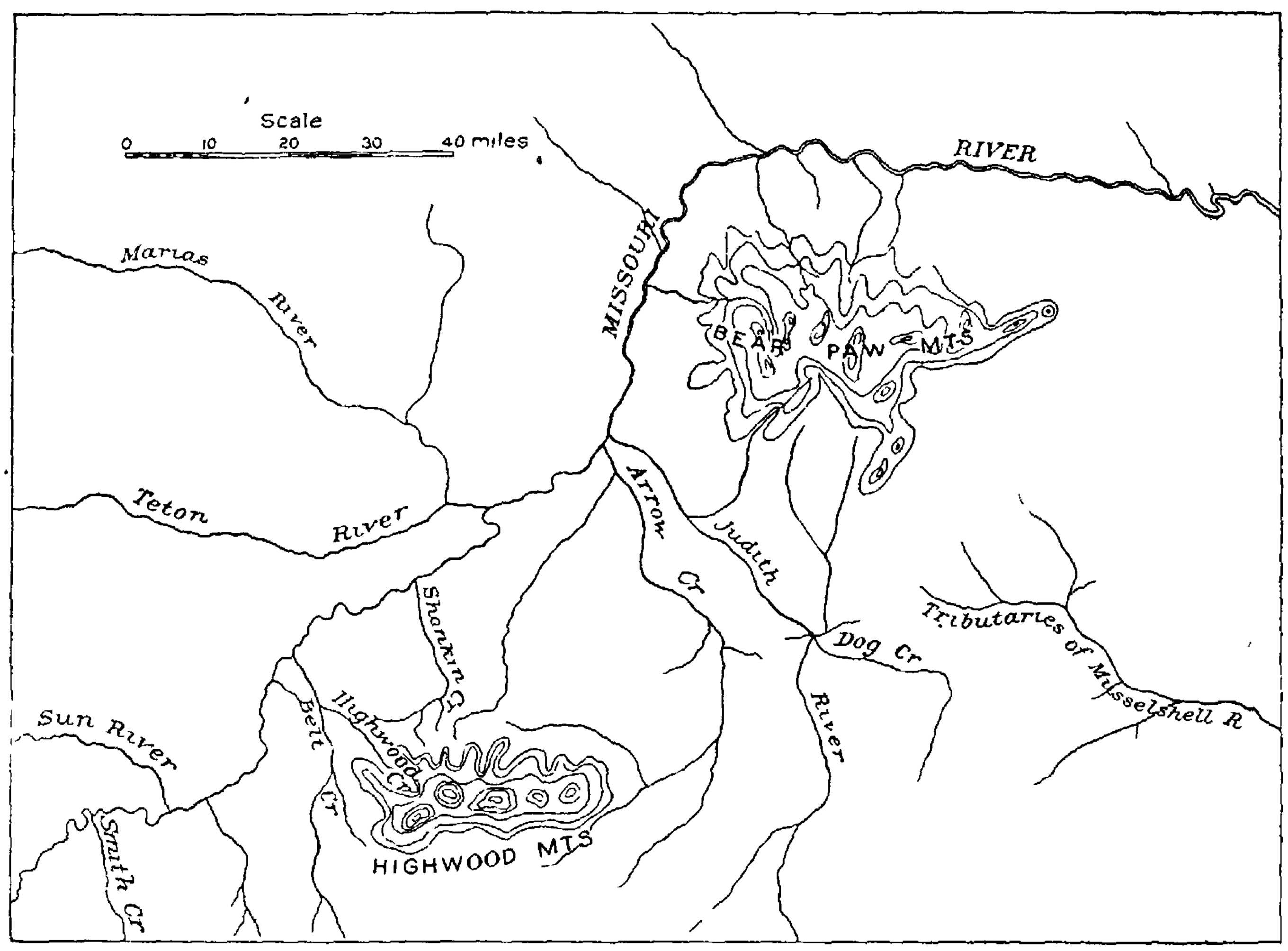


FIG 16 —Map showing pre-Glacial river system of northern Montana

Fig 16 illustrates the pre-Glacial drainage system, fig. 19 the post-Glacial system, and figs. 17 and 18 intermediate stages. Fig. 16 is more or less ideal, for, owing to the weathering of the soft sandstone, valley contours have been greatly modified by the drift, making difficult the work of restoring the minor drainage lines

The more important changes in drainage caused by the ice sheet appear to be closely connected with the history of the Shonkin Sag, a valley which runs from Highwood Creek to Arrow River. The sag is in places nearly a mile wide and over 500 feet deep. It is entirely independent of rock structure and runs across the present drainage lines at right angles. Another curious feature of its position is that it is superimposed on the northern slope of the Highwoods. It would be

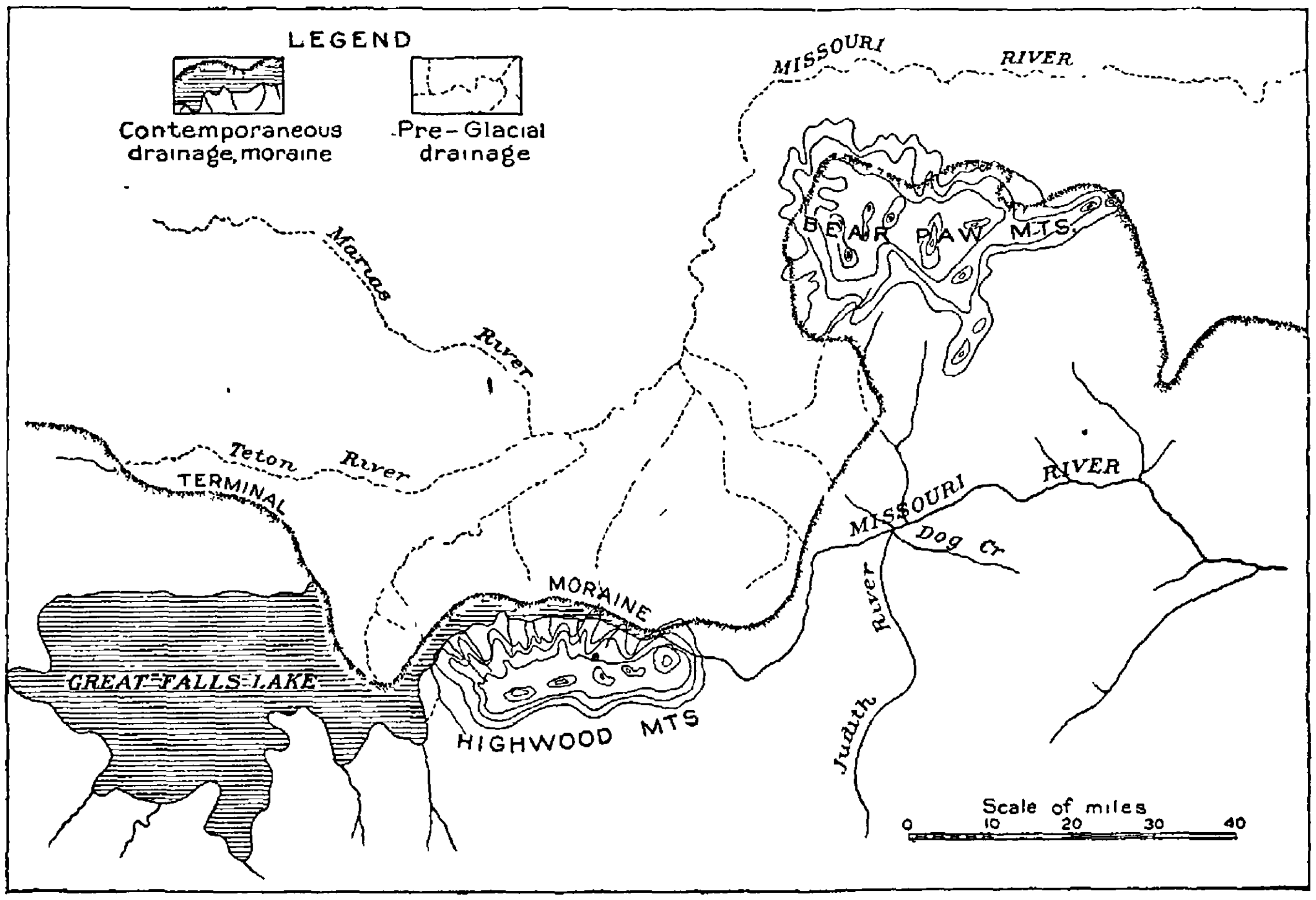


FIG 17 —Map showing drainage of northern Montana when ice had maximum extent, and also pre-Glacial river system.

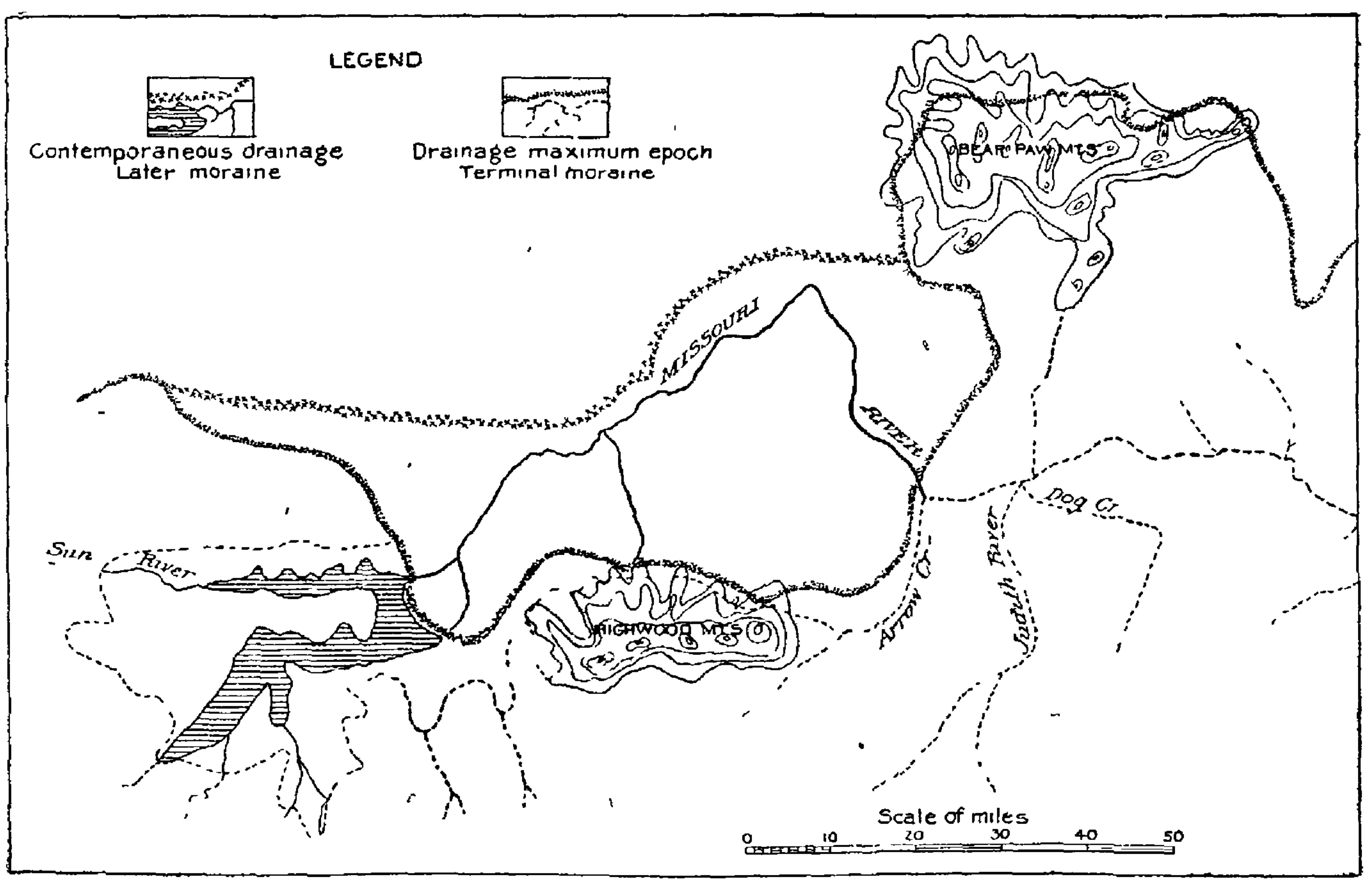


FIG 18 —Map showing drainage of northern Montana at stage of younger moraine impossible for a river in the normal course of development to erode such a channel. At the time of the maximum extent of the ice sheet, the drainage of Great Falls Lake was to the eastward. The west end of the Shonkin Sag must have been covered by the ice edge because the waters touched the 3,900-foot contour level.

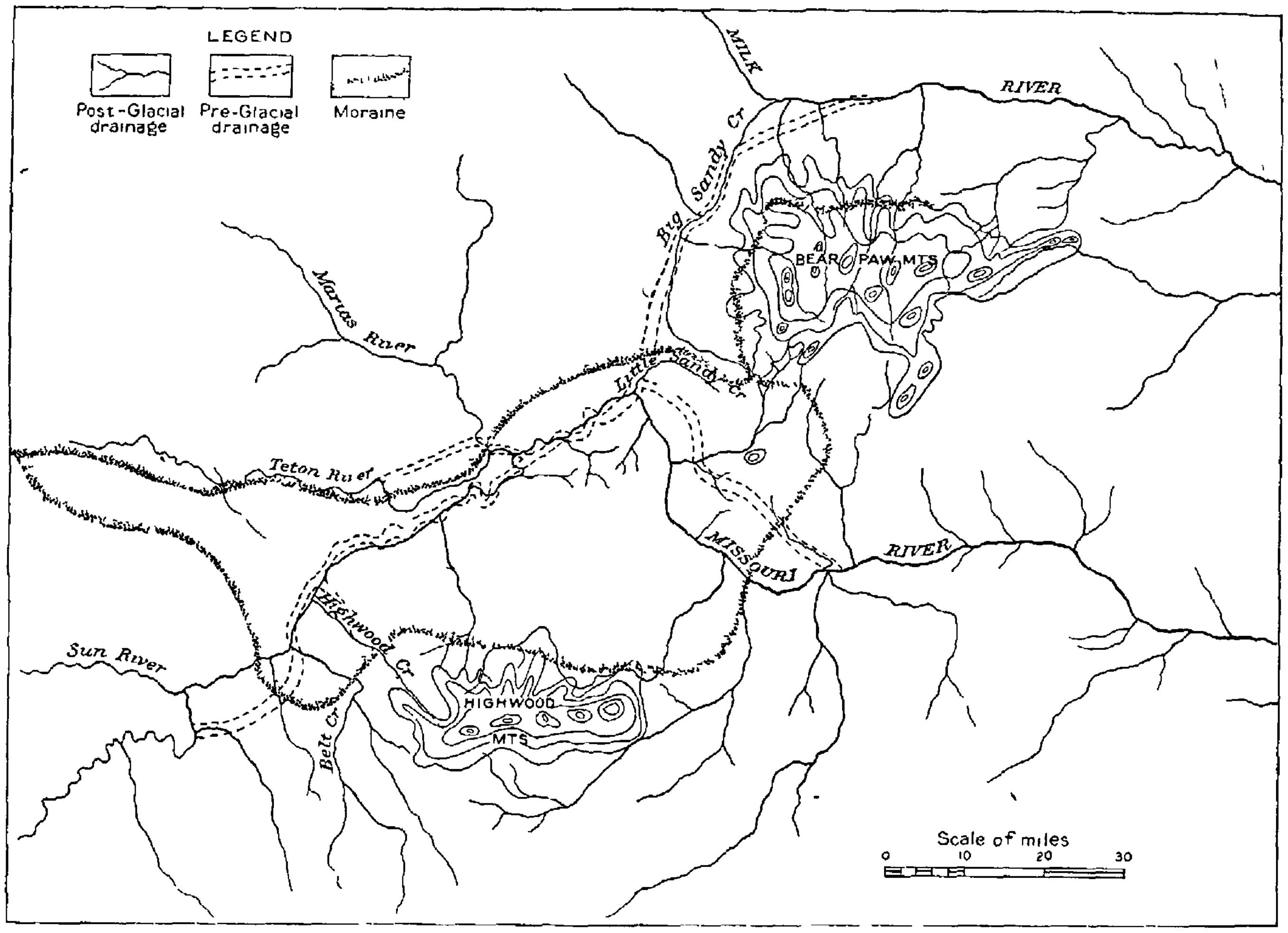


FIG 19 —Map showing post-Glacial drainage system of northern Montana, with a part of the pre-Glacial system

At this level a wide, shallow valley extends 200 or more feet above Belt and Highwood creeks and runs at right angles to them. Though most plainly marked between these two streams, the same valley is found at intervals along the south bank of the sag, sometimes with two banks, sometimes with one, the north wall in the latter case having been formed by the ice itself (fig. 20).

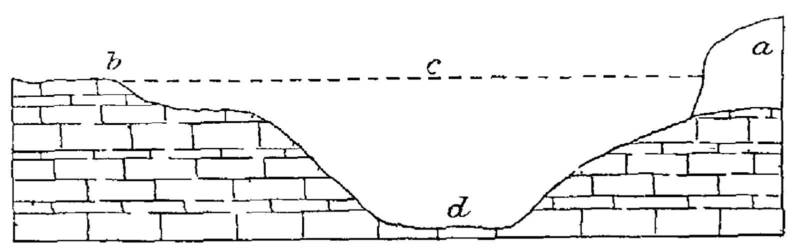


FIG 20 —Cross section of the Shonkin Sag when the ice was present *a*, Edge of the ice, *b*, terrace on south bank of the sag, *c*, level of water in the outlet to Great Falls Lake, *d*, the sag

The valley is such as would be formed by a great quantity of water flowing for a short time from a lake After this valley had been cut and the floating ice had carried the bowlders over the region covered by Great Falls Lake, the ice retreated to the north bank of the sag and allowed the waters to flow at a lower level. The method of formation of the sag seems to have been as follows· The drainage of the lake was forced by the position of the ice edge across the streams flowing from the Highwood Mountains. The waters of the lake took advantage of each col and tributary and swung in great meanders around the mountains. The sag appears to be the result of superimposing across the pre-Glacial valley a dramage

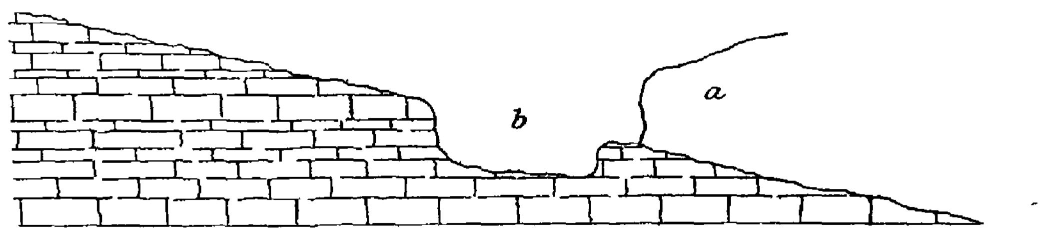


FIG 21 —Section across the Shonkin Sag, showing how it was formed on the slope of the Highwood Mountains

system determined partly by topography and partly by the position of the ice edge. Figs 21 and 22 illustrate the manner in which this change was brought about

The sag continued to be the outlet for the waters of the lake until the ice had retreated north of Fort Benton. The ice then either halted for a considerable

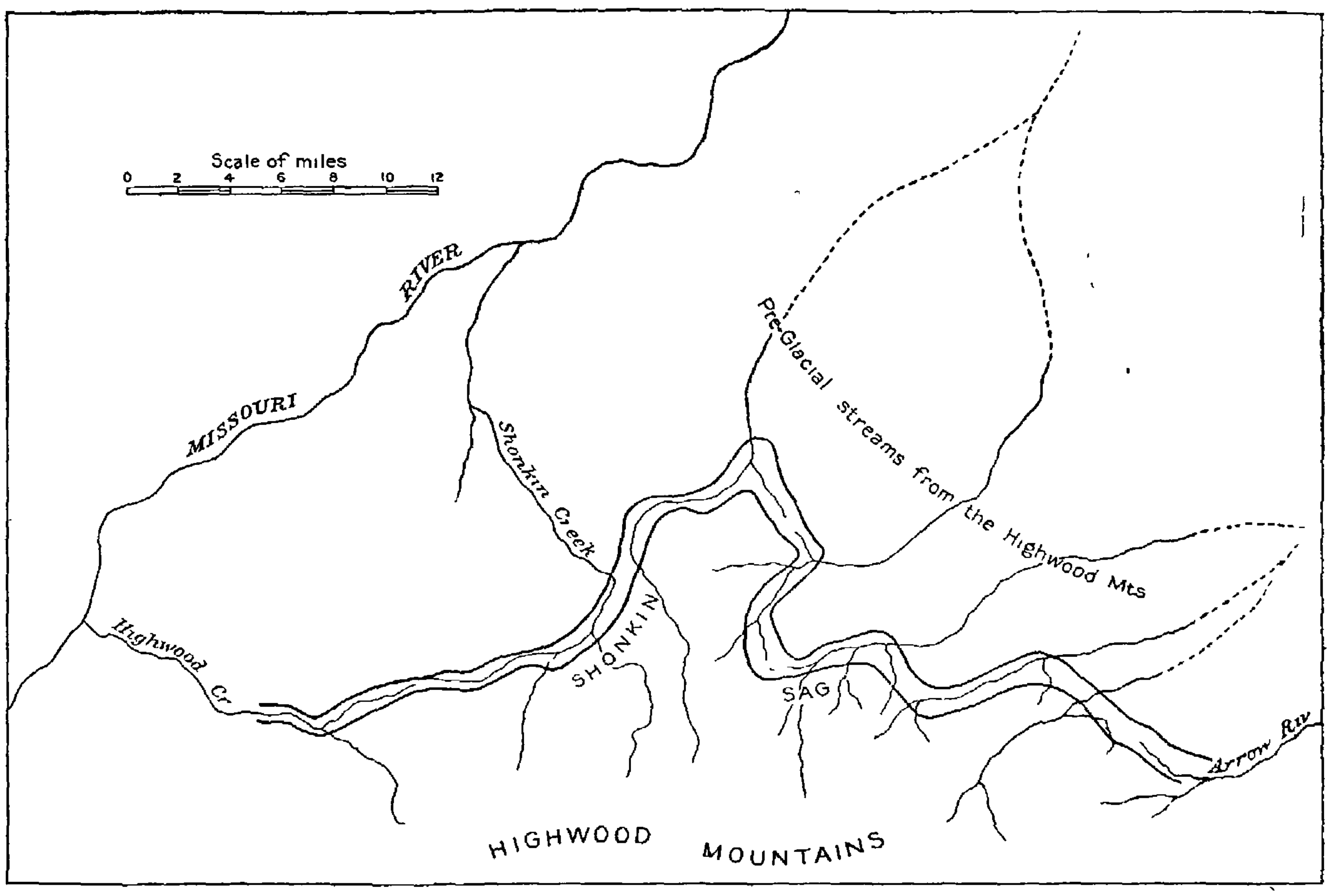


FIG 22 —Sketch map showing how the Shonkin Sag was developed from pre-Glacial valleys

length of time, forming a recessional moraine along the north bank of the Missouri, or retreated to an unknown distance. In the latter case, a readvance of the ice formed a later moraine which stretches from the Teton Ridge to the Bearpaws. In either case this moraine seems to have determined the position of the present channel of the Missoúri for a greater part of the distance between Great Falls and the mouth of the Little Sandy This moraine was also responsible for the permanent diversion of the Missouri to the south at the mouth of Little Sandy Creek. With its old channel leading north filled with Glacial ice and drift, the waters found an outlet to the south either through a small tributary to the Missouri from the south, or through Arrow River, which in pre-Glacial time may have emptied into the Missouri at this point The latter hypothesis appears for many reasons to be the true one The valley of the Arrow enters that of the Missouri at the present time in such a manner as to suggest that it once flowed north. Not only does the angle at which the two valleys meet suggest this, but the tributaries to the Missouri above the junction of the Arrow indicate that the river formerly flowed northward The elevation of the bench near the junction of the two streams is greater

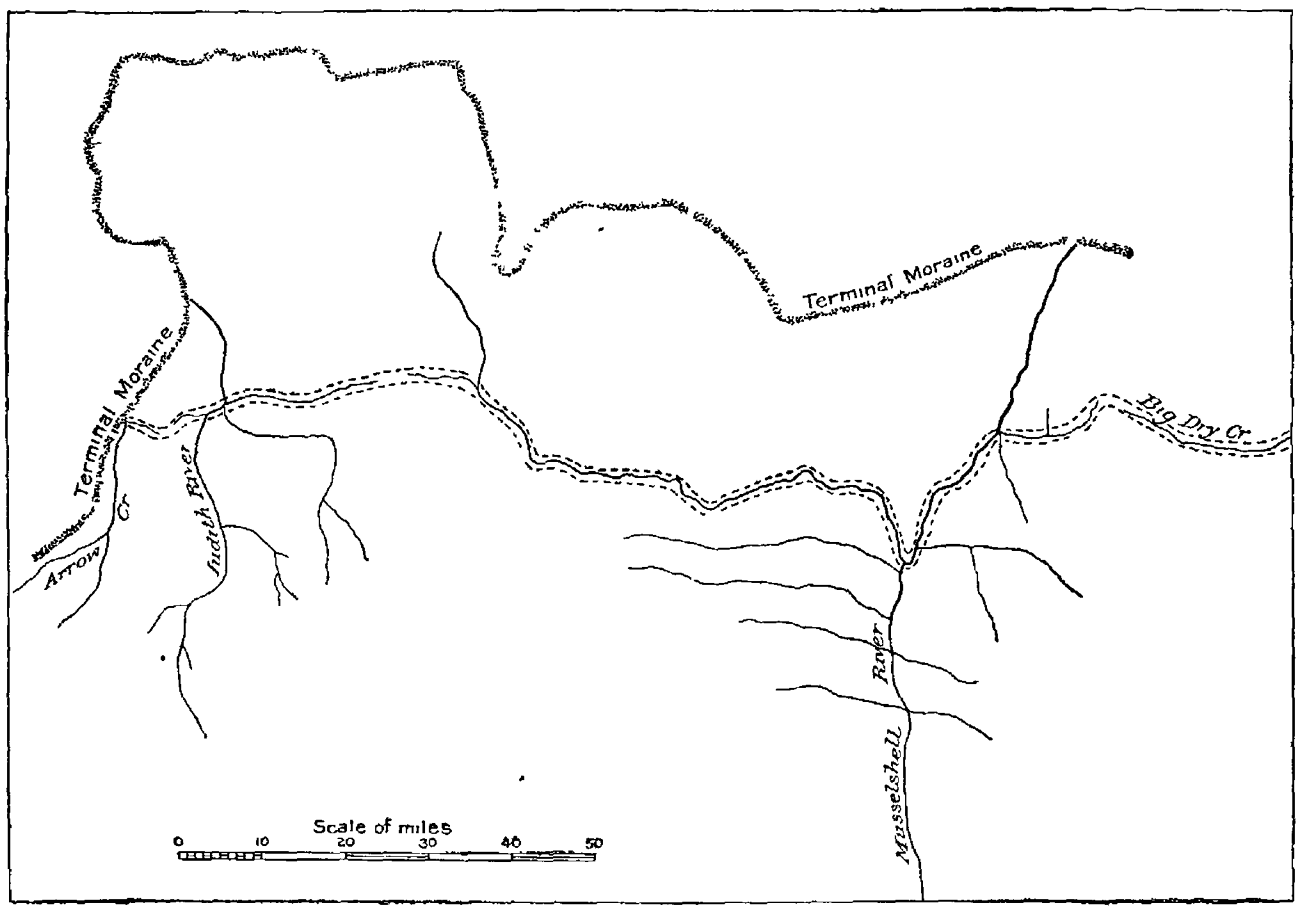


FIG 23.—Map showing in detail how the Missouri was forced across the valleys of Arrow, Judith, and Musselshell rivers.

than any portion of the bench to the north Either the Missouri at this point is an antecedent stream or the pre-Glacial drainage was through the Arrow north to the Missouri west of the present mouth of the Little Sandy

The waters, finding no outlet south through the Arrow, turned to the east and, following a tributary from that direction, passed over a narrow divide into a tributary of the Judith. This was doubtless the course followed by the waters of the lake that existed while the ice was advancing from the former mouth of the Missouri near Havre until it retreated again beyond Fort Benton. The course for the new stream had already been determined by the drainage from Great Falls Lake. The peculiar course of the Missouri between the mouth of the Arrow and the mouth of the Judith, as well as the shape of its valley, would seem to favor this conclusion. The map shows the relation between the tributaries of the Judith and the Arrow and the valley of the post-Glacial Missouri (fig 23)

During pre-Glacial time the course of the Judith was northward, joining the Missouri near the mouth of the pre-Glacial Arrow Since the Missouri was thrown across the Judith at right angles, it has cut 500 feet below the old channel of that stream This is shown by the great valley that stretches away to the north 500 feet above the level of the Missouri, and by the behavior of the Judith and other streams tributary to the Missouri at this point Fig. 24 shows the relation between the slope of the old Judith valley and the present slope. The same condition exists also in the valley of the Dog, though in this case it is even more pronounced

For 30 miles east of the Judith the bench on either side of the Missouri rises gradually; then falls again to the east into the Musselshell system. The Dog flows westward for 25 miles parallel to the Missouri The other streams also come in at such angles as to lead one to expect them to empty into a river flowing either west or north. East of the divide just mentioned, the tributaries again enter the main stream, following the usual law It would appear that what took place west of the Judith was repeated east of that stream The waters flowed eastward through a tributary of the Judith over a col into a tributary of the Musselshell

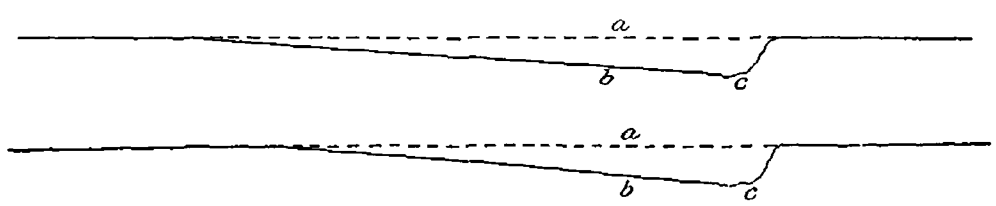


FIG. 24—Longitudinal profiles of Judith River and Dog Creek valleys a, Level of the old valley, b, level of the present valley, c, valley of the Missouri The cutting of the Missouri from a to c, at the mouths of Judith River and Dry Creek, has caused these tributaries to work back

This stream is also supposed to have flowed north through the Great Lonesome Prairie Valley, joining the Missouri in the vicinity of Saco The same process was repeated in the valley of the Big Dry From this point the river again found its old channel and flows in a modified pre-Glacial valley eastward for many hundred miles.

On the whole the changes in drainage induced by the ice of the Keewatin sheet in the area studied were not great. If, as Dawson thinks, an earlier drift sheet covered the region, changes in drainage may have been brought about by that more far reaching and more profound than those induced by the later ice.

INTERRELATIONS OF SURFACE FORMATIONS.

THE QUARTZITE GRAVELS AND THE TWO DRIFT SHEETS

The surface formations of the area have been described in detail. It now remains to consider their relations to each other.

The quartzite gravels may be summarily treated. In the area between the drifts of the two ice sheets the gravel occurs as a surface formation, lying on Cretaceous beds Near the mountains the gravels are found under the drift of the local glaciers This relation is seen north of the forty-ninth parallel in the vicinity of Duck Lake and on the high ridge north of North Fork of Cutbank Creek. The sections show a layer of rounded, weathered, quartzite gravel covered by angular striated bowlders, having among them a large proportion of limestone and diorite. In sections exposed along the edge of the Keewatin drift sheet the gravels are likewise found beneath the till Their relative positions are shown in fig. 29, page 48.

The position of the quartzite gravels makes them older than both the mountain drift and the northeastern drift. Their age, an interesting question because of the conclusions of Dawson upon the subject, will be discussed after the relations of the other surface formations have been treated.

THE NORTHEASTERN AND THE MOUNTAIN DRIFT SHEETS.

As already stated, a number of broad valleys have been cut into the Cretaceous rock of the plains Into these valleys glaciers deployed, forming moraines, outwash deposits, and valley trains. Into these same valleys from the east came the ice from the Keewatin Glacier, which threw moraines across the valleys and formed at its edge various extra-morainic deposits. It is the relation of such deposits to each other in the several river valleys that is now to be considered.

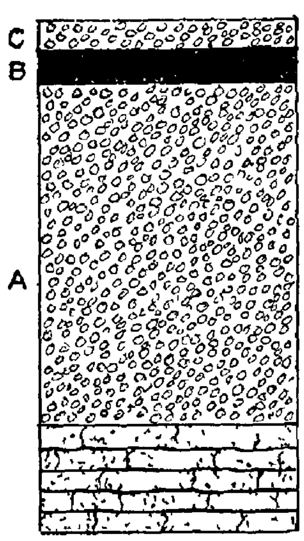


FIG 25 —Section on Birch Creek A, Valley train containing striated limestone pebbles, 20 feet, B, soil, C, gravel made up to a large extent of crystalline pebbles

In Sun River Valley the moraines of the two ice tongues are about 60 miles apart. Down the stream for some distance from the moraine of the mountain ice extends a valley train. In front of the Keewatin ice sheet there existed in Sun River Valley a large lake, in which lacustrine clay was deposited. The relation between these two formations, if they come in contact anywhere, would give a clue to the relative age of the two ice movements, but, though such a relation doubtless exists, it was not seen in any section along Missouri or Sun rivers. Similar formations are found in the valleys of Teton River and Muddy Creek, but, though a relation between the deposits in front of the two ice sheets ought to be made out in these valleys, in no section was such a relation shown. Gravels are found along these rivers under the lacustrine clay, but they are of soft limestone, without glacial marking, and whether they belong to the valley train or to fluvial deposits of unknown age was not determined.

In Birch Creek Valley, however, the two moraines are only about 18 miles apart As along Sun River, a glacio-fluvial train extends down the valley of the Birch and into this the stream has since cut a narrow channel At a number of places along the creek there are exposures showing a thickness of from 20 to 30 feet of these gravels. Although a few of these are striated, the majority have been subjected to so much water action that all trace of glaciation has been removed. Lying on the gravels, and never in or beneath them, are large crystalline bowlders of northeastern origin, which were carried by floating ice on the lake extending along the Keewatin ice edge, and which were scattered at irregular intervals over the lake bottom Farther east, nearer the terminal moraine of the Keewatin ice sheet, the lacustrine clay appears, also lying on the gravels. Fig 25 shows the relations of the bowlders and the clay to the gravels of the valley train.

On Birch and Dupuyer creeks and on the tributaries opening into them are many sections which show essentially the same order and deposits In these valleys, then, we may see the relative age of the two drift sheets as shown by the deposits formed in front of the ice (fig 26)

In the valley of the Two Medicine also the moraines come close together, and here two very interesting and comprehensive sections are found within 2 miles of each other The first occurs where the terminal moraine of the Blackfoot Glacier is trenched by Two Medicine River and the second where a meander of the same river has recently undermined a portion of its bank

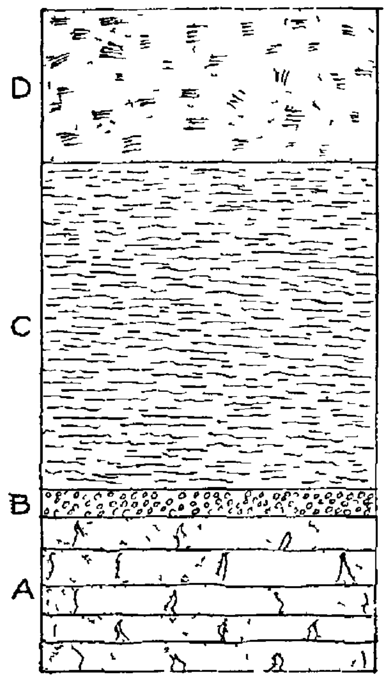


FIG 26—Section near mouth of Dupuyer Creek A, Sandstone, B, valley train from Birch Creek Glacier, C, lacustrine clay containing crystalline pebbles, D, eolian deposit

The first section (fig 27) shows that the ice of the Blackfoot Glacier formed its moraine across Two Medicine River and retreated, and then the northeastern ice sheet pushed into the valley and deposited its moraine within a mile of the edge of the mountain drift, while in the lake formed west of its edge lacustrine clay was laid down above the till from the mountains

In the second section (fig 28) the 50 feet of till belonging to the Keewatin drift sheet lies above a layer of glacial gravel of mountain origin, which was doubtless deposited at the time the valley to the west was occupied by the mountain ice Between the till and the valley train two formations intervene Resting upon the gravel is a layer of sand and clay, part of which was deposited by wind and part by water, and above this layer a bed of lacustrine clay occurs It would appear that after the deposition of the clay in the lake along the front of the ice, the ice advanced and covered a part of its own lake deposit In this section the till of the northeastern drift sheet lies above the deposit formed in front of the Blackfoot Glacier

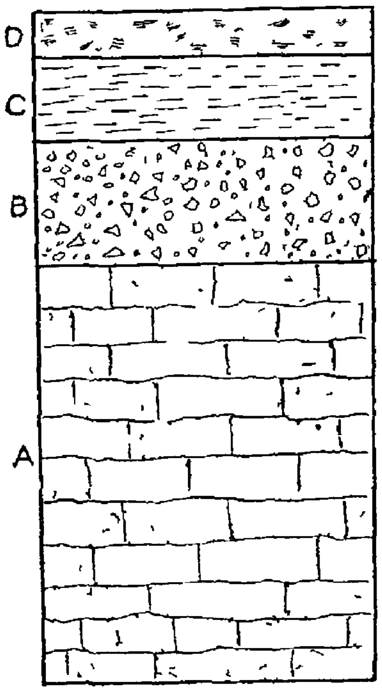


FIG 27—Section on the Two Medicine at point where Blackfoot Glacier crossed it A, Sandstone, 50 feet, B, till formed by Blackfoot Glacier, 15 feet, C, lacustrine clay formed in the lake which existed in front of the Keewatin ice sheet, 10 feet, D, windblown deposit, 5 feet

We have seen how the ice in the mountains in St Mary River Valley, after it had crossed Milk River Ridge from north to south, spread eastward, depositing its moraine along the north slope of the ridge It has also been shown (p 23) how the Keewatin ice sheet was held back by the same ridge and deposited its terminal moraine along the same north slope

In the coulee in which Galbraith's ranch is located, near the ranch, the moraine of the mountain glacier disappears under the drift of the northeastern ice sheet

Although in general the two drift sheets are quite distinct, the line of demarcation is not sharply drawn The Keewatin drift contains mountain bowlders which were picked up by the ice as it moved westward over the earlier drift sheet Lying upon the drift from the mountain are fragments of crystalline rock from the northeast, which were carried out beyond the edge of the eastern drift sheet by floating ice. The two drift sheets are not exposed in section in this valley

In St Mary Valley proper the mountain ice pushed much farther north Great argillitic bowlders from the Rockies are found 10 miles north of the forty-ninth parallel in such a position that it is evident that they were left by mountain ice Others are found on top of St Mary Ridge, at a point where the ice from the northeast reached the top of the ridge and mingled its bowlders with the mountain drift Figs 29 and 30 show significant sections along St Mary River

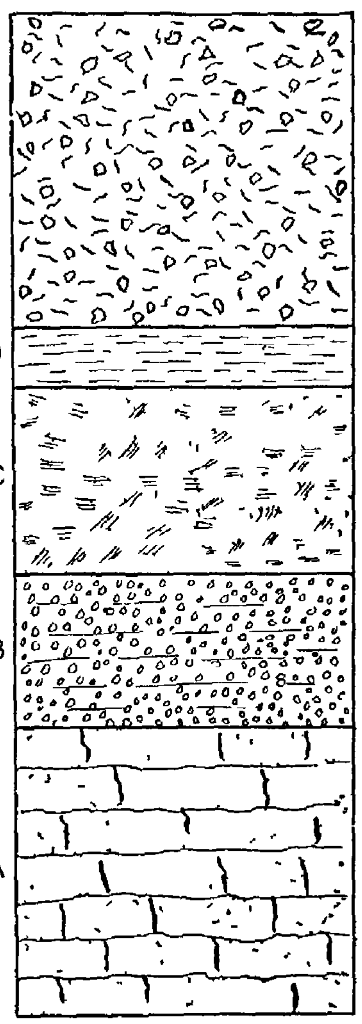


FIG 28—Section on the Two Medicine 7 miles west of mouth A, Sandstone, B, valley train from Blackfoot Glacier, 25 feet, C, eolian deposit, 30 feet, D, lacustrine clay, 30 feet, E, northwestern till, 50 feet

In the valley of Belly River the contact of the two drift sheets is seen in section About 10 miles north of the forty-ninth parallel the moraine of the northeastern ice sheet crosses Belly River and swings in a northwestern direction toward Waterton River Two hundred yards south of the point where the moraine crosses the river, and therefore outside of the northeastern drift sheet, the river has cut through about 60 feet of drift The lower 30 feet consists of a bed of roughly stratified, somewhat glaciated mountain gravels Above this is 30 feet of heavy bowlder clay The bowlders are, without exception, from the mountains, and are ice marked to an unusual extent At the very top of the section, lying upon the mountain till, but never in it, a few crystalline bowlders are found

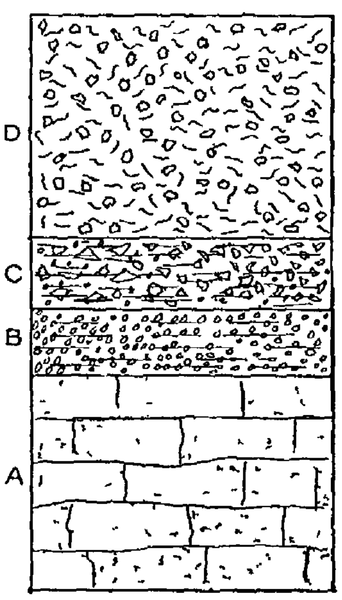


FIG 29—Section on St Mary River, near Sloan's ranch A, Sandstone, B, waterworn, nonglaciated gravels, C, glaciated, angular pebbles from the mountains, not waterworn to any extent, but apparently part of a valley train, D, till of the northeastern ice sheet, containing many small crystalline pebbles, but no large bowlders, B and C grade into each other, B is evidently a pre-Glacial formation

It was over such a till formation as this that the ice from the northeast moved. In most of the sections exposed by post-Glacial cutting within the edge of the eastern drift the two tills are mixed, showing that the later ice handled, to a greater or a less extent, the material deposited by the valley glaciers Only one section, where the line between the two bodies of drift was sharply marked, was seen, though in many places the plane of division could be made out approximately The drift from the northeast contained but few bowlders, while that deposited by the mountain ice was heavily loaded In any mixed body of drift, the upper part would contain both crystalline and sedimentary bowlders in small numbers, while the heavy bowlder clay at the bottom of the section, though it sometimes contained a few crystalline bowlders, represented the mountain drift sheet, as far as it could be made out. The talus always present along the banks of the streams often obscured this indefinite division line. Within the moraine, not far from the edge of the drift, the section shown in fig. 31 is exposed. This section is the only one along the banks of Belly River that shows the two drift sheets separated from each other by a definite division line.

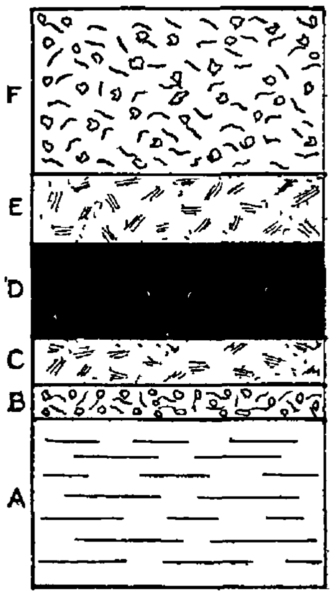


FIG 30 —Section on St. Mary River, north of Sloan's ranch A, Shale, B, northeastern drift, 2 feet, containing many decomposed bowlders, C, typical loess, 5 feet, containing concretions, hard shells, and bones of small animals, D, soil, 10 feet, of black clayey loam, consisting of the weathered surface of the lower loess bed; E, loess, 6 feet in thickness, sandy at the top, F, northeastern till, containing crystalline bowlders This section furnishes the only discovered evidence of two distinct glacial epochs As no other section was found showing like or similar phenomena, little stress is laid upon this

Thus, in these river valleys, a definite relation has existed between the two drift sheets—a relation which warrants the conclusion that the Keewatin ice sheet advanced into the region after the deposition of the moraines of the mountain glaciers

DEDUCTIONS FROM INTERRELATIONS.

AGE OF THE QUARTZITE GRAVELS.

As has been shown, the quartzite gravels are found on the plateaus that mark the earliest level of the plain next the mountains, on the slopes that lead to lower erosion plains, on the terraces above the present stream beds, and in the stream channels themselves. The topographic position of these gravels and their nature are such that they could not have been deposited by the ice which formed the existing moraines in the present mountain valleys. This is seen in their topographic relations, in the absence of glacial markings, in the absence of limestone and diorite bowlders, and in the great weathering to which they have been subjected. The till laid down by the mountain glaciers contains a large percentage of limestone bowlders, the glacial markings are distinct, and very little weathering has taken place The gravels are found above the level reached by the ice in the mountain valleys and outside of the area covered by the Keewatin ice sheet or by the lake which existed in front of it. These facts prove that the gravels antedate the last Glacial epoch

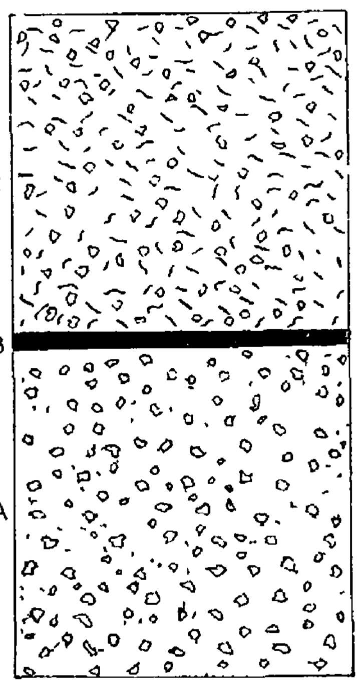


FIG 31 —Section on Belly River within the terminal moraine of the Keewatin ice sheet A, Till formed by Belly River Glacier, containing many bowlders, all of which are smoothed and striated to an unusual degree, 75 feet, B, soil, of which only a small exposure was seen, which contained no fossils, C, till formed by the Keewatin ice sheet, 80 feet

The question of most importance is whether they are or are not of glacial origin. Were they deposited by earlier mountain glaciers or by an earlier Cordilleran ice sheet, or were they formed by streams? Dawson[a] is of the opinion that they are of glacial origin, and calls the formation the Albertan.

[a] Dawson, G M, Glacial deposits of southern Alberta. Bull Geol Soc America vol 7, pp 39, 42, 54

His description is as follows:

> Deposits of coarse gravels, often containing stones up to 6 inches in diameter, all well smoothed and waterworn, but often not perfectly rounded. They are generally arranged in rather tumultuous manner—that is, not in regular lines graded according to size, and with pebbles sometimes standing on end The stones are chiefly Rocky Mountain quartzite, but a considerable number of pebbles of limestone from the same source are included Some of these gravels are striated The Saskatchewan gravels of the plains represent and gradually pass into a western bowlder clay in approaching the mountains

The only bowlder clay seen along the eastern face of the mountains is that deposited by recent ice action, and none was found passing into the gravel formation. Those who have seen the great moraines and have observed their lakes, the freshness of their bowlders, the slight weathering and erosion to which the surface of the till has been subjected, and their general look of newness, would call them Wisconsin in age rather than Albertan.

As Dawson suggests, the gravels are older than any Keewatin drift found in the region They are also older than any till deposited by mountain glaciers, and, as will be shown later, older even than the valleys now occupied by Milk River, Cutbank Creek, and Two Medicine River. The question of their origin is a troublesome one, but from a careful study of the formation south of the boundary line, they are believed to be not of glacial origin, but to have been deposited by streams in pre-Glacial time. In support of this interpretation there are the following reasons

The gravels are waterworn and generally rounded Their size is uniform over a great extent of country, though the pebbles found near the mountains are a little larger than those 20 miles out on the plains From the forty-ninth parallel south there is a change in the character and position of these gravels which would suggest water deposition, for in each river basin the pebbles are similar to the rock exposed along the upper course of that particular river, though the varieties in the basins differ from one another The pebbles, too, are wanting on some of the higher divides and buttes An ice sheet of size sufficient to have covered the gravel area would have left a more heterogeneous deposit, and one covering the heights.

On the other hand, there seems to be no reason whatsoever for assuming them to be glacial The question of the origin of these gravels was kept in mind during the entire summer, and the area covered by them was carefully worked over, but they show no marks of an ice-deposited formation There are no glacial markings of any kind where they have not been affected by the ice of the later Glacial epoch In no case is till associated with the gravel, nor is there ever a suggestion of terminal or ground moraine topography, though the gravels are found on tops of great plateaus, where any such formation would naturally have been preserved Then, too, in regions where the moraines deposited by mountain ice contain limestone and other easily weathered rocks, the gravels are composed of only the most durable materials.

The valleys which have been developed in the drift are small, those which have cut into the plain since the gravels were deposited are very large Two Medicine, Milk, and Sun rivers flow at the bottom of valleys which are in places 500 to 1,200 feet deep and 5 to 10 miles wide. Between these river valleys are flat plains covered with gravel formation, wide near the mountains, but toward the east gradually narrowing to a small ridge, and finally disappearing altogether. Where the slope is great the energy of the stream has been spent in downward cutting Farther east, where the slope is less, the river has cut laterally and developed flood plains at the expense of the divides, which are of approximately the same height. There appears to be a slight slope to the southeast, which would indicate that the major streams responsible for this base-level flowed in that direction The gravels must have been deposited before these great valleys were cut and at the time of the development of this first base-level, otherwise their position on isolated points could not be explained

The date of the first base-leveling epoch has not been exactly determined. It must have occurred after the Cretaceous sea had retired from the region, and long enough before Glacial time for the development of the great river valleys which trench the western portion of the plains This may carry it back into the Tertiary—perhaps to the end of the Miocene, for there are a few scattered Miocene deposits on some of the isolated high points which rise above the Canadian plains. This, too, would throw the date of the first base-level back far enough to give time for the erosion of the great valleys. If the base-level is referred to the Pliocene, it is hardly conceivable that Milk River and Cutbank valleys could have been eroded.

The distribution of the gravels resembles to a remarkable degree the distribution of the Lafayette formation in the east, though the relief of the underlying surface is much greater here The various stages in the history of their deposition appears to have been as follows: Base-leveling in the later part of the Tertiary removed a great part of the Eocene and Miocene beds that are now exposed in a few isolated places in Canada and left the Cretaceous rocks exposed over a great plain stretching north and south along the face of the mountains. If then the mountains were slightly lifted while the plain was not, the streams would have been rejuvenated and the carrying out of the mountain material begun At the foot of the mountains and at the border of the plain the velocity of the streams was checked and the material carried out deposited somewhat evenly over the surface, the coarser material near the mountains and the finer farther out. Next followed a rise of the whole region and the streams of the new cycles began to cut into the plain covered with the gravels from the mountains As erosion went on, the gravels followed the streams both vertically and horizontally, tending all the while to become concentrated in the bottoms of the valleys and scattered eastward along the banks of the streams. While the gravels were descending from the upper plain to the lower terraces, gravels of the same sort were being brought out by mountain streams and mingled with those reworked from the older formations. At the time of the Glacial epoch the valley trains forming in front of the moraine contained not only bowlders marked and polished by the ice but also the gravels that had been lowered into the stream beds by lateral erosion and side wash The original formation remains as it was first deposited only upon the old high levels. Below these high levels it has been augmented at all stages by the accession of material washed out from the mountains by streams of later times.

There seems to be one conclusion to be drawn from the nature, character, and position of these gravels, and that is that in their original form they are not a glacial or fluvial-glacial formation, but are of pre-Glacial age. On the lower levels material derived from the older formation is mingled with material carried out during and since Glacial time, segregated along the banks of the streams and covered by later drift deposits.

AGE OF THE NORTHEASTERN DRIFT.

The general opinion among geologists has been that the drift sheet of this area belonged to one of the earlier epochs of glaciation. Dawson correlates it with the "Iowan drift," the western extent of the Wisconsin being marked by the Missouri Coteau. Tyrrell calls it Kansan. On the Glacial map prepared by the United States Geological Survey this region is mapped as covered by Kansan drift.[a] The Wisconsin drift is represented only east of the Missouri Coteau and north of the forty-ninth parallel. In the light of recent studies, this correlation of the drift in the area under consideration is no longer tenable. The conclusion is held that the drift sheet under consideration was deposited by ice of the Wisconsin and probably of the late Wisconsin stage, this hypothesis being based on the newness of the region in terms of erosion, the sharply defined character of the terminal moraine, and the relation of the drift of the Keewatin sheet to that deposited by the mountain glaciers.

Evidence from erosion.—In order to discuss a question involving so many factors as the rate of erosion of a land surface, something besides the amount of weathering and trenching which have taken place must be considered In the Montana region the post-Glacial cutting, with the exception of that accomplished by the large superimposed streams, has been slight; the lakes and marshes are still undrained; the till is weathered but a short distance from the surface, and the surface bowlders of the drift have suffered but little change.

The erosion along the moraine and the amount of weathering on its surface is about the same as that suffered by the drift of the Green Bay lobe in the vicinity of Baraboo, Wis. The following table shows the amount of rainfall for the last four years at Portage, Wis , and at Kipp, Mont , near the edge of the drift of the two regions.

Rainfall at points in Wisconsin and Montana, 1896–1899

Locality	1896	1897	1898	1899
Kipp	26 28	22 23	18 26	25 61
Portage	26 97	28 04	25 00	30 43

It will be seen from the table that while the average rainfall is greater at Portage the difference is not so great as to affect profoundly the amount of erosion. A factor favoring erosion at Kipp as compared with that at Portage is the concentration of rainfall at the former place. Other conditions being equal, a great amount

[a] Leverett, Frank, The Illinois glacial lobe Mon U S Geol Survey, vol 38, 1889, Pl I Upham, Warren, The Glacial Lake Agassiz Mon U S Geol Survey, vol 25, 1895, Pl XVI

of rainfall during a single shower will occasion greater erosion than the same amount distributed through a longer interval. From personal observation in both regions it may be said that the amount of water falling in the course of a few hours is much greater in Montana than in Wisconsin When the amount of post-Glacial erosion and the number of undrained lakes and depressions are taken into account, the Montana drift edge appears as young as that in Wisconsin. The conditions for erosion are different in the two regions, but the difference has not favored either place in the final results.

The amount of weathering suffered by the bowlders and the upper surface of the drift is less in the Montana region than in Wisconsin In Wisconsin the drift is leached of its soluble materials to a depth of from 2 to 3 feet In Montana the average depth of the weathered zone is rather less. The bowlders in the former drift sheet are decomposed, in some cases, so badly that a blow of the hammer will shatter a granite bowlder a foot in diameter, while the bowlders in the drift of the western area are not decomposed to a great extent. On the other hand, mechanical agents of weathering, such as wind erosion (Pl. VII, *B*, p. 36) and the sudden changes of temperature, are active On taking these various factors of erosion and weathering into consideration, it is thought that the age of the Montana drift can not be greater than that of Wisconsin

Evidence from the topography of terminal moraine.—The edge of the Kansan drift sheet is generally attenuated. It is somewhat thickened in places and occasionally ridged, but is not usually marked by a definite terminal moraine. The edge of the Iowan formation is better marked, though in no place is it known to form a continuous or conspicuous ridge. The ice of the Wisconsin sheet alone appears to have produced the great terminal ridges which cover the country. In Dakota Prof. James E Todd has described a series of these moraines which correspond roughly with the series found in Montana The Dakota moraines are of Wisconsin age, and when these have been traced westward it may be found that they join those in Montana. If sharp terminal topography counts for anything in the classification of drift sheets, the Montana moraine is of Wisconsin age.

Evidence from relations of the two drift sheets.—As has been shown, the Keewatin drift of this region is, at its edge at least, younger than the drift of the mountain glaciers If any data could be obtained that would throw light upon the age of the latter, the relative age of the former might be assumed. Very little has been written concerning the age of the mountain drift, but the main portion has usually been assumed to belong to a late stage of the Glacial epoch. It is so mapped on the two plates to which reference has been made (p. 52, footnote). The drift deposits of Colorado, Wyoming, California, Utah, and Washington are supposed to be the work of glaciers belonging to a late epoch, the Wisconsin.

The moraines of Montana appear as young as those of these other States Their fresh moraine topography, their lakes, and the little erosion to which they have been subjected all stamp them as young formations. In the mountain canyons the exposed rocks in situ still bear marks of the glaciers in the form of polishings, striations, and grooves No long interval of time could have intervened since the last advance of the ice without the destruction of all marks of glacial action by weathering Especially this would be true in a region where the work of the wind and sudden changes of temperature are ever active

Granting that the mountain ice is of Wisconsin age, the Keewatin drift sheet must belong to the same Glacial epoch. The length of time that existed between the deposition of the till from the mountains and that laid down by the Keewatin sheet can not be told definitely by any field observations. The amount of erosion to which the two drift sheets have been subjected is the same so far as field studies show. The agents of weathering have attacked the surface of the till and the bowlders to about the same extent in each drift sheet. Where the two sheets of drift are found side by side, as in the St. Mary basin, it would be difficult to tell their relative ages from any topographic feature.

The ice from the mountains and from the Keewatin centers may have been formed by the same climatic episode. The ice in the mountain valleys may have pushed out upon the plain, deposited its moraines, and then, not being of large extent and hence being easily and quickly affected by climatic changes, may have withdrawn promptly at the beginning of adverse climatic conditions The continental ice sheet, on the other hand, with its vast dimensions and its center far to the north, may have continued to push outward for some time after adverse conditions on its extreme southwestern border had set in, and hence may have invaded the area of the more local drift after the mountain glaciers retired The general conclusion is that the two drift sheets were formed during the same ice epoch, and that where they overlap they were deposited within a short period of each other.

THE DRIFT OUTSIDE OF THE TERMINAL MORAINE.

Beyond the terminal moraine the glacial deposits are of two kinds—scattered bowlders with till, or a thin till sheet, grading at the edge into a bowldery area. The edge of this till sheet is in some places marked by a slight ridge that resembles a terminal moraine in a feeble state of development More often there is no definite ridge, but a rolling country, covered with shallow lakes and lake basins, which frequently gives place to a simple thinning out of the till sheet, with no evidence of either a terminal ridge or of ground-moraine topography.

The bowlders are scattered over areas that were once covered by Glacial lakes. These lakes have already been described as existing along the western margin of the ice edge in two separate basins, and also south of the ice sheet in the valley of the Missouri That these bowlders were deposited in lakes is evident from the fact that in each small valley tributary to the main basin the bowlders are found at the same general level above the river. In many cases the level of the old lake may be followed for miles around the head of a valley, every few rods being marked by a deposit of one or more bowlders of northeastern origin The bowlders are most numerous along the shores of the lake, where floating ice grounded. Over the bottom of the valley such deposits are fewer and more scattered. Near the border of the lake an ice floe or iceberg carrying morainic material would strike the shore and remain there until it was entirely melted, leaving its deposit in a small heap near the old shore line. In some of the smaller valleys, distant from the ice edge, instead of a regular line of bowlders two or three small bowlder piles were found. Over the bottom of the lake there are few such piles, the material having apparently been dropped a little at a time as the ice drifted over the surface. The bowlders are more numerous on the eastern valley slope than on the western, and decrease in number with increase of distance from the ice edge. Around the inlet of these lakes, where the currents made by the entering rivers were strong, few or no bowlders are found. They are most numerous along the outlet.

The thin sheet of drift is present at various places along the ice edge. In the vicinity of Great Falls there is a large area of the deposit, which grades into the bowlder belt. North of the Highwoods the same formation is found. In the valley of the Musselshell and on the north bank of the Missouri opposite the mouth of the former river, a formation occurs which may have been deposited either by ice or by water. The edge of this deposit has not been completely mapped, and sufficient field work has not been done to determine its nature. On the map the edge that has been traced is marked by a full line, while the dotted line marks the supposed position of the part not yet surveyed.

The fact that there is such a border of drift without the terminal moraine suggests two different ice epochs, but very little was found in the field to support this theory.

The material of the ground moraine within the terminal moraine does not differ essentially from the material in the till sheet which borders it. The bowlders are of the same variety, and exist in the same proportion. A limestone is equally abundant and equally weathered on both sheets. No embedded soil or other evidence of interglacial phenomena is found, although unusual opportunity was offered both for its preservation and its discovery. The till in many places rests upon a bed of pre-Glacial gravels in such a way that not a stone seems to have been disturbed or removed by the ice. Certainly ice that passed so lightly over a gravel surface would not destroy evidence of old soil or other indications of an interglacial period.

Excellent opportunities were offered for studying sections of the drift at and within the terminal moraine. The Missouri has exposed sections of the drift 200 feet thick. The Great Northern cut-off near Fort Benton has exposed sections that clearly show drift from bed rock to the top of a 250-foot exposure, but in no section was there any suggestion of an interglacial period.

The evidence in favor of the existence of two distinct till sheets is also not convincing. The relation of the terminal moraine to the border of the thin drift is such as to suggest the pushing in of the ice after the deposit of the first sheet. In other words, the moraine appears to be later rather than recessional. This relation is shown on the map (p. 30). If the moraines were recessional, one would expect a thin border fronting the moraine at all points instead of occurring only here and there along the edge. The fact that there is more erosion in the thin than in the thicker drift ought to be indicative of their respective ages. Along the Missouri, between the mouth of the Highwood and the mouth of Little Sandy, 27 coulees of size large enough to be mapped are found. Seven of these come in from the north, or from the area of the thick drift, and 20 from the south, or from the area of the thin drift sheet. It is probable, though, that the greater amount of erosion in this area may be accounted for by the fact that there is greater drainage from this direction on account of the presence of the mountains south of the drift border.

SUMMARY.

The Keewatin ice sheet covered the northern part of Montana east of the Rocky Mountains and extended south to the Highwood Mountains and into the valley of Musselshell River. The point where the meridian 113° 15′ crosses the forty-ninth parallel marked its westernmost extent in the United States North of the boundary line, in Alberta, the drift is found still farther west Its southern edge was lobate in form, the lobation being due to the presence of the Highwood, Bearpaw, and Little Rocky mountains, which retarded the forward progress of the ice while the great valleys between them allowed it to move farther south

The Sweetgrass Hills, just south of the Canadian line and about 30 miles back from the edge of the ice, were not covered, but stood as three great nunataks, the highest reaching 2,000 feet above the ice surface.

From data gathered here and at the edge of the drift, it was found that the average slope of the glacier must have been about 50 feet per mile Wherever, along the sides of various valleys, measurements could be taken, it was found that the slopes of the surface had been slight.

Along the Rocky Mountains glaciers issued from the valleys and deployed upon the plain to the east The moraines of 14 of these glaciers were traced and mapped. In a number of cases, the ice from several mountain valleys had united and formed piedmont glaciers. The ice from a single mountain valley seldom reached far out on the plain, but the piedmont glaciers extended many miles from the foot of the mountains. This was especially true of the Blackfoot Glacier, formed by the union of the Two Medicine, Birch Creek, Blacktail, and Whitetail glaciers This sheet of ice extended 35 miles from the foot of the mountains, measuring in its widest part over 30 miles Each glacier deposited at its edge a very well defined moraine, characterized in general by bowlders peculiar to the mountain valley from which the ice issued. These moraines were in places 200 feet high and often a mile or more wide

The basins of four large rivers—the St Mary, Two Medicine, Teton, and Missouri—were dammed by the ice and the drift of the Keewatin ice sheet. The result was the formation of extensive lakes in the river basins west of the ice These lakes can be divided into two classes—those formed in front of the ice itself and those formed in front of the drift dam The former were large and existed only while the ice was present. The latter were more restricted in size but were more permanent, remaining until the drift dam had been cut through The deposits made by the first lakes consisted largely of bowlders carried out by floating ice The deposits in the smaller and later lakes were clays and gravels brought in by the rivers. The largest of these bodies of water was caused by the damming of the Missouri.

Just south of the forty-ninth parallel, between the meridians 113° 10′ and 113° 15′, the till of the Keewatin ice sheet and that of the mountain glaciers overlap. At no other point south of the boundary line did ice from opposite directions occupy the same territory, but in Two Medicine Valley the ice from the east advanced to within 2 miles of the position occupied by the ice from the mountains

The Keewatin sheet reached its most advanced position after the valley glaciers from the west had retreated, for the drift of the former overlies the drift of the latter at various points both north and south of the national boundary In some cases the till from the northeast overlies the till of the mountain glaciers This is true in the St Mary Valley, as mentioned above, and also in the valleys of St Mary River, Belly River, and Lees Creek In other places till from the east overlies fluviatile deposits that are connected with the western drift, but extend down the valleys several miles beyond the ends of the mountain glaciers Again, we find that lake and berg deposits, having their sources in the northeastern ice, overlie the till left at an earlier time by the mountain glaciers.

It is believed at the present time that as many as five separate ice sheets covered the northern part of the United States. These, named in chronologic order, are as follows: (1) Sub-Aftonian, (2) Kansan, (3) Illinoian, (4) Iowan, (5) Wisconsin. The drift deposits formed by the mountain glaciers belong to a late epoch They are certainly not earlier than the Iowan and are probably as recent as the Wisconsin So far as can be shown by the evidence gathered, no great period of time elapsed between the deposition of the Rocky Mountain drift and the deposition of the Keewatin drift Beyond the edge of the Wisconsin drift sheet is one somewhat older, though the data obtained in the region covered were not sufficient to determine its age.

In the region between the two drift deposits, there is, on the high divides between the rivers, on the terraces along the flood plains, and in the stream beds, a curious formation which has been called the quartzite gravels They are composed of resistant quartzite and slate and contain no limestone or other less durable rock. Though waterworn, they show no signs of glaciation. From their topographic position and from their character it was concluded that they were deposited by streams flowing over a flat plain This deposit occurred along the eastern front of the mountains and extended out from them many miles Subsequently the land was raised, great valleys were cut into the old base-level, and the quartzite gravels were lowered upon the terraces and scattered still farther eastward along the courses of the revived rivers. The base-level probably occurred in the latter part of the Tertiary, and the gravels date from that time. When the Keewatin ice advanced into the region, many of these gravels were picked up, glaciated, and deposited in the under portion of the drift sheet They are undoubtedly the Saskatchewan gravels of the Canadian geologists, by whom, because of their weathered appearance, their glacial markings, and their position at the bottom of a young drift sheet, they were classed as an earlier glacial deposit—the Albertan. It seems necessary now to reject the Albertan, and to class these gravels not as an old glacial deposit, but simply as old river gravels incorporated in a later drift.

As a result of the deposition of drift of the mountain glaciers, there were minor changes in drainage. Streams were shifted from one side of the valley to the other and their slope was modified More marked were the changes effected by the Keewatin ice. The Shonkin Sag was developed by ponded glacial waters. The Teton River was shifted from its old valley into the valley of the Missouri and minor changes were produced in the courses of Two Medicine River, Birch Creek, Cutbank Creek, and St. Mary River Missouri River was turned from its course at a number of places, causing the falls in the river near the city of Great Falls and the rapids and narrows in other parts of its course This ice sheet also undoubtedly turned the Missouri from a northern course and made it tributary to the Mississippi River.

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[Professional Paper No 50]

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