STATE

Geological Survey

Of North Dakota

Sixth Biennial Report

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BISMARCK
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ADMINISTRATIVE REPORT

ADMINISTRATIVE REPORT

University, N. D., Dec. 1, 1910.

To the President of the Board of Trustees of the University of North Dakota.

SIR: I beg to submit herewith my report on the work of the North Dakota Geological Survey during the years 1909 and 1910.

During the first four or five months of 1909 much of the time of the State Geologist was occupied in the preparation of the material for the Fifth Biennial Report and in supervising the printing of the volume. Early in April some time was spent in Bismarck reading a portion of the proof, and the printing of the report was practically completed by the end of May, though it was not bound and ready for distribution until the middle of the summer. The report, which forms a volume of 278 pages with several maps and many illustrations, contains chapters on the geology and coal deposits of southwestern North Dakota, the geological formations of the northeastern part of the state with particular reference to cement materials, the manufacture of hydraulic cement, the Bottineau gas field, good roads and road materials, and the geological history of North Dakota.

During the summer of 1909 work was carried on in the region included in the topographic map of the United States Geological Survey known as the Bismarck quadrangle. The area covered lies about equally on the west and east sides of the Missouri river, in Morton and Burleigh counties, but includes a small portion of Emmons County and a few square miles of Oliver County. The North Dakota and the United States geological surveys co-operated in the work on the Bismarck quadrangle, the Federal Survey bearing half the expense. By this arrangement the State Geologist and his party, composed of W. H. Clark and R. L. Sutherland, were able to spend the entire season in the field and accomplished nearly twice as much work as could have been done without this cooperative agreement. The different geological formations were carefully investigated and mapped, and the entire region was studied in considerable detail.

The results of the field work will be published as a geologic folio by the United States Geological Survey and the material will also be available for the Sixth Biennial Report of the State Geological Survey.

The Bismarck area is of special interest since in it are found two formations which have a wide distribution in the Great Plains region and the age of which has long been in doubt. The fossils collected in both these formations will assist in determining the age of the beds.

Early in June, 1910, I attended a conference of state geologists which was held in Washington at the invitation of the Director of the United States Geological Survey. This conference was called for the purpose of discussing the work of the State and Federal surveys, to arrange to cooperate as far as possible, and to become acquainted with the methods and plans adopted by the various organizations represented. The meeting also afforded an opportunity for conferring with the government geologists regarding the problems in the region, and exchanging views and opinions regarding them.

Upon my return from Washington I spent several days in Bottineau County studying the gas wells of that region. There are between fifteen and twenty producing wells ranging in depth from 150 to 200 feet. The gas occurs in a sand bed at the base of the drift, and its source is probably the Cretaceous shales on which the sand rests. Eight of the wells are located about nine miles south of Westhope, and from five of them it is piped into town and used by 120 consumers. The rock pressure varies from 55 to 65 pounds and the flow from one well was 3,200,000 cubic feet in 24 hours, the gas escaping with a loud roaring noise. Three wells have been drilled five miles east of Lansford and supply gas to that town. A report on natural gas in North Dakota has been prepared for the United States Geological Survey and will be published as one of the papers in a bulletin which is now in press.

During the summer of 1910 the field work of the previous year on the Bismarck quadrangle was extended so as to include all of Morton and portions of adjoining counties, the party being composed of the State Geologist, William Greenleaf and F. B. Farrow. The boundary of the Lance formation, which contains only a few workable coal beds, was mapped and it was found that fully one-half of Morton county, including the Standing Rock Indian Reservation, is underlain by this formation. Workable beds of lignite occur in it on the Little Heart River and at a few points on the Cannon Ball River and Cedar Creek above their confluence. With the exception of these few beds practically all the workable coal of Morton and Adams counties is in the Fort Union formation. The 8-foot coal bed mined for so many years at Sims lies near the base of the latter formation, and the same is true of the 13-foot coal bed near Haynes. The coal seams worked near New Salem and Glen Ullin are from 200 to 250 feet above the base of the Fort Union.

The Heart River was found to have formerly emptied into the Cannon Ball River instead of entering the Missouri at Mandan as at present. Its old abandoned valley extends in a southeasterly direction from the sharp bend at DuVaul, passes about two miles north of Flasher, and its lower portion is now occupied by Louse Creek for some miles from its junction with Dogtooth Creek. The Heart River was compelled to leave this broad and well developed valley of its earlier years, and through the process of stream capture or piracy it was forced to take its present course to the northeast.

Another interesting discovery was that the basin of the Little Heart River was occupied during the Glacial Period by an ice lobe from the continental glacier which covered most of North Dakota. The evidence of this is found in the typical boulder covered morainal hills which occur about the margin of the basin, being composed of the debris dumped there by the ice. The valley of the Little Heart and its tributaries was filled to a great depth with outwash silt from the melting glacial ice, forming the rich soil of the Little Heart flats and vicinity.

Professor Howard E. Simpson, assisted by W. R. Holgate, spent about a month in the study of the Devils Lake and Stump Lake area. Particular attention was given to the physical features of that interesting region, including the old lake beaches and the former outlets. The highest beach was found to be about 40 feet above the present level of the lakes. Broad, deep valleys were discovered leading from both Devils and Stump lakes south into the Sheyenne River. Levels were run to determine the height of these outlets above the lakes, and they were found to correspond to the highest beaches. It is evident, therefore, that when the surface of these lakes was 40 feet higher than at present they emptied to the south into the Sheyenne River.

During the next few years the Geological Survey will continue its investigations of the coal deposits and other economic resources of the state. The coal fields are so extensive, and the appropriation for the Survey work is so small that it will require many years of detailed work to examine and locate the workable beds, as has been done in Billings County.

The Survey has been engaged during the past year or two in gathering data regarding the underground waters of North Dakota. This is a work of the greatest importance, since when sufficient information has been secured from well drillers and others in all parts of the state it will be possible to tell approximately at what depth a supply of water may be struck in any particular region. The United States Geological Survey is cooperating in these investigations of the underground waters, and the work is being pushed as rapidly as possible with the funds available.

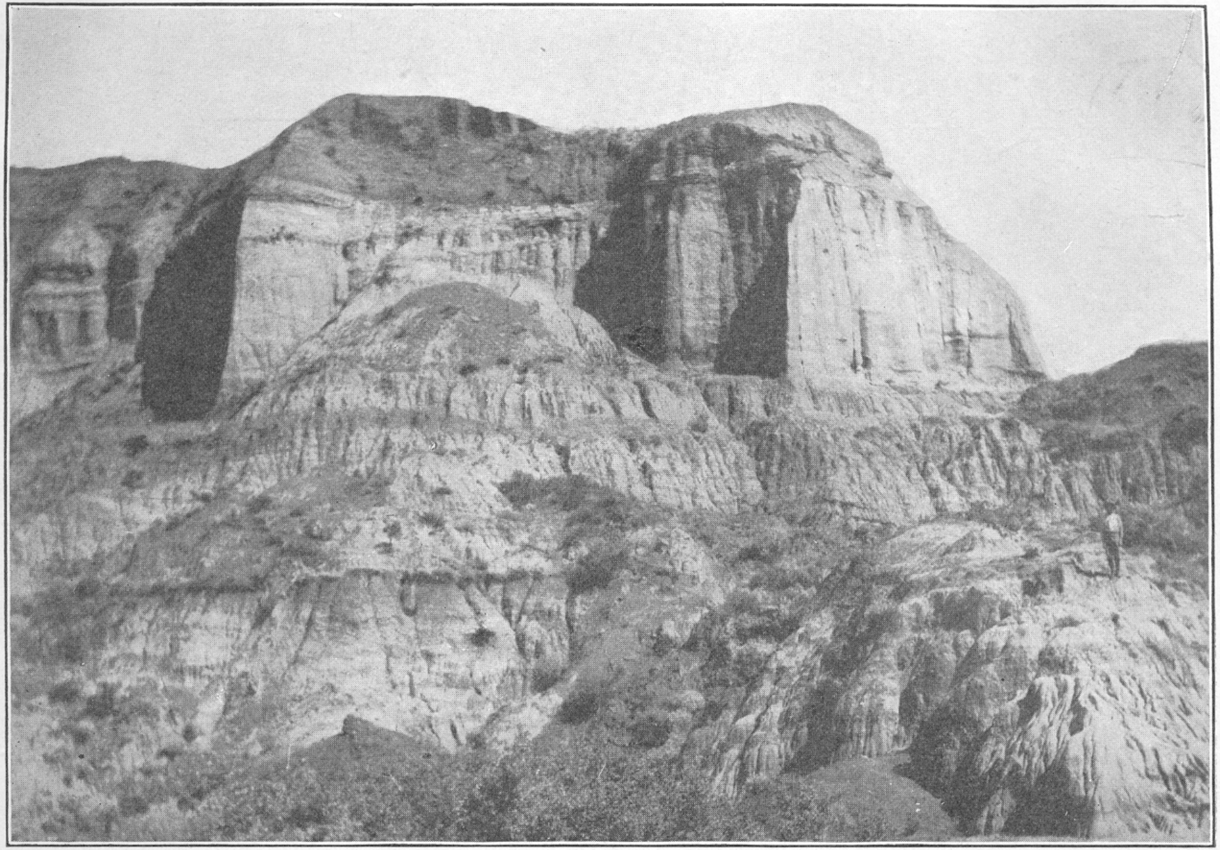
During the past few years no topographic mapping has been done in North Dakota by the United States Geological Survey.

since the State Survey has had no money with which to cooperate. Many of the states realize the great value and usefulness of these topographic maps and by appropriating large sums of money for the work are cooperating with the Federal Survey. The latter organization does all the work of preparing the maps and publishing them, all it asks of the states being that they bear half the expense of the field work. The United States Geological Survey agrees, so far as possible, to put in a dollar for every dollar contributed by the state. The State Survey should have an appropriation large enough so that several thousand dollars could be expended for topographic mapping.

The State Geological Survey now has in preparation a geologic map of North Dakota which will appear in the next biennial report.

Respectfully submitted.

A. G. LEONARD,
State Geologist.



Bluff on the west side of the Missouri River formed of Lance beds, four miles north of Gwyther, Morton County.

THE GEOLOGY OF SOUTH-CENTRAL NORTH DAKOTA

BY

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THE GEOLOGY OF SOUTH-CENTRAL NORTH DAKOTA

BY A. G. LEONARD.

INTRODUCTION

The area described in this report occupies the south-central portion of North Dakota and is divided into two parts by the Missouri River, which traverses it from north to south. It includes Morton and Emmons counties, together with a large part of Burleigh and Kidder, southeastern Hettinger, and the eastern townships of Logan and McIntosh. It is bordered on the south by South Dakota and extends north 80 miles, while in its widest portion it has a width of nearly 150 miles.

The many outcrops in this region afford an excellent opportunity for the study of the character and relations of the geological formations and make it possible to map their areal distribution. A number of coal beds and valuable clay deposits occur in the area and these also outcrop at many points. During Pleistocene times most of the region was covered by the continental ice sheet, which left behind countless numbers of glacial boulders, along with considerable till, now found chiefly east of the Missouri River. The Cretaceous and Tertiary formations which are present in this part of the state are the Pierre, Fox Hills, Lance, and Fort Union.

Work was commenced in this area during the summer of 1909 in cooperation with the United States Geological Survey. The Federal Survey had previously completed a topographic map of a portion of the region which was published as the Bismarck Quadrangle. It covered that part of the larger area, described in the following pages, which lies between the parallels 46 degrees 30 minutes and 47 degrees north latitude, and meridians 100 degrees 30 minutes and 101 degrees west longitude, embracing approximately 820 square miles. During the field season of 1909 the geology of the region comprised in the Bismarck Quadrangle was studied in as great detail as the time allowed, and a geologic map was made showing the distribution of the different formations represented in the district. The report on the Bismarck area with accompanying geologic map will appear as one of the folios of the United States Geological Survey. During the season of 1910 the field work was extended to include the area west of the Missouri River covered by the Lance formation, the boundary between the latter and the Fort Union being traced from the South Dakota line to its northernmost limits, and the coal deposits of the region being also carefully studied to learn their location and extent. The boundary of the Lance formation east of the Missouri can be determined only approximately on account of the heavy mantle of drift which covers the underlying beds so that outcrops of the latter are exceedingly rare.

PHYSIOGRAPHY

DRAINAGE

The greater part of the area is drained by the Missouri and its tributaries, the Cannon Ball, Heart and Little Heart rivers on the west, and Beaver, Long Lake and Apple creeks on the east. The Missouri River, as already stated, crosses the region from north to south, and its volume is many times that of all the other streams combined. Both the Cannon Ball and Heart rivers rise far to the west in Billings County, and have a general easterly course, although each makes a great southward bend before emptying into the Missouri. The North Fork and the South Fork (also called Cedar Creek) of the Cannon Ball unite to form the river of the same name. Its chief tributaries are Dogtooth and Louse creeks, which likewise unite to form a single stream some miles above their confluence with the Cannon Ball, and Chanta Peta Creek. The principal tributaries of the Heart in this region are Antelope, Heart Butte, Big Muddy (or Curlew) and Sweet Brier creeks, the two last named being followed for many miles by the Northern Pacific Railroad. The area between the lower Cannon Ball and Heart rivers is drained by the Little Heart River, a tributary of the Missouri.

The largest tributary on the east side of the Missouri is Beaver Creek, on which Linton is located; next comes Apple Creek, and the smallest of the three is Long Lake Creek. When the continental glacier had commenced to shrink in size, and while the Altamont moraine was forming along its margin, Apple and Beaver creeks constituted two important drainage channels for the glacial waters and these streams doubtless had much greater volume than today. The former creek has one peculiarity in common with several small tributaries of the Missouri River, that is, after entering the valley of the latter it flows for miles nearly parallel to the main stream before finally emptying into it. Apple Creek turns abruptly to the south near the State Penitentiary and flows over eight miles in this direction before joining the Missouri. This behavior of the tributaries is perhaps due to the slight outward slope of the flood plain away from the river, which prevents them from entering the main stream until it swings over to the side of the valley along which the tributary takes its course.

The fall of the Missouri River is seven and one-quarter inches per mile between Bismarck and the South Dakota line, a distance measured along the channel of 94 miles. The Heart River has a fall of six feet per mile along the general course of the valley between a point ten miles south of Richardton and the mouth, but below the mouth of the Big Muddy the river has a gradient which probably does not exceed four feet per mile of valley. The fall of the Cannon Ball River between Mott and the mouth is five feet per mile of valley, and below Stevenson it is four feet per mile. The valley of the Big Muddy has a gradient of eight feet per mile.

TOPOGRAPHY.

The region presents two chief topographic types, the upland plain with its rolling to rough surface, and the more level valley lowlands along the streams. In addition there are occasional areas of badlands along the Cannon Ball and other rivers.

The Upland.—The elevation of this upland varies from 1,730 to 2,400 feet above sea level. The streams have deeply trenched the surface of the plain and have so thoroughly dissected it over much of the area that only scattered remnants of the former plateau remain to bear witness to the extensive and long continued erosion. The largest of these is in southeastern Burleigh and southwestern Kidder counties, where there is an extensive outwash plain formed by the waters of the melting ice sheet when the Altamont moraine was being heaped up. Much fine silt was washed out from the ice border and spread over the surface for many miles beyond to form the outwash plain, which has undergone but slight erosion. It has an elevation of from 1,730 to 1,800 feet and over above sea level, and contains several shallow depressions occupied by lakes and marshes, among which Long Lake is by far the largest, with a length of about 12 miles. In the vicinity of Hazelton, in northern Emmons County, the upland has an elevation of at least 2,000 feet. West of the Missouri River in Morton County many upland areas have elevations ranging from 2,300 to 2,400 feet above sea level. Some occur only a few miles back from the Missouri, as in the case of those south of Little Heart River.

Rising from 100 to 200 feet and more above the general level of the upland plain are many buttes, which form conspicuous topographic features of the region. Among these are Three Buttes, Twin, Coffin, Mitchell, Dogtooth, Little Heart, Heart, and Crown buttes. A number are capped with a hard layer of sandstone, which has protected the softer rocks below, and many have small summits and are cone-shaped.

In some places the upland ends abruptly in an escarpment which overlooks a lower plain or the valley lowlands. Such an escarpment is found five to six miles southwest of the Big Muddy, in the northern part of T. 137 N., R. 87 W., and the southwestern corner of T. 138 N., R. 87 W. Standing on the edge of this line of steep bluffs one looks out upon a broad depression formed by Big Muddy Creek and its tributaries, which have formed a surface that is rough and much cut by valleys and ravines. Another conspicuous escarpment occurs several miles south of Three Buttes, and back eight or nine miles from the Cannon Ball River. It overlooks a lower rolling plain which extends to the river. Short, V-shaped ravines have been cut back from the edge into the upland plain.

A third escarpment is seen at the headwaters of Little Heart River forming the very abrupt eastward slope of the divide between the latter and Heart River. This narrow upland area slopes gently toward the west, and along its higher eastern border has an elevation of about 400 feet above the plain of the Little Heart. The highest and most commanding escarpment, however, in the entire region is that occurring on the west side of the Missouri Valley between the Cannon Ball and Little Heart rivers. The steep, grass covered slope, deeply furrowed and indented by many ravines and gulches, rises 600 feet above the alluvial plain.

The divide between Dogtooth and Louse creeks forms a very conspicuous topographic feature, and this sharp, serrate ridge, of which Dogtooth Buttes form a part, may be seen from a great distance. The divide is so narrow toward the summit that it has been cut through in many places, giving it a jagged outline when seen against the sky, and the origin of the name "Dogtooth" Buttes is readily apparent.

The Valley Lowlands.—The lowlands of the valleys occupy considerable areas along the Missouri, Cannon Ball, Heart and other streams of the region. In many places these lowlands rise by gentle slopes into the upland plain, merging into the latter, so that it is impossible to draw any line between the two; in other places, as indicated on a previous page, abrupt slopes lead from lowland to upland and the distinction between them is well marked. A large proportion of the surface included within the region under discussion is formed of slopes leading from the upland areas down to the lowlands of the valley bottoms.

The great depression formed by the valley of the Missouri River constitutes the most striking topographic feature of this portion of the state. The river has cut a great trench with a depth of from 400 to 600 feet, and from two to three miles wide at the bottom. Approximately 200 square miles are included in the level plain constituting the valley bottom of this river, between the 47th parallel and the South Dakota line.

The "first bottom" or flood plain lies 12 to 15 feet above the normal stage of the river. A large portion of this bottom land forms a natural hay meadow on which great quantities of wild hay are cut. Other portions are covered with a thick growth of brush and timber. The flood plain has an elevation of between 1,580 and 1,650 feet above sea level.

A terrace 45 feet above the normal water level of the river occurs at several points in the Missouri valley. Part of Bismarck is built upon this terrace, and it appears between the city and the Northern Pacific bridge. The main wagon road to Fort Lincoln traverses this terrace and the Fort itself is located upon it. Between this upper terrace and the river there is a lower one only six feet above the flood plain, or 21 feet above the normal stage of the river. Livona, in northwestern Emmons County, is located on a well-developed terrace which extends for three or four miles along the valley, with an elevation of 60 feet above the Missouri and an average width of about one-half mile. On the west side of the river for some miles below the mouth of the Little Heart, the "River Road" to Cannon Ball Post Office follows a well-developed terrace about 50 feet above the ordinary stage of water level. Traces of still others are found at intervals along the valley. These terraces are composed in part of the shales and sandstones in which the valley has been eroded, and in part of gravel, sand and river silt deposited on this bed rock.

West of Sibley Island, five miles south of Bismarck, a well defined depression representing the old channel of the Missouri River, follows around near the base of the bluffs, and the wagon road traverses a higher portion of the valley bottom lying between the abandoned and present channels.

The Heart River has cut a valley varying in its lower course from 150 to 250 feet in depth and averaging three-quarters of a mile in width. That portion which has been eroded in the upper sandstone of the Lance formation is a narrow gorge walled in by steep cliffs, presenting a marked contrast to the portions above and below, with their more gentle slopes and greater width. This narrow sandstone gorge extends down the river for a distance of five or six miles below the bridge on the Glen Ullin-Leipzig road. Then the black shales appear beneath the massive sandstone, the valley grows wider, and slipping or slumping of the bluffs has taken place on a large scale. Great masses have broken away and slid down to the bottom of the valley, and for several miles these extensive landslides form a very conspicuous feature.

Terraces of gravel and sand appear at many points along this valley, and are particularly prominent along the lower course of the Heart. In this portion the upper is about 110 feet, and the lower 70 feet above the river. The lower terrace is especially well shown on the south side of the valley three miles west of Mandan, where it has a width of nearly one-half a mile and is followed for over a mile by the wagon road. The upper terrace, which has undergone considerable erosion, appears across the Heart River south of Mandan. Near the bridge on the Glen Ullin-

Leipzig road three terraces occur along the valley, these being 20, 31, and 83 feet respectively above the river.

Another noticeable feature of the Heart valley, particularly for several miles above the mouth of the Big Muddy, is the large number of alluvial fans. These are found at the mouths of short ravines and gullies, where the sand and gravel have been spread out by the streams which formed them. Many of the fans were built long ago, and are now grassed over, with good sized trees growing on them or in the ravines from which the material was washed. Others were formed only recently, as shown by their fresh appearance.

Old Valley of Heart River. The Heart River has not always emptied into the Missouri at Mandan, as at present, but was formerly a tributary of the Cannon Ball River. Instead of making the sharp bend seven miles north of Flasher, and flowing north and east from that point, it continued its southeasterly course in a valley now occupied by the lower portion of Louse Creek and a tributary of the latter from the north. Where the old valley leaves the Heart it forms a broad, well marked depression from one to two miles wide corresponding in size to that of the present river. The bottom of this depression rises gradually for a distance of about two miles south of the sharp bend of the Heart, and after attaining an elevation of 125 feet above the latter river it descends gently to the south, thus forming a low divide separating the drainage of Louse Creek from that of the Heart. The bluffs bordering this abandoned valley on the east and northeast are continuous with those along the present Heart valley and rise 270 feet above the river, or about 150 feet above the old valley bottom at its highest point. When the Heart River followed this course it flowed diagonally across T. 135 N., R. 84 W., and T. 134 N., R. 83 W., and joined the Cannon Ball River in Sec. 36, T. 134 N., R. 82 W. For a distance of sixteen miles Louse Creek and its tributary now follow this valley and the stream formed by the confluence of Louse and Dogtooth creeks flows in it four miles before entering the Cannon Ball. A small northward flowing stream tributary to the Heart now occupies the northern end of the old valley.

It is evident from the preceding that at the time the Heart River had its course to the southeast into the Cannon Ball it flowed in a valley whose bottom was over 100 feet above that of to-day. Since the river was diverted to its present course it has eroded its valley 125 feet deeper than it was formerly.

What, then, is the cause of the sharp bend of the Heart and the diversion of its waters to the northeast into the Missouri? The most probable explanation is that we have here a case of stream piracy, or the capture of one stream by another, a process by no means uncommon. The capture appears to have been made by a short and vigorous tributary of the Missouri River which entered the latter stream at Mandan and had much the same course as the lower Heart of to-day. Being younger and having a shorter course to the Missouri it had a greater fall than the Heart, and on account of its swifter current was enabled to erode its valley faster than that river. The stream constantly increased in length until the divide separating it from the Heart was cut through by this northward flowing tributary of the Missouri, the Heart River was captured and its waters diverted into this new channel. The Heart River was also at a disadvantage compared with its rival owing to the fact that the Cannon Ball River into which it flowed was forced to cut its valley, for over ten miles above its mouth, in the Fox Hills sandstone, which is much less easily eroded than the soft shales in which the rival stream was cutting its valley. Since the Heart could not deepen its valley any faster than the Cannon Ball River, the more vigorous stream on the north had an additional advantage.

The valley of the Cannon Ball, like the valleys of the Missouri and Heart rivers, forms a very marked topographic feature of the region. At Shields it has an average width of one mile, and varies from 100 to 200 feet in depth. For some miles below the mouth of Dogtooth Creek the valley is broad, with an extensive alluvial plain and broad terraces 20 to 40 feet above the river. On the other hand, that portion which is eroded in the Fox Hills sandstone forms a narrow gorge with nearly vertical walls and having a depth of 80 to 100 feet. Extending back on either side of this gorge-like valley is a broad gently rolling to flat plain or terrace several miles wide. Rising from this plain are low bluffs with gentle slopes, evidently the sides of the broad valley of the Cannon Ball before it had commenced to sink its channel in the Fox Hills sandstone. The top of the sandstone corresponds to the surface of this terrace, and the latter evidently owes its origin to the more resistant character of the Fox Hills compared with the softer shales and sandstones of the Lance formation. The inner gorge has been cut in the sandstone, and the broad outer valley was eroded in the overlying Lance beds. The high terrace marking the former valley bottom is strewn with numerous glacial boulders, showing that at least the outer valley is preglacial, and it is not improbable that a portion of the inner gorge was eroded before the ice invasion.

At Mott the Cannon Ball River flows in a broad and relatively shallow valley with gently sloping sides, a wide flood plain and several low terraces. Cedar Creek, or the South Fork of the Cannon Ball River has a valley similar in character to the latter. At Stowers, several miles above the Morton County line, there are four terraces with elevations of 13, 17, 35, and 75 feet respectively above river level.

Big Muddy Creek has a notably broad and well graded valley, considering the length and volume of the stream which now flows in it. The flat alluvial bottom averaging half a mile wide affords a natural grade for the Northern Pacific Railroad from Almont nearly to Antelope, or a distance of nearly 40 miles. The valley between Almont and Hebron has a gradient of seven feet per mile. In like manner the Mott extension of the Northen Pacific follows the valley of Louse Creek for a distance of nearly 30 miles, the average gradient here being fifteen feet per mile.

Badlands. Rough badland areas occur along some of the steam valleys of the region. One of the most extensive is on the Cannon Ball River in the vicinity of Stebbins, where the bare clay slopes and fantastic erosion features characteristic of the badlands are well shown. These are also found along the lower courses of Dogtooth and Louse creeks, and in places along the Big Muddy. As in the case of the badlands occurring elsewhere, these are formed chiefly through the agency of rain and stream erosion acting on shales and soft sandstones, which are carved into a great variety of buttes, mesas, domes and pinnacles whose bare clay slopes expose the strata composing them.

THE LITTLE HEART BASIN AND ITS MORAINES

The drainage basin of the Little Heart River presents many features of special interest which are due largely to the action of the continental ice sheet which covered the region during the Glacial Period. Below its confluence with the Southeast Branch, about ten miles above the mouth of the Little Heart, the river has a comparatively narrow and deep valley bordered by steep slopes. Above the confluence its valley is broad, with relatively gentle slopes, and included in it are the Little Heart Flats which extend east and west a distance of eight or nine miles, with a width of two to three miles. They comprise not only the alluvial plain of Little Heart River, which is of small extent, but also the broad valley bottoms of the Southeast Branch and South Branch.

The notable change in the character of the valley of the Little Heart River, shown in its greater width and its broad flats, is due to an ice lobe of the continental glacier which occupied this drainage basin during the Glacial Period. This lobe formed the belt of morainic hills which nearly encircles the valley plain and deposited more or less drift in the preglacial valleys of the Little Heart and its tributaries. As it melted, the waters flowing from it deposited much outwash silt, building the valley trains of the South and Southeast branches, and the broad plain of which the Little Heart Flats form a part. (Plate II, Figs. 1 and 2.)

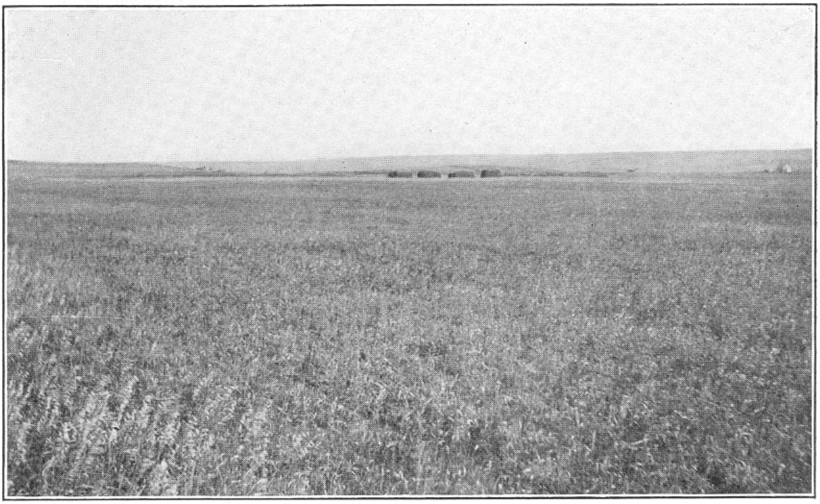


Fig. 1. The broad flat of the Southwest Branch of Little Heart River, formed of glacial outwash silt. Morainic hills show back of the four grain stacks.

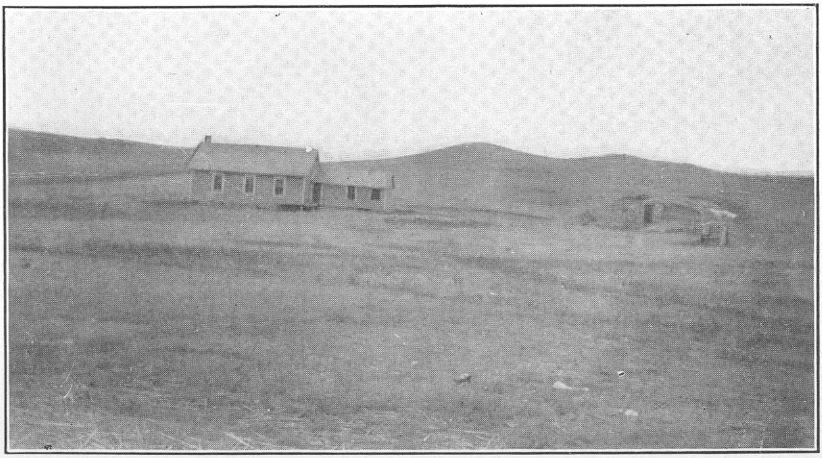


Fig. 2. Morainic hills stretching across the valley of the Southeast Branch of Little Heart River, Morton County.

That a considerable thickness of silt was deposited is shown by the fact that the divide which must at one time have separated the upper valleys of the two branches was obliterated by the filling up of the valleys. A belt of low morainic hills rising above the plain of the valley train is all that today separates the headwaters of the Southeast Branch from those of the South Branch, and forms the ill-defined divide between them, in Sec. 32, T. 136 N., R. 81 W.

A number of partially buried morainic hills rise above the plain formed by the valley train of the Southeast Branch, some of them just appearing above the level floor of the valley, like islands rising from the sea. (Plate III, Figs. 1 and 2.) The valley trains bear a very definite relation to the morainic hills which border the flats, sloping away from the moraine with a gradient which is relatively steep near the hills and becomes more gentle farther away.

The Southeast Branch winds about over its plain and among the morainic hills in a shallow V-shaped trench 8 to 10 feet in depth in its upper portion. The South Branch flows for miles in a trench even shallower and more poorly defined.

Though the moraines do not form a conspicuous feature of the Little Heart basin they are nevertheless well developed and typical drift hills. They are perhaps best shown near the head of the Southeast Branch where the moraines cross the valley bottom at several points, and also occur about the margin near the base of the slopes. In the south half of Sec. 4, T. 135 N., R. 81 W., the morainic belt crosses the upper valley of the Southeast Branch, some of the hills resting on the slopes east of the valley, and others rising from the flat. Above the moraine the valley is narrow, with almost no flood plain, while below the morainic belt the valley train is two-thirds of a mile wide. The drift hills shut in the upper valley so that the plain beyond cannot be seen, and the creek winds about among the hills which rise 20 to 40 feet above the surrounding surface. (Plate III, Figs. 1 and 2.)

The morainic belt of boulder covered hills and ridges continues unbroken along the south side of the valley of the South Branch for a distance of about twelve miles. It is particularly well developed in Secs. 31 and 32, T. 136 N., R. 81 W., where the hills as usual occur near the base of the slope. The cultivated fields extend up to the moraine and end here where the soil becomes too rocky and the slopes too steep for cultivation. The moraine crosses the upper valley of the South Branch, which is completely shut in by the hills, near the north-south township line. The road leading north from the southwest corner of T. 136 N., R. 81 W. passes between two pairs of morainic hills, one pair on the south and the other on the north side of the creek, and between a third pair just north of the forks of the road.

The morainic hills are also found on the north side of the broad valley of the South Branch, where they extend as far west and north as Sec. 23, T. 136 N., R. 82 W. The road along the north line of Sec. 32, T. 136 N., R. 81 W. leads over a typical morainic belt thickly strewn with boulders and lying on the slope 50 feet and over above the valley plain The moraine continues around to the west side of the valley of the Southeast Branch and extends north along the slope as far as the deep ravine near the north line of Sec. 20, T. 136 N., R. 81 W. Beyond this point no drift hills were observed.

On the east side of the valley there are few morainic hills north of the center of Sec. 21, T. 136 N., R. 81 W. A cluster of them occurs about the house on the north line of Sec. 28, where they lie in the valley and cover some 40 acres. The moraine is here nearly half a mile wide and extends a short distance up the slope. South of this point it is broken by the deep ravine in Secs. 33 and 34, T. 136 N., R. 81 W, but in the eastern part of Sec. 34 and in Sec. 3, T. 135 N., R 81 W. a wide belt of irregular hills is present, their sides thickly covered with boulders.

In addition to the scattered drift hills which rise above the valley plain there are three clearly defined moraines crossing the valley bottom of the Southeast Branch, all of them having a northeast-southwest trend. One extends from the Harm place in the SW ¼ of Sec. 4, T. 135 N., R. 81 W. across to the northeast corner of the same section; (Plate II, Figs. 1 and 2.) A second crosses the valley in the west half of Sec. 33, T. 136 N., R. 81 W. The creek has cut its post-glacial valley through both these moraines. The third moraine, which forms the divide between the two branches of the Little Heart river, is in the northwest corner of Sec. 32, T. 136 N., R. 81 W. Several kettle holes, so characteristic of moraines, are here found among the hills.

The soil of these drift hills is too stony to cultivate, and the wheat fields of the plain extend only to their base, so that the knolls with their many boulders present a striking contrast to the surrounding grain fields.

The morainic hills are also present on the north side of the main valley of the Little Heart, where they are found on the slope some distance above the flats, in one place as much as 150 feet. The hummocky knolls and hills, thickly strewn with boulders, extend from the Mandan-Flasher road east as far as Sec. 28, T. 137 N., R. 81 W. Several morainic hills also appear east of the Little Heart, in the east half of Sec. 28. The hill in the NW. ¼ of Sec. 30, of the same township and range, is formed in part at least of drift, and has on top several low,

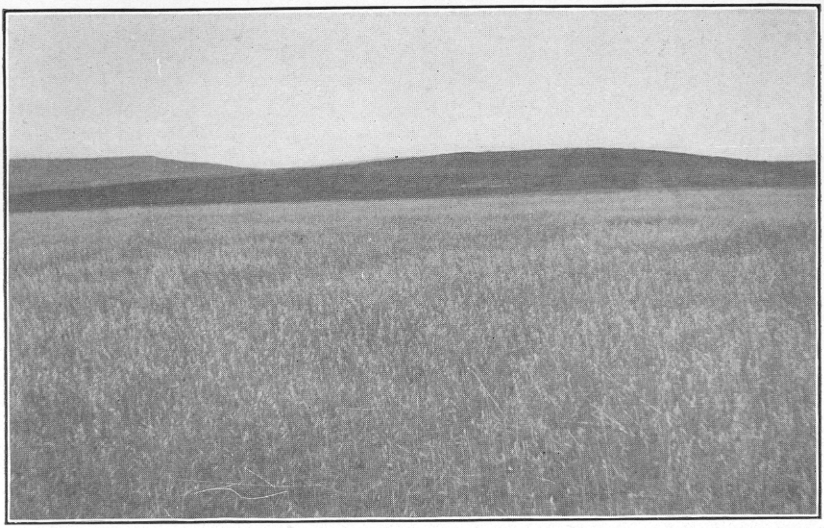


Fig. 1. Morainic hill rising above the flat valley train of the Southeast Branch of Little Heart River, Morton County.

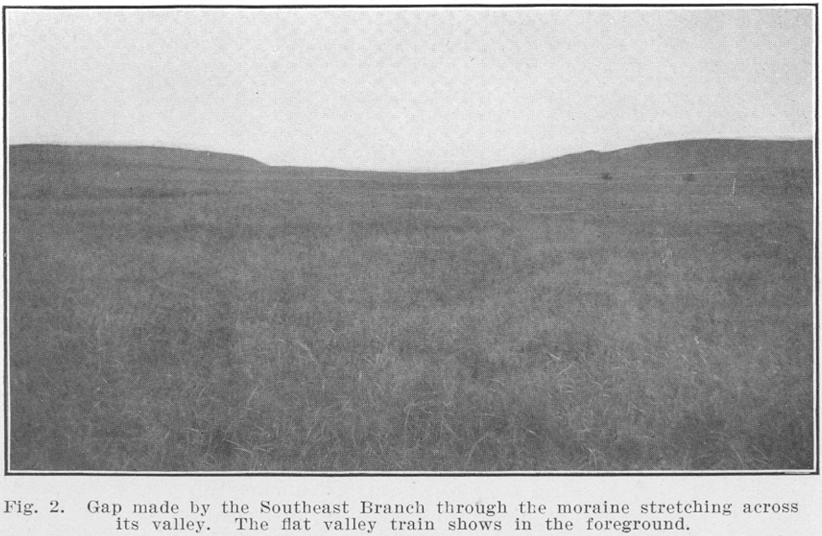


Fig. 2. Gap made by the Southeast Branch through the moraine stretching across its valley. The flat valley train shows in the foreground.

irregular knolls with great numbers of large boulders.

Rising out of the valley plain, in Secs. 33 and 34, T. 137 N., R. 82 W., is an area of morainic hills which rises almost 100 feet above the Little Heart Flats surrounding it on all sides. Its rough, hummocky surface has many low knolls which are almost paved with boulders. This area has a length east and west of one and a half miles, and a width of about one mile. Its eastern end is crossed by the main wagon road from Mandan to Flasher.

These moraines of the Little Heart Basin appear to be marginal accumulations of drift about an ice lobe which occupied the basin for a considerable period after the continental glacier had retreated some distance from its extreme western limit in this region. The limit was 40 or 50 miles farther west, as indicated by the presence of numerous glacial boulders, though little or no till or boulder clay is now found west of the Little Heart area. The ice was several hundred feet thicker in the drainage basin of the Little Heart than over the surrounding upland, and therefore probably occupied this deep depression long after it had disappeared from the highlands. When the glacier began its final retreat from this basin the sediment-laden waters flowing from the melting ice formed the valley trains of the South and Southeast branches, and also the broad valley flats of the Little Heart.

Apple Creek has a broad and comparatively shallow valley with gently sloping sides. At the time the continental ice sheet was forming the Altamont moraine, which is crossed by the Northern Pacific Railroad between Driscoll and Sterling, a portion of the drainage of the melting ice was through this valley, which at that time was doubtless much deeper than today. Evidences of this are furnished by the well at the Penitentiary, and another two miles south of McKenzie. Both of these wells passed through 200 feet of silt and struck a bed of glacial boulders which rested on several feet of sand mingled with fragments of lignite. This deep preglacial valley was filled with a great thickness of silt washed out from the melting ice, and Apple Creek must at that time have been a stream many times larger than at present. Several outcrops of sandstone which occur along the creek in the southeastern corner of T. 139 N., R. 79 W., are probably on the south side of this old preglacial valley. In some places a terrace is present 45 feet above the creek, the upper portion of it at least being composed of gravel and sand.

The depressions in the vicinity of Menoken appear to be due to the irregular deposition of the outwash material from the moraine. The long narrow one extending southeast from town is part of a large marshy tract in which one branch of Apple Creek has its source. Long Lake also occupies such a depression in the outwash plain.

Beaver Creek has cut a deep valley bordered by rather steep slopes. While the Altamont moraine was being formed by the continental glacier, the drainage of a considerable portion of the ice margin must have followed the valley of Beaver Creek. During this time much outwash sand and gravel was deposited along the stream, forming the valley train which now appears in many places as a terrace or terraces. The lower portion of the valley is cut in the Fox Hills sandstone and the latter rises nearly 150 feet above the creek for a distance of several miles above the mouth. The top of this formation forms a high terrace or bench, in which the stream has eroded its present comparatively narrow valley. The depth of the valley as a whole is between 150 and 200 feet, and back from it a greater or less distance numerous buttes rise above the adjoining surface.

The present topographic features of south-central North Dakota have been produced very largely by long continued erosion acting on a high plain or plateau having an elevation of 2,200 to 2,400 feet above sea level and formed of soft sandstones and shales. All that is left of this plateau are the scattered remnants which constitute the present upland areas, all the valleys and lowlands having been carved from the original plateau.

Five or six miles southeast of Bismarck, in T. 137 and 138 N., R. 79 W., there is an area of some eight or ten square miles which is very sandy, and in many places the sand has been heaped up by the wind into good sized hills. The Fort Yates stage road from Bismarck traverses the area for several miles and the station of Magnus is on its western edge. The sandy belt trends northwest and southeast for a distance of five or six miles and its width is not over two miles. The sand dunes are irregular in shape and height, some of the largest being 50 to 100 feet high. They are for the most part covered with grass, which prevents the sand from shifting. It will be noted that the dune area lies just east of the depression followed by the Minneapolis, St. Paul and Sault Ste. Marie Railroad southeast of Bismarck. This depression probably marks the former course of Apple Creek, when it emptied into the Missouri in Sec. 17, T. 137 N., R. 79 W. The sand was deposited along the old valley at the time it was occupied by the creek, and has since been shifted one or two miles to the east by the prevailing west winds.

PREGLACIAL VALLEY OF MISSOURI RIVER

Some evidence was found that the Missouri valley, at least in this portion of its course, is preglacial. Just above the point where Little Heart River enters the valley of the Missouri the gentle slope between the base of the bluff and the latter stream is broken by low knolls which are thickly dotted with glacial boulders, many of them of large size. They have apparently been deposited in their present position by the glacier itself, and could scarcely have reached this location if the valley had been eroded since the disappearence of the ice. Two miles south of Sugar Loaf Butte are other hills in the valley, and on them are a number of good sized boulders. Again, less than one mile north of Mandan, in the south ½ of section 23, the new branch line of the Northern Pacific Railroad passes through a cut in a terrace 55 feet above the Missouri River. Twelve feet of very coarse stratified gravel and sand are here seen resting on the uneven eroded surface of the Cretaceous shale exposed in the cut; mixed with the gravel are many boulders, some of them two and three feet in diameter, and resting almost directly on the shales. The base of the gravel at its lowest point is about 35 feet above the river. These glacial materials were doubtless deposited in the valley of the Missouri during the time that the ice sheet was melting and retreating northward and at the time of their deposition the river had lowered its valley to within at least 35 feet of the present river level.

LIST OF ELEVATIONS

The elevation above sea level of many points in the region is given in the following list:

Almont	1,935
Antelope	2,415
Arnold	1,889
Bessoba	1,733
Birdsell	2,309
Bismarck	1,672
Bismarck, Missouri River, low water	1,618
Bismarck, Missouri River, high water	1,638
Blue Grass	2,041
Burt	2,361
Carson	2,293
Crystal Springs	1,782
Curlew	1,958
Dawson	1,751
Driscoll	1,875
Eagles Nest	2,100
Elgin	2,333
Flasher	1,906
Fort Yates	1,670
Gall	1,829
Glen Ullin	2,090
Hague	1,899
Hazelton	1,980
Hebron	2,160
Judson	1,951
Knife River	2,026
Kurtz	2,026
Lark	2,066
Lawther	2,252
Linton	1,712
Little Heart Butte	2,239
Louse Creek	2,141
Lyons	1,752

Mandan	1,644
Menoken	1,745
Missouri River at mouth of Beaver Creek	1,582
Missouri River at mouth of Cannon Ball River	1,592
Missouri River at South Dakota Line	1,563
Mott	2,402
McKenzie	1,705
Napoleon	1,955
New Leipzig	2,317
New Salem	2,163
Parkin	1,698
Richardton	2,467
Sedalia	2,034
Solen	1,675
Steele	1,760
St. Anthony	1,783
Strasburg	1,805
Sunnyside	1,662
Sweet Briar	1,804
Tappen	1,769
Timmer	1,742
Wye at mouth of Cannon Ball River	1,610
Zeeland	2,012

STRATIGRAPHY

The geological formations which are found in south-central North Dakota belong to the Cretaceous, Tertiary and Pleistocene periods. Since outcrops are much more numerous west of the Missouri River in Morton County and the conditions are therefore more favorable for the study of the formations, the greater part of the field work was devoted to the investigation of the geology and coal deposits of that area. The portion of the district east of the river was, however, studied so far as time would allow and information was secured regarding its general features. The Cretaceous is represented by the Pierre, Fox Hills, and perhaps by a third formation, the Lance beds, whose age is still in doubt, but which belongs either to the Cretaceous or Tertiary; the latter period is represented by the Fort Union, and the Pleistocene by the various glacial deposits of the region.

CRETACEOUS SYSTEM

PIERRE SHALE

The Pierre shale is exposed in this region only along the Missouri valley, where it extends twenty miles north of the South Dakota line, or as far as the mouth of Beaver Creek, in Emmons County. It is a marine formation and was deposited in the great interior Cretaceous sea which formerly covered the Great Plains region, stretching from the Gulf of Mexico to the Arctic Ocean.

The Pierre formation is a bluish gray to dark gray, jointed shale, which often weathers into small, flaky fragments. The rock commonly shows spots or stains of iron oxide. The topmost beds of the Pierre contain numerous calcareous concretions varying in size from a few inches to six and eight feet in diameter. Some of these concretions are rich in invertebrates, which are characteristic of the upper part of the Pierre, while others are barren of fossils. Many are cut by a network of calcite veins which are commonly lighter colored than the matrix.

FOX HILLS SANDSTONE

The Fox Hills sandstone is the most recent of the marine formations of the Great Plains region. After the deposition of the materials composing it the sea disappeared from the country now traveresd by the upper Missouri River and the region has never again been covered by it. As shown on the map, this sandstone is found along the Missouri River as far north as old Fort Rice, about eight miles above the mouth of the Cannon Ball river; it extends up the latter stream a distance of nearly sixteen miles, and on Beaver Creek is found almost as far east as Linton.

At the mouth of Beaver Creek the top of the Fox Hills has an elevation of approximately 1,735 feet above sea level, or about 150 feet above the Missouri River. The sandstone dips to the north at the rate of about six feet per mile, its dip to the east is three feet per mile and its westward dip is between two and three feet per mile.

The Fox Hills formation is exceptionally well shown on the lower Cannon Ball River, for a distance of ten or twelve miles above its mouth. In many places it forms cliffs rising abruptly from the water's edge, and the cuts made for the new branch line of the Northern Pacific afford many excellent exposures. It rises 80 to 90 feet above the Cannon Ball River.

The sandstone when unweathered is gray with yellow patches, but in weathered outcrops it is yellow or brown in color. The rock is rather fine-grained and for the most part so soft and friable that it can be crumbled in the hand. Cross-bedding is very common and the rock contains great numbers of large and small ferruginous sandstone concretions or nodules, many of these likewise exhibiting cross-bedding. The nodules are apparently due to the segregation of the iron into irregular patches, cementing the sand into firm, hard masses, considerably harder than the sandstone in which they are imbedded. In many places the iron has impregnated certain layers and formed indurated ledges which resist weathering and project beyond the softer portions. (Plate V, Figs. 1 and 2.) The nodules vary in size from an inch and less to six and eight feet. Small, irregular, twisted or stem-like forms are abundant at certain points. Some portions of the rock are so completely filled with these brown concretions that they constitute the main bulk of the fromation, and the gray, loosely cemented sandstone forms a kind of matrix in which the hard nodules are imbedded. In the process of weathering these more resistant nodules project far beyond the softer rock, and at the base of slopes and scattered over the surface in many places these are exceedingly abundant. Where the rock has only a few of these concretions, and therefore where the iron has not been segregated to so large an extent at certain points, the sandstone is of a yellow color, due to the disseminated iron oxide. On the other hand, where the brown ferruginous nodules are thickly scattered through the beds, the rest of the rock is gray, the iron having been largely leached from it and concentrated in the nodules. Many of the latter are of good size and spherical in shape, and it is these which have given its name to the Cannon Ball River, since they occur abundantly along that stream.

In section 28, T. 134 N., R. 80 W., the following shells were collected in a bed of sandstone forty feet below the top of the formation, and about an equal distance above the river:

Tancredia americana M. and H.
Callista deweyi M. and H.
Tellina scitula M. and H.

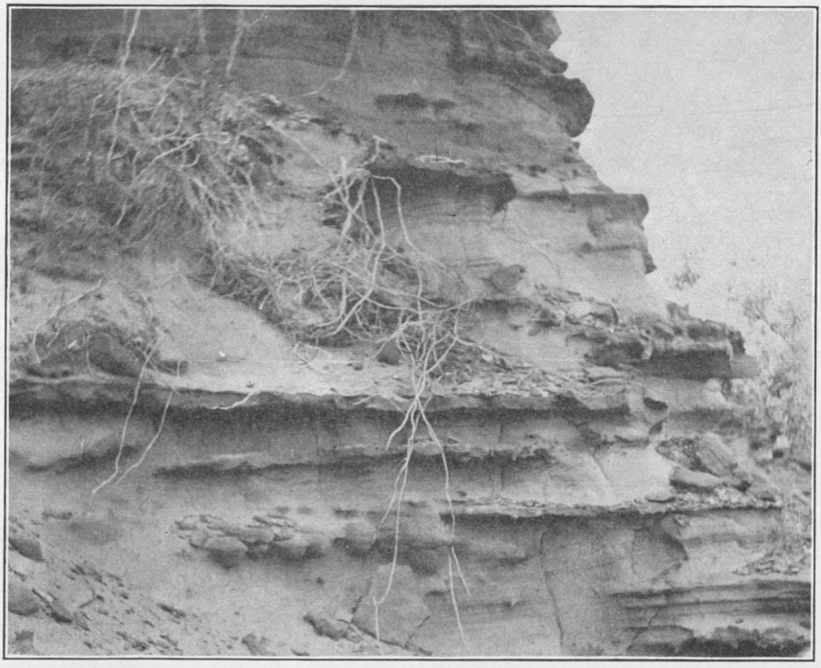
At the same locality but from a higher horizon only about ten feet below the top of the Fox Hills the shells named in the following list were collected:

Ostrea pellucida M. and H.
Avicula linguiformis E. and S.
Avicula nebrascana E. and S.
Protocardia subquadrata E. and S.
Tellina scitula M. and H.
Mactra warrenana M. and H.
Mactra? sp.
Scaphites cheyennensis (Owen).

Here also, on a slope a few feet below the top of the Fox Hills, were found two teeth. Mr. C. W. Gilmore identified one of these as the tooth of a large fish, the other as the tooth of some Morosaurus, "remains of which do not occur above the Fort Pierre." While these teeth were not found in place, it was evident from their position that they must have come either from the Fox Hills or the overlying Lance beds. It would appear to be impossible for the teeth of the Morosaurus found at this locality to have been derived from the Fort Pierre, since the nearest outcrop of the latter is fifteen miles to the south, along the Missouri River.

About three miles below this locality specimens of *Mactra warrenana* M. and H., *Dentalium gracile* M. and H.?, and *Cinulia cincinna* M. and H.? were collected. All the above fossils were identified by Dr. T. W. Stanton.

In the bluffs in Sec. 28, T. 134 N., R. 80 W., the contact of the Fox Hills with the overlying Lance beds is well shown, the



Fox Hills sandstone in the bluffs of the Cannon Ball River, showing how weathering has left the harder portion projecting.

latter resting comfortably on the sandstone. At the top of the Fox Hills there is a light gray, almost white, sandstone which exhibits cross-lamination, the laminae being one-fourth to one-half inches thick. This ledge is one foot to eighteen inches in thickness.

The Fox Hills formation is exposed at the bridge over Rice Creek, where the "River Road" crosses the creek in Sec. 15, T. 135 N., R. 79 W., about one-half mile above its junction with the Missouri. The sandstone here forms a cliff rising abruptly from the water level to a height of 30 feet above the creek. The rock exposed here is a soft, yellowish to gray sandstone which can be crumbled in the hand. It is filled with ferruginous, sandy nodules which are scattered thickly through the rock, some small and only a few inches in length, others large and six to eight feet in diameter. The Fox Hills is also exposed near the northwest corner of Sec. 15, about one-half mile above the bridge, and again in the cut bank or low cliff overhanging the Missouri in the SW. ¼, Sec. 14, T. 135 N., R. 79 W., just below the mouth of Rice Creek, where the beds rise 30 to 40 feet above the ordinary stage of the water. The river, as it swings against the cliff at this point, is undermining it and the harder layers of sandstone form projecting ledges.

East of the Missouri the sandstone extends at least as far north as the north line of T. 135 N., in the vicinity of which it disappears below river level. It is well shown in the cliff forming the river bank in the eastern half of Sec. 6 and the NW. corner of Sec. 7, T. 135 N., R. 78 W., where the Fox Hills formation rises 50 feet above the normal stage of the river. It was traced up the valley of Long Lake Creek a distance of four miles above its mouth. For many miles above the last outcrop noted there are no exposures, so that the extent of the sandstone in this direction could not be determined. About one-quarter of a mile above the bridge of the Fort Yates stage road over Long Lake Creek there is an outcrop in which the sandstone rises at least 60 feet above the creek. Here in Sec. 19, T. 135 N., R. 78 W., the following Fox Hills shells were collected 40 feet above the creek:

Avicula linguiformis E. and S.
Tellina scitula M. and H.
Chemnitzia cerithiformis M. and H.

The easternmost outcrop of the sandstone observed in the valley of Long Lake Creek was in a cut along the wagon road in the extreme NW. corner of Sec. 21, T. 135 N., R. 78 W. On Beaver Creek, which enters the Missouri about seventeen miles south of Long Lake Creek, the Fox Hills outcrops much farther eastward. It extends up the valley to within two or three miles of Linton, and near the mouth of the creek the brown, ferruginous sandstone rises over 150 feet above water level, the Pierre shale being exposed beneath it.

The thickness of the Fox Hills formation varies from 50 to 200 feet, and in the area under discussion is not much over 100 feet.

CRETACEOUS OR EOCENE ROCKS

LANCE FORMATION

Overlying the Fox Hills is a non-marine formation which has been variously called the "Ceratops beds," "Lower Fort Union," "Somber beds," "Laramie," "Hell Creek beds," and "Lance formation." The United States Geological Survey has recently adopted the name "Lance formation," derived from the term "Lance Creek beds," which was applied to the deposits by J. B. Hatcher, and this name is employed in the following pages. As already stated, the age of the Lance formation is still unsettled, some geologists regarding it as part of the Fort Union and thus early Eocene in age, while others believe that it includes, or is part of the Laramie, and is therefore Cretaceous.

The Lance beds have a wide distribution in North Dakota and eastern Montana, as well as in northwestern South Dakota and northeastern Wyoming. The largest area in North Dakota is that in the district under discussion, where the Lance formation occupies a large part of Morton County and all the Standing Rock Indian Reservation outside the Pierre and Fox Hills outcrops; east of the Missouri River it covers southern Burleigh and the greater part of Emmons County together with the adjoining portions of Kidder, Logan, and McIntosh counties.

As shown on the map, the Lance beds occur along the Missouri valley to within ten or twelve miles of Washburn. Wherever the streams have eroded the overlying Fort Union beds the Lance formation appears at the surface, and therefore along the valleys its outcrop extends much farther west than in the upland areas. It will be noted that the beds are exposed on the North Fork of the Cannon Ball almost as far as the Hettinger County line; on the Heart River they extend up to within eight or nine miles of the Stark County line; and on the tributary of Sweet Briar Creek followed by the Northern Pacific Railroad they outcrop as far west as Judson, near which station they disappear below the valley bottom. East of the Missouri River the Lance beds are for the most part covered with a mantle of glacial drift, and outcrops are not numerous even along the few streams of the region. For this reason the exact position of the eastern margin cannot be definitely determined, and it may lie some miles on one side or the other of its location on the map.

The portion of the area lying west of the Missouri affords by far the best opportunity for the study of the Lance formation by reason of the excellent exposures found along the Cannon Ball and Heart rivers and their tributaries. On Cedar Creek, or the South Fork of the Cannon Ball River, the Lance beds occur for a distance of twelve to fifteen miles in southeastern Adams County. They consist of dark gray and brown sandstones and shales which present a striking contrast to the light gray and yellow strata of the Fort Union which are exposed higher up the creek.

In passing down the North Fork of the Cannon Ball River from the western edge of Morton County to the junction with the South Fork, and thence down the Cannon Ball River to its mouth, one traverses the entire thickness of the Lance formation from the Fort Union above to the Fox Hills below. About ten miles below the Hettinger County line, in Sec. 5, T. 133 N., R. 89 W., the contact of the Fort Union and Lance formations is well shown in the following section, exposed in a high bluff of the river:

		Feet	Inches
15	Shale, light gray and yellow, to top of bluff	16	
14	Shale, chocolate brown	1	6
13	Shale, light gray	6	
12	Shale, light yellow, soft and readily crumbled	6	
11	Shale, light gray	15	
10	Coal	4	2
9	Shale, gray	23	
8	Coal	2	
7	Shale	1	6
6	Coal		31
5	Shale, sandy, light gray	10	
4	Coal	1	6
3	Sandstone, light gray, cross-bedded	25	
2	Shale, sandy brown, with much iron		4-6
1	Sandstone, soft, yellow, with concretions and some thin limonitic streaks, exposed above river	50	

Numbers 1, 2, and 3 of the above section belong to the Lance formation, while the other numbers are Fort Union. As is the case at a number of points, a coal bed (No. 4) occurs at the contact, and there are also two workable beds above this. The upper, yellow sandstone of the Lance formation extends down the river seven or eight miles below this section, forming in many places vertical cliffs rising from the water's edge. Then a dark shale appears beneath the sandstone, as shown in the following section, which is seen about ten miles below the previous one, in Secs. 29 and 30, T. 133 N., R. 88 W.:

		Feet
5	Sandstone, soft, yellow, to top of bluff	20
4	Shale, dark gray to black, alternating with thin-bedded shaly sandstone	15
3	Shale, dark gray to black, when moist	70
2	Sandstone, yellow, with hard ledge near top	20
1	Shale, dark gray to black, sandy, exposed above river	25

Only twenty feet of the upper sandstone of the Lance formation appears at this point, and the bluffs are here formed largely of the underlying black shale.

The beds near the middle portion of the Lance formation are well exposed in the bluffs on the south side of the Cannon Ball River near Shields, where the following section occurs:

	Feet	Inches
Soil and subsoil	4-5	
Sandstone, yellow to gray, soft and friable	31	
Shale, gray and yellow	10	
Sandstone, gray and yellow, containing thin shale layers and brown, carbonaceous streaks	38	
Shale, gray, containing iron concretions	15	6
Shale, black and brown, carbonaceous, containing dark brown ferruginous concretions		6-10
Shale, gray	15	6
Shale, gray, sandy	3	
Shale, brown, carbonaceous	1	
Shale, brown, carbonaceous		18
Coal		6
Shale, black, coaly	1	4
Shale, gray, sandy	11	
Shale, brown, carbonaceous	1	6
Shale, very sandy	1	6
Shale, brown, carbonaceous	2	6
Shale, gray	7	6
Sandstone, gray, soft, with shale layers near middle, 2-4 feet thick	44	
Shale, gray	8	
Unexposed to river	20	
Total	219	

One of the characteristics of the Lance beds, exhibited in many widely scattered localities, is well shown in this section; namely, the many brown, carbonaceous layers which are present, often forming a conspicuous feature of the formation, as along the Little Missouri River. It will be noted that the beds are here composed about evenly of shales and sandstones, though the latter are confined to the thick members.

About thirty miles below Shields, and ten or twelve miles above the mouth of the Cannon Ball, in Sec. 28, T. 134 N., R. 80 W., the lower Lance beds are exposed, together with the underlying Fox Hills sandstone, (Plate V, Fig. 1), as shown in the following section:

	Feet
Drift gravel and sand	2
Shale, dark colored	27
Sandstone, soft, with many thin, brown, carbonaceous laminae	11
Sandstone, yellow, soft	16
Shale, brown, carbonaceous, with two coal seams, one 3 inches and the other 7 inches thick	8
Shale, gray	3
Sandstone, gray	8
Shale, gray	4
Shale, brown, carbonaceous	3
Sandstone and shale in alternating layers, the former predominating; colors, dark gray, brown and yellow	57
Shale, dark gray, with a few brown bands	22
Sandstone, Fox Hills	80
Total	241

From the lower sandstone of this section, Fox Hills shells were collected. The Lance beds here seem to rest conformably on this sandstone, and there appears to have been a gradual change from the marine conditions of Fox Hills time to the fresh water conditions under which the Lance beds accumulated, with continuous deposition throughout.

The strata forming the upper 350 feet of the Lance formation, comprising the upper massive sandstone and the underlying dark shales, are very well exposed in the valley of the Heart River, in Morton County. For a distance of five or six miles below the bridge on the Glen Ullin-Leipzig road this valley is a narrow gorge walled in by sandstone cliffs. This rock, which forms the upper member of the Lance formation, is a massive, gray, brown, and yellow sandstone, having a thickness of approximately 100 feet. The underlying shales are dark gray to black when moist, and weather to a yellow color. They are cut by several sets of joint cracks and along these cracks the change from gray to yellow first takes place, the gray, unweathered material being left in the areas enclosed by the joints. Near the surface the shales are weathered and oxidized throughout, but at some depth the yellow color is confined to narrow bands on either side of the joint cracks. In places these beds are composed of thin layers of black shale and gray, very sandy shale or sand.

At the mouth of Heart Butte Creek the dark shales below the upper sandstone rise over 60 feet above river level, while about twenty miles below, or several miles west of the confluence of the Heart and Big Muddy Creek, they reach an elevation of 180 feet above the river. These shales and the overlying sandstone are well shown at this latter point, which is nearly south of Almont, in the northern part of T. 136 N., R. 86 W. The section here is as follows:

		Feet
5	Sandstone, yellow, soft, massive	50
4	Shale, yellow and light gray, with several brown layers containing streaks of coal	61
3	Sandstone, white	30
2	Sandstone, yellow and brown below, gray toward the top. The upper sandstone of the Lance formation	95
1	Shales, dark colored	180
	Total	416

Numbers 1 and 2 belong to the Lance formation, and the three upper numbers are Fort Union.

The sandstone forming the upper member of the Lance beds outcrops on Sweet Briar Creek, a tributary of the Heart River which is followed for a number of miles by the Northern Pacific Railroad. It extends up the creek to a point about two miles north of the railroad. It is also well exposed in the vicinity of Judson and east of that station, but disappears below the valley bottom a short distance west of Judson.

The dark colored Lance shales occurring below the sandtone are well shown along the Heart River near Mandan. (Plate VII, Fig. 2.)

The following section appears on the south side of the Heart River two miles above Mandan, in the NW. 1/4 of Sec. 32, T. 139 N., R. 81 W.:

	Feet	Inches
Soil, sandy	3	
Sand, Pleistocene	20	
Shale, gray and black, mottled; arenaceous in part, the sand being very fine; many sandy layers have yellow color. Some portions contain considerable carbonaceous material, which gives the rock its black color. Shale cut by several sets of joints running irregularly in many directions, but all making large angle with the horizontal. These joint cracks are filled with gypsum and the sides stained with iron. The mottled character shows on weathered face of the bluff, where there are large blotches of black on the gray surface	28	
Shale, dark gray and yellow, some layers sandy; more thinly bedded than overlying member	7	6
Sandstone, soft, fine-grained, gray and yellow	7	6
Sandstone, argillaceous, forming hard projecting ledge	2	
Shale, dark gray to black, alternating with bands of laminated, fine-grained, yellow sand	3	
Shale, dark gray to black when moist	9	6
Sandstone, soft and incoherent, yellow	1	
Unexposed to river level	27	
Total	108	6

The next section is exposed on the north side of the Heart River near the city limits, and just above the Northern Pacific Railroad bridge:

		Feet	Inches
12	Shale, black and gray, jointed irregularly, the joint cracks filled with gypsum; breaks into large, angular fragments. When weathered this shale has mottled appearance. To top of bluff	44	
11	Sandstone, gray below and yellow above, contains many limonitic nodules	5	
10	Shale, dark brown to black, carbonaceous, alternating with very fine-grained, finely laminated, soft, yellow and gray sandstone. The sandstone layers grow thicker and more numerous toward top of this member until they form the main bulk of the rock. The joint cracks are filled with gypsum	11	
9.	Sandstone, fine-grained, yellow, soft		5
8	Shale, sandy, dark brown	3	
7	Sandstone, soft, gray, with indurated ledge; the upper portion contains black shale layers	5	
6	Shale, black and carbonaceous, and fine-grained yellow and gray sand, in alternating layers		6-8
5	Sandstone, yellow, soft, fine-grained, laminated		6-15
4	Shale, black, carbonaceous, alternating with layers of fine-grained yellow and gray sand	6	6
3	Sandstone, yellow, soft, fine grained	1	
2	Shale, black and carbonaceous, alternating with layers of fine-grained, gray and yellow sand, ½ to 2 inches thick	15	
1	Shale, sandy, dark gray to dark brown, with some layers of soft sandstone, to river level	8	
	Total	100	10

The same dark colored shales together with a few sandy layers are well exposed in the bluff at the east end of the Northern Pacific Railroad bridge over the Missouri River. The upper beds of the section are excellently shown in the deep cut made by the railroad in its approach to the bridge. (Plate VII, Fig. 1)

BISMARCK BRIDGE SECTION

	Feet	Inches
Drift, resting on the eroded surface of the Lance formation	15-20	
Shale, dark gray to black, with thin, light gray streaks; many joint cracks a few inches apart cut the shales in many directions, the faces of the joints being stained brown by iron	42	
Shale, sandy, black	1	
Shale, black	3	6
Sandstone, dark gray to black	1	
Shale, black	2	6
Sandstone, yellow	4	
Shale, dark gray to black, and yellow, fine-grained sandstone and sandy shale, in alternating layers	22	
Shale, black	30	
Unexposed to river	15	
Total	141	

A little over two miles north of the bridge, near the line between sections 13 and 24, T. 139 N., R. 81 W., the beds forming this same horizon of the Lance formation are somewhat more arenaceous, as shown in the following section which appears in the river bluff:

BURNT CREEK SECTION

	Feet	Inches
Drift	10	
Sandstone, gray and yellow, with large concretions	22	
Shale, sandy, light colored, containing gypsum	22	
Shale, black, some layers sandy, jointed, contains considerable gypsum	30	
Shale, gray	5	6
Shale, black, sandy below	5	
Sandstone, black and yellow	5	6
Shale, black, alternating with yellow sandstone	12	
Unexposed to river	25	
Total	137	

Seven miles southeast of the Bismarck bridge section the Lance beds are exposed in the steep bluff on the east side of Apple Creek, in Sec. 26, T. 138 N., R. 80 W. As shown in the following section, the formation is here made up largely of sandstone, and the shales are comparatively unimportant.

APPLE CREEK SECTION

	Feet	Inches
Sand, fine-grained	12	
Sandstone, yellow, and gray shale, in alternating layers	27	
Coal		6
Shale, gray, with carbonaceous streak	3	
Shale, brown, carbonaceous	2	
Shale and sandstone in alternating layers	10	
Shale, dark gray to black, weathers to a very sticky clay	22	
Shale, sandy, chocolate brown, carbonaceous	1	6
Sandstone, argillaceous, gray	10	
Sandstone	1	6
Shale, sandy, gray	3	
Sandstone, gray, coarse-grained	20	
Shale, gray		5
Sandstone, coarse-grained, gray, containing several thin shale layers, exposed about creek	30	
Total	142	11

The beds forming the lower portion of the Lance formation are shown in the section already given on the Canonn Ball River several miles above its mouth. They are also well exposed in the high bluffs which border the Missouri River on the west in T. 136 N., R. 79 W. (Plate I, and Plate V, Fig. 2.) The following section is found three miles northwest of old Fort Rice, in the NE. 1/4 of Sec. 21, of the above township and range:

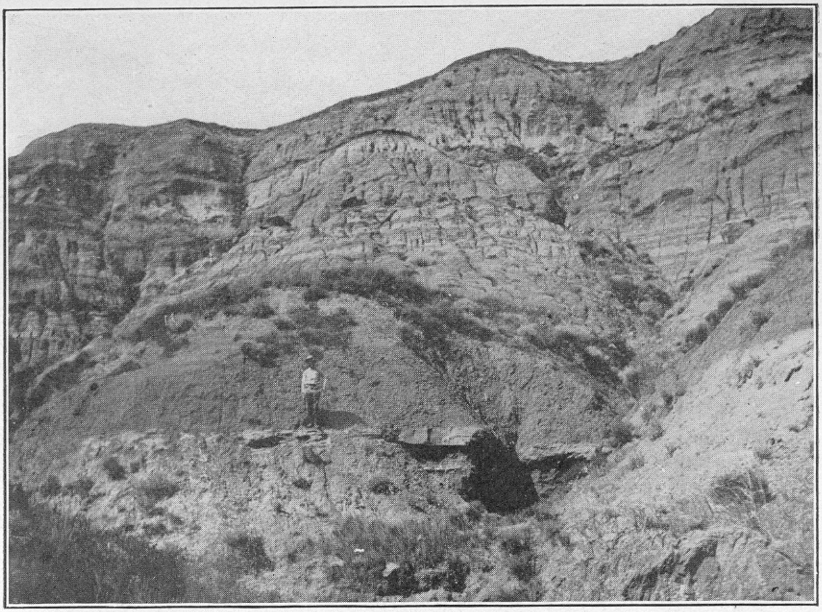


Fig. 1. Contact of Fox Hills sandstone and Lance formation, on Cannon Ball River. The ledge on which the man stands forms the top of the Fox Hills.

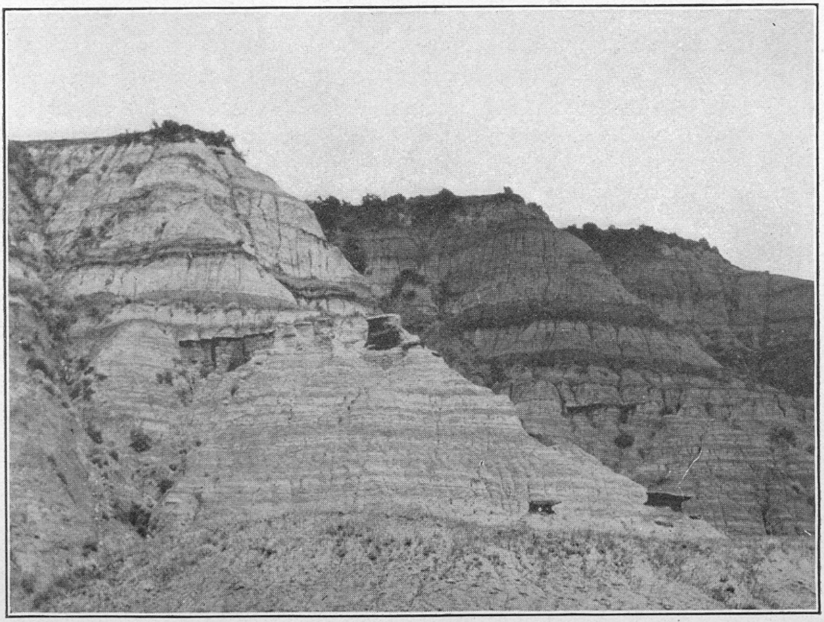


Fig. 2. Bluff on the west side of Missouri River near Gwyther, showing Lance beds rising to a height of 350 feet above the river.

	Feet	Inches
Unexposed to top of bluff	15	
Clay shale, gray	6	6
Shale, brown, carbonaceous, with thin coal seams at top and bottom; bottom coal seam two inches thick and top seam one inch thick	1	6
Shale, brown and gray, with some sandy layers	13	
Coal, with brown carbonaceous clay below		6
Shale, brown, carbonaceous, with sandstone and sandy shale toward top	15	
Sandstone, yellow and gray, soft	28	
Sandstone, soft and loosely cemented, very ferruginous and brown, with impure limonitic concretions arranged mostly in two bands, two to four inches thick	6	
Shale, dark colored, almost black when moist, brown in places		6
Sandstone, massive, shows cross-lamination, rather coarse, gray; forms vertical cliffs	44	
Shale, sandy in some layers, and sandstone, soft gray; contains dark brown ferruginous concretions at several horizons, one near the top, but these concretionary layers are not persistent	32	
Sandstone and shale, gray, in alternating layers	16	
Sandstone, soft, gray, with several thin, brown, carbonaceous bands	22	
Sandstone, gray and sandy shale, in alternating layers	4	
Unexposed to river	150	
Total	354	

The base of the above section, the lower 150 feet of which is not exposed, cannot lie far above the Fox Hills sandstone, since the latter outcrops only about four miles to the southeast.

East of the Missouri River the Lance formation outcrops at many points in Emmons County. It is perhaps best shown in the bluffs of the river in the extreme northwest corner of the county, in T. 136 N., R. 78 W. The sandstones and shales are well exposed in the cuts along the Linton Branch of the Northern Pacific Railroad between Moffit and Linton. They are seen several miles south of the former station, and also in the vicinity of Hazelton and Larvik. The beds outcrop in places along Beaver Creek above Linton, and in the buttes of the region.

The Lance formation of south-central North Dakota, as shown by the sections along the Cannon Ball and Heart rivers, consists of three members; an upper sandstone about 100 feet thick, a middle member composed of dark shales with a few sandstone layers and having a thickness of 200 to 250 feet, and a lower member made up of sandstones and shales in alternating layers. The latter member has a thickness of 350 feet or over, and the maximum thickness of the entire Lance formation is probably not far from 700 feet in this region.

Very little coal is found in this formation in the area under discussion. Thin beds are present in some places, but workable coal is of rare occurrence. There is a coal mine on the South Fork of the Cannon Ball River, in Sec. 5, T. 129 N., R. 88 W., another near Livona, in Emmons County, and a bed five feet thick is mined at various points on Little Heart River. With the exception of these beds, practically all the workable coal in Morton County and adjoining districts is in the overlying Fort Union formation. In Billings County, North Dakota, and in Montana the Lance beds contain thick coal seams, but farther east in the Missouri valley region the conditions were not favorable for the formation of extensive beds of coal.

Fossils occur sparingly in the Lance formation of this area. A portion of the tibia *Triceratops*[1] was found at a horizon about 150 feet above the Fox Hills sandstone, in the NE 1/4 of Sec. 33, T. 136 N., R. 78 W., northwestern Emmons County, and in 1908 Dr. T. W. Stanton collected dinosaur bones a few miles north of the mouth of the Cannon Ball River These were identified as Ceratopsia and Trachodon and came from beds approximately 100 feet above the Fox Hills sandstone.[2] Dr. Stanton also collected the following plants from strata a few feet above the highest observed dinosaur bones:

Taxodium sp.
Populus amblyrhyncha Ward.
Sapindus affinis Newb.
Quercus sp.
Sassafras sp.
Ficus sp. new?
Ficus sp. new

Dr. F. H. Knowlton obtained the following fragmentary plants from near the base of the bluff one and a half miles above the mouth of Apple Creek.[3]

Adiantum? sp.
Salix sp.
Quercus sp.
Ficus sp.
Laurus? sp.
Carpites sp.

The Lance formation lies near the boundary line between the Cretaceous and Tertiary, and for many years there has been much discussion concerning the age of its beds. These have recently been carefully studied by the geologists of the United States Geological Survey, and their investigations seem to show that in many places in Wyoming, Montana, and South Dakota where the contact has been observed the Lance formation rests uncomformably on the Fox Hills sandstone.[1] It has already been

1. Identified by Mr. C. W. Gilmore.
2. Proc. Wash. Acad. Sci., Vol. II, No. 3, 1909, p. 250.
3. Proc. Wash. Acad. Sci., Vol. II, No. 3, 1909, p. 200.

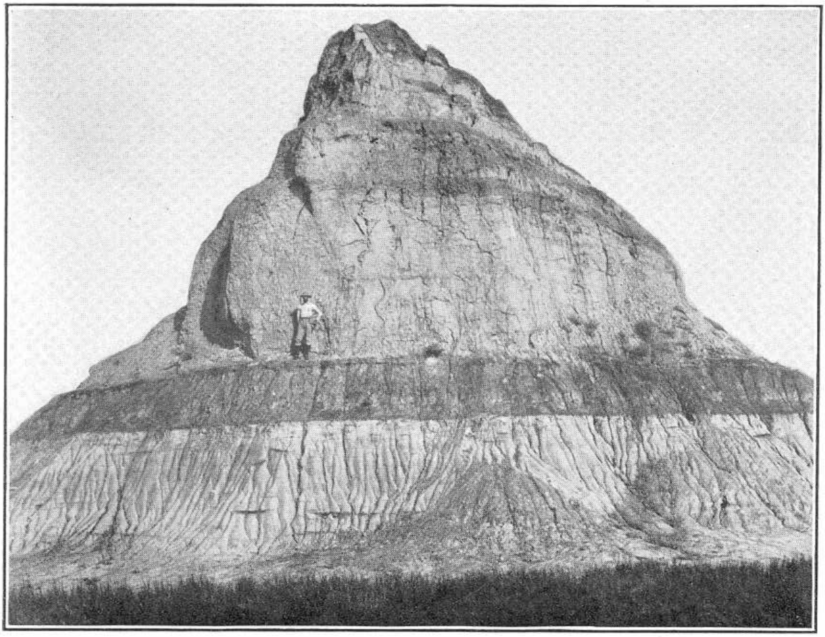


Fig. 1. One of the Twin Buttes, 8 miles south of Bismarck, on the east side of Missouri River. The butte is formed of Lance beds and shows well the effect of rain erosion on the soft clays and sands.

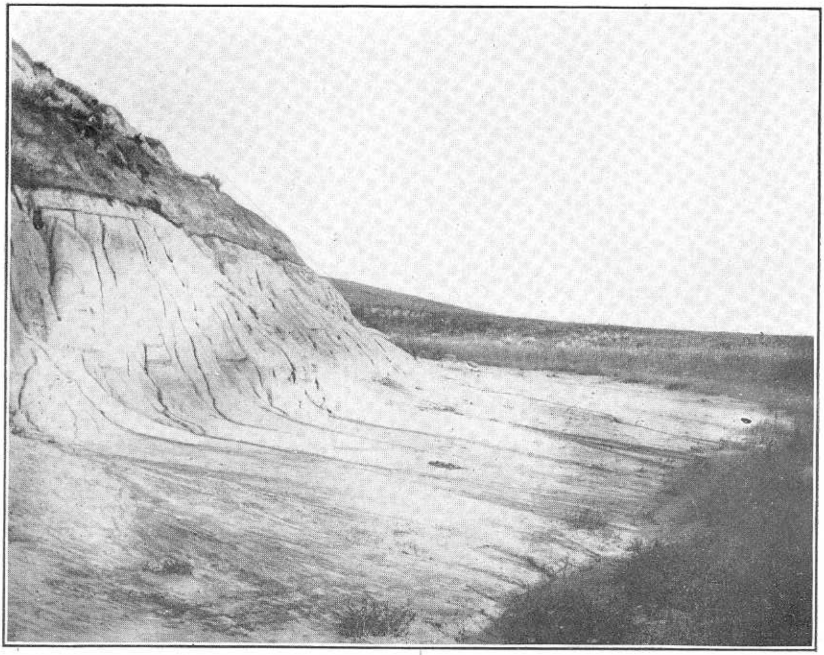


Fig. 2. Outwash material at the base of one of the Twin Buttes, 8 miles south of Bismarck, showing the result of rain erosion.

shown on a previous page that on Little Beaver Creek in Bowman County, North Dakota, the Fox Hills sandstone had undergone erosion before the deposition of the Lance beds, and although it has been questioned whether this erosion represents a long time interval, the relationship elsewhere suggests the probability of a true unconformity here. The Lance formation everywhere passes conformably into the Fort Union above, so that on stratigraphic grounds it is more closely related to the Fort Union than to the Fox Hills.

Its plants also indicate a close relationship with the Fort Union formation. According to Dr. Knowlton 193 forms of plants have been found in the Lance beds and of these, 84 species have been positively indentified.[2] Since the greater number of these plants (68 species) are common to the Fort Union, he considers the Lance beds the lower member of the Fort Union formation and therefore of Tertiary age.

On the other hand, the Lance beds are regarded by Dr. T. W. Stanton as of Cretaceous age by reason of "the pronounced Mesozoic character of the vertebrate fauna with absence of all Tertiary types, and by the close relations of its invertebrate fauna with the Cretaceous."[3] But the more recent investigations referred to above seem to indicate that the uncomformity at the base of the Lance formation is not as unimportant as it was thought to be by Dr. Stanton and that it represents a very long period of erosion during which hundreds and in places even thousands of feet of strata were removed, and on the basis, therefore, of the stratigraphic evidence the Lance formation is closely allied to the Fort Union, rather than the Fox Hills.

But to whichever system it is ultimately referred, and at the present time there is considerable evidence that it is Tertiary, it constitutes a transition formation from the Cretaceous to the Tertiary.

1. F. H. Knowlton, "Further Data on the Stratigraphic Position of the Lance Formation (Ceratops Beds)," Jour. of Geol., Vol. XIX, 1911, pp. 358-376.
2. Proc. Wash. Acad. Sci., Vol. XI, No. 3, 1909, p. 219.
3. Proc. Wash. Acad. Sci., Vol. XI., No. 3, 1909, p. 293.

TERTIARY SYSTEM.

EOCENE SERIES

FORT UNION FORMATION

The Fort Union is one of the most important and best known formations of the Northwest. It covers a vast area east of the Rocky Mountains, stretching from Wyoming to the Arctic Ocean in the valley of the Mackenzie River, and including several Canadian provinces, much of western North Dakota, eastern Montana, northwestern South Dakota and central and eastern Wyoming.

The name Fort Union was first used by Dr. F. V. Hayden in 1861 to designate the group of strata containing lignite beds in the country around Fort Union, at the mouth of the Yellowstone River, and extending north into Canada and south to old Fort Clark, on the Missouri River above Bismarck. It is a fresh water formation and is composed of clay shales alternating with soft, rather fine-grained sandstone, and containing many beds of lignite. The Fort Union is remarkably uniform in color, composition and appearance throughout the entire region. The prevailing color is either a light ash gray or yellow, but in places the beds are nearly white.

The distribution of the Fort Union formation is shown on the geological map accompanying this report. It will be seen that the beds have been extensively eroded, the streams having cut their valleys through the Fort Union and into the Lance beds. The former is therefore found on the upland areas where it has escaped the erosion which has swept away the beds over so large a part of the area. West of the Missouri River the boundary between the Lance and the Fort Union formations may be traced without much difficulty on account of the large number of outcrops, not only along the streams, but back from these on the uplands. East of the Missouri the drift covers these formations so that there are few outcrops and the position of the boundary can be determined only approximately.

In following up the South Fork of Cannon Ball River, also known as Cedar Creek, the Fort Union beds are first encountered nine or ten miles northwest of Lemmon, or not far from the east line of T. 130 N., R. 93 W. There are several excellent exposures here which show the typical yellow and ash gray shales and sandstones of this formation. Along Timber Creek, in T. 131 N., R. 91 W., there are numerous good outcrops, many of the beds being white, with some yellow shales. The Lance beds occur only in the southeast corner of the township. In Hettinger County the Fort Union beds are well exposed along the North Fork of the Canonn Ball River and on Thirty Mile Creek, and along the former stream they are found several miles east of the Morton County line. The white and light gray shales and sandstones outcrop at many points north of the Cannon Ball valley for fifteen to twenty miles east of this line, and the formation is known to extend still farther in the same direction, as shown on the map.

On the Heart River the Fort Union is well exposed near the east line of T. 136 N., R. 90 W., where the following section occurs:

	Feet	Inches
Coal, containing two-inch clay parting; the upper bed, which is mined at several points	4	
Unexposed	41	
Shale, yellow, forming the top of bluff bordering the river; typical Fort Union	19	
Shale, gray and yellow, with shell layer at top	22	8
Shale, yellow, with layer containing many shells	10	4
Shale, ash gray	2	4
Coal; the lower bed		24 to 30
Shale, chocolate brown to black	2	
Shale, gray	2	6
Sandstone ledge	1	6
Shale, yellow and light gray, with large calcareous concretions near base	21	
Sandstone, massive, gray, exposed above river	26	
Total	154	4

The lower sandstone of the above section probably belongs to the Lance formation, while the bulk of the overlying beds is to be included in the Fort Union. The latter appears also just west of Judson along the creek followed by the Northern Pacific Railroad.

The most easterly area of Fort Union strata south of the Heart River forms the high and narrow divide between the headwaters of the Little Heart River and the Heart. The beds in this divide have escaped erosion, and some 150 feet of Fort Union shales and sandstones are here present.

In the northeastern corner of Morton County, on the high divide between the Missouri River and the south branch of Otter Creek, in the southwest corner of T. 140 N., R. 81 W., the yellow clay shales of the Fort Union are found. They contained the following shells:[1]

Corbula mactriformis M. and H.
Campeloma multilineata M. and H.
Viviparus trochiformis M. and H.

East of the Missouri River there are few exposures of these beds. The formation is known to be present over the northern portion of Burleigh County, and it is found within six or seven miles of Bismarck. It does not occur much below an elevation of 2,000 feet above sea level, or some 350 feet above the river. All strata lying above this horizon in central Burleigh County belong to the Fort Union. They are well exposed two miles

1. Identified by Dr. T. W. Stanton.

northwest of Sather, in the SW. quarter of Sec. 1, T. 140 N., R. 81 W., where the following section appears:

	Feet	Inches
Unexposed to top of hill	28	
Sandstone, very soft, and containing many shells, including gastropods and a few Unios	1	
Sandstone, soft, ash gray, fine-grained	15	
Shale, yellow, containing some limonite		4-6
Shale, ash gray	16	
Coal	1	6
Sandstone, soft, very fine-grained, gray and yellow	2	
Shale, yellow	2	6
Sandstone, fine-grained, soft, ash gray and yellow, exposed	13	
Total	79	6

The ash gray and yellow shales and soft sandstone of this section are very typical of the Fort Union formation. The following shells were collected from the upper sandstone of this outcrop:[1]

Unio sp. Fragments.
Campeloma multilineata M. and H.
Campeloma producta White.
Viviparus retusus M. and H.

At the top of the high, flat topped butte in the SE. quarter of Sec. 30, T. 141 N., R. 80 W., a yellow and gray sandstone is exposed. It is at least 50 feet thick and some layers are soft while others are hard. It contained the following leaves[2] and shells:

Populus daphnogenoides Ward
Populus amblyrhyncha Ward
Populus cuneata Newb.
Aralia notata Lesq.
Platanus Haydenii Newb. Young leaf.
Viburnum sp.
Corbula mactriformis M. and H.
Viviparus multilineata M. and H.

Most of the hills in the vicinity of Sather, and to the north and northwest of the Post Office, which have an elevation of 2,000 feet or over, are capped with ledges of an indurated sandstone which generally outcrop about the summit. Fragments which have broken from the ledges above are scattered down the slopes. This sandstone has protected the hills from erosion and to a large extent determined their present height. Since there are many sandstones in the Fort Union at various horizons and separated by no very great thickness of shale, it is difficult to determine whether these ledges capping the hills belong to one or more horizons. It is perhaps more probable that they should be referred to several horizons which are not widely separated.

1. Identified by Dr. T. W. Stanton.
2. Identified by Dr. F. H. Knowlton.

Other thick sandstones of the Fort Union are well exposed in T. 140 N., R. 79 W., where they appear again at the tops of the ridges and buttes. They are particularly well shown in secs. 7, 10, 16, 18, 22, and 23. In the NW. quarter of sec. 33, T. 141 N., R. 79 W. 30 feet of yellow and gray sandstone outcrop and there are several other exposures of a similar sandstone in sec. 36 of the same township.

Judging from these outcrops and from well records the Fort Union of west-central Burleigh County is composed largely if not wholly of sandstone throughout a thickness of from 100 to 200 feet.

Near the middle of the south line of sec. 10, T. 140 N., R 79 W. the following leaves were collected in this formation:

Populus daphnogenoides Ward
Populus sp.
Populus amblyrhyncha Ward
Platanus nobilis Newb.
Grewiopsis populifolia Ward
Eucnymus? sp.

Besides the light gray and yellow beds of the typical Fort Union there are in southwestern North Dakota white, sandy clays and very pure plastic clays which belong to the same formation. They occur for the most part to the west of the area under discussion, but are present in the extreme northwest corner of Morton County and adjoining parts of Mercer and Stark counties. They are exposed in the buttes north of Hebron, and are especially well shown in the clay pit of the Hebron Pressed and Fire Brick Company. These high grade clays are restricted to the tops of the higher ridges and divides, or to an elevation of from 2,450 to 2,600 feet above sea level. Near Hebron they lie about 600 feet above the base of the Fort Union, and their maximum thickness is 150 feet.

The Fort Union formation everywhere contains beds of lignite. These vary in thickness from an inch and less to thirty-five feet, beds six, eight, and ten feet thick being common. Coal is much more liable to be present in the Fort Union than in the underlying Lance formation, for the latter is practically barren of coal in many localities and over large areas. One rarely finds an outcrop of the former where several hundred feet of strata are exposed that does not contain at least one or more coal beds. These range from top to bottom of the formation and do not appear to be confined to any particular horizon or horizons, In Morton County many of the coal beds occur well toward the base, as the one near Sims, for example. The lignite beds are described more at length in another portion of this report.

One of the most conspicuous features of the Fort Union is the vast quantity of burnt clay or clinker produced by the heat of the burning coal beds. This has been sufficient to burn the overlying clays to a red or salmon pink color and in many places to completely fuse them to slag-like masses. The beds of clinker vary in thickness from five or six to forty feet, or over, and some of them can be traced many miles in the bluffs bordering the valleys, and in the ridges and divides, while large numbers of the lower buttes are capped with these protecting layers. Such a bed of burned clay appears near the top of the bluffs bordering the valley of Big Muddy Creek for many miles above and below Glen Ullin. In the vicinity of the latter town there are three clinker horizons, the lowest about 80 feet above the railroad.

The maximum thickness of the Fort Union is not far from 1,000 feet in western North Dakota, but in the south-central part of the state the upper portion of the formation is absent. The beds have been greatly eroded, have been entirely removed over large areas, and from much of the region several hundred feet have been carried away. The thickness in Morton County is probably nowhere over 700 feet.

The Fort Union beds, which are early Eocene in age, contain a flora of nearly 400 species, and a fauna comprising both vertebrates and invertebrates.

Lists of those found in this area have been given on previous pages, and include plants and shells. Vertebrate fossils are rare in this formation, but in the western part of the state the bones of fishes, turtles, and the aquatic reptile *Champsosaurus laramiensis* have been found in the undoubted Fort Union.

QUATERNARY SYSTEM

PLEISTOCENE SERIES

The Pleistocene deposits are very different in origin from those thus far considered. Instead of being marine or ordinary fresh-water sediments, they have been formed through the agency of the vast continental glaciers which once covered the region. They present a marked contrast to the Cretaceous and Tertiary formations not only in origin but in appearance and mode of occurrence. The deposits were formed long after the Fort Union beds were laid down and they overlie the earlier formations without regard to altitude, forming a thin veneer over part of the area, and a thicker sheet over other portions east of the Missouri River. Only in the latter region are they of sufficent thickness to modify to any notable degree the preglacial topography. The Pleistocene deposits include (a) glacial boulders, (b) till, or boulder clay, and (c) more or less stratified silt, sand and gravel in terraces along the streams, and forming the valley trains of the Little Heart basin.

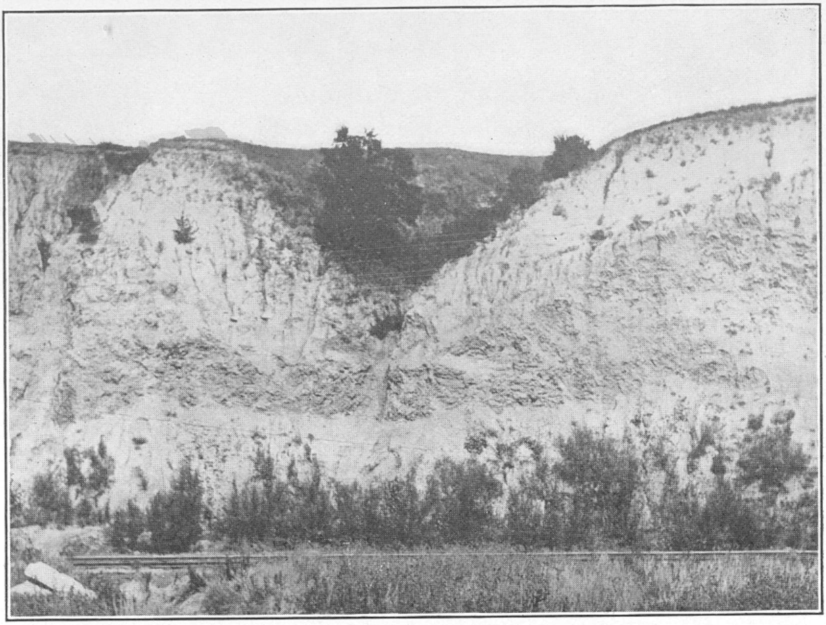


Fig. 1. Glacial drift resting upon the eroded surface of the Lance shales, at the east end of the Northern Pacific bridge at Bismarck.

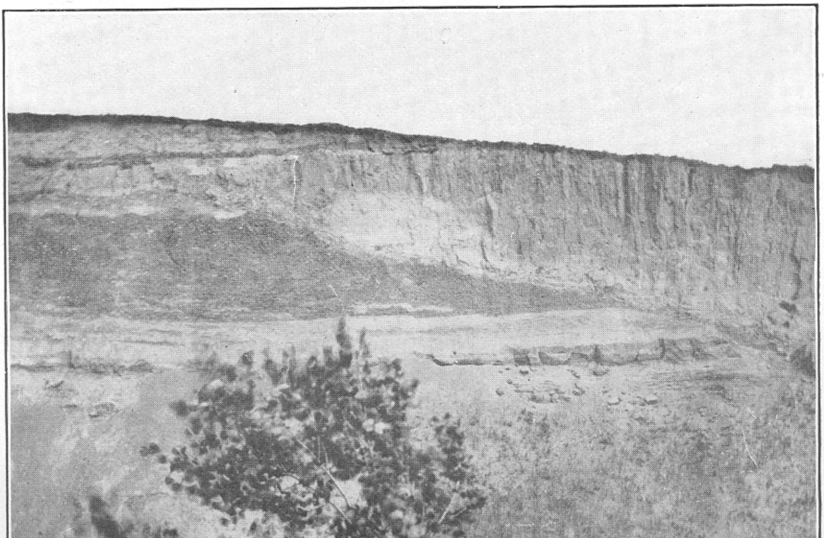


Fig. 2. Pleistocene sand resting on the eroded surface of the Lance formation, on the Heart River near Mandan.

THE ALTAMONT MORAINE

The broad belt of irregular hills and ridges which constitutes the Altamont moraine forms one of the most conspicuous features of the region. During Pleistocene time the ice moved out from the centers east and west of Hudson Bay and advancing southward overspread all of New England, the country north of the Ohio River and east of the Missouri River, including also some territory west of the latter stream. There were several periods during which the continental glacier advanced far to the south, separated by others when it retreated northward and left the surface free of ice. The last or most recent of these ice invasions was that of the Wisconsin ice and the outermost or most westerly moraine formed by this is known as the Altamont moraine. This crosses the region under discussion from northwest to southeast and throughout this part of its course lies from twelve to fifty miles east of the Missouri River. The Northern Pacific Railroad crosses the moraine between Driscoll and Sterling, and the Minneapolis, St. Paul and Sault Ste. Marie Railroad traverses it for a distance of nearly eighteen miles, beginning several miles east of Wishek in McIntosh County. The town of Lehr is located in the midst of the hills forming the moraine, and the railroad from Braddock to Ashley is only three or four miles west of the moraine.

The Altamont moraine was formed along the margin of the ice sheet where it remained stationary for a long period, the rock debris carried by the glacier being heaped up and accumulating to form the drift hills, which are in many places dotted with numerous boulders. This moraine forms a very rough belt of country characterized by irregular hills and hollows, the hills rising 50 to 100 feet and over above the intervening hollows. The depressions are often filled with water, forming the lakes and ponds so common in moraines. The rough belt varies in width from about six to twenty miles. East of the Altamont moraine the shales and sandstones of the Cretaceous and Tertiary are covered in most places by a heavy mantle of glacial debris left behind by the Wisconsin ice, and known as Wisconsin drift. The surface of this drift sheet forms a gently rolling plain which stretches eastward to the Red River Valley and beyond. Like the morainic belt it contains numerous lakes and has few streams of any size, forming an area of poor drainage.

EXTRA-MORAINIC GLACIAL TILL

During one of the earlier ice invasions the continental glacier extended far to the west of the Altamont moraine, crossing the Missouri River and moving forward to within twelve miles of the Hettinger County line between the Cannon Ball and Heart rivers. The ice margin between these rivers was 100 miles west of the present moraine, and nearly 60 miles west of the Missouri. The ice of this invasion probably left a sheet of glacial till west of the latter river but the fine debris composing the drift has been almost wholly removed by erosion during post-glacial time, since very little till is now found in Morton County. East of the Missouri River, in Burleigh and Emmons counties, till appears to be present over much of the area, though outcrops are not common and it is covered in many places by outwash material from the Altamont moraine.

West of the Missouri valley the glacial till is confined chiefly to the basin of the Little Heart River, where it has been heaped up into the morainic hills of that region. These hills have already been described under the heading of "Topography," and little need be added to what has already been given. The till was here deposited mostly in the form of irregular morainic hills and ridges which are commonly near the base of the slopes of the valley sides, and in the bottom of the valleys themselves. The boulder clay forming the higher hills probably has a thickness of from forty to sixty feet and over. Good outcrops showing the drift are, however, very rare. The best one occurs in a cut bank on the north side of the valley of Little Heart River, just below the mouth of the Southeast Branch, where ten feet of boulder clay, gravel and sand are exposed. Till also appears along the road on the opposite side of the valley, just east of the bridge across the branch.

The great number of boulders west of the Missouri River indicates that the ice sheet which overspread this region carried much coarse debris and it seems not unlikely that it also contained considerable fine material which would be left behind when the ice melted. This would have formed a sheet of till of greater or less thickness covering much of the area. The almost complete absence of glacial till west of the river, except in a few localities, is probably due, as stated above, to the fact that the fine materials of the drift have been removed by erosion and only the coarse debris, represented by the numerous boulders, has been left behind. The latter commonly rest directly on the bed rock.

East of the Missouri River and between that stream and the Altamont moraine more boulder clay is present, but even here the occasional outcrops appear to indicate that it forms only a thin veneer over the underlying rocks, seldom exceeding eight or ten feet in thickness. The till appears to be thin and patchy, being entirely absent over considerable areas from which it has perhaps been removed by erosion.

In the bluffs of the Missouri River three miles northwest of Bismarck ten feet of till are found, and in the cut at the east end of the Northern Pacific bridge across the river it attains a thickness of fifteen to twenty feet. (Plate VII, Fig. 1.) In this cut several good sized boulders are seen at the base of the drift. Boulder clay appears in a number of the cuts along the Minneapolis, St. Paul and Sault Ste. Marie Railroad north of Bismarck, generally associated with water-laid drift. Near the north line of Sec. 15, T. 139 N., R. 80 W., the following section is found:

	Feet
Soil	2½ to 4
Gravel and boulders, large and small; in places this member consists largely of boulders	2
Till, light gray	6

About three-quarters of a mile south of here, in the same section, eight feet of shale are exposed, overlain by four feet of gravel containing boulders. In sec. 22, T. 139 N., R. 80 W. an outcrop shows:

	Feet
Boulder clay	7
Shale	3½

In the NW. quarter of sec. 33, T. 141 N., R. 79 W., the Fort Union sandstone is overlain by five feet of gravelly till composed largely of local material, but containing occasional pebbles of granite and other igneous rock.

In the till of this locality and others along the railroad already mentioned Fort Union shells are found imbedded in the drift. They were doubtless incorporated in it along with the shale and sand of that formation and large numbers of them have been remarkably well preserved.

Boulder clay appears at several points on Apple Creek. An outcrop in sec. 36, T. 139 N., R. 79 W. shows eleven feet of sandstone overlain by twelve feet of till, and about four miles below, near the line between secs. 3 and 4, T. 138 N., R. 79 W., ten feet of boulder clay are exposed near the top of a cut bank.

In the many cuts of the Northern Pacific Railroad between Moffit and Linton only a little glacial till appears, although boulders are seen in many places. In several of the cuts a few feet of till was observed overlying the Lance formation.

The glacial till of south-central North Dakota, like that of much of the western part of the state, is extra-morainic drift and lies outside the outer (Altamont) moraine. This moraine is thought to mark approximately the western border of the Wisconsin drift sheet. The drift which occurs outside the Altamont moraine is thin and patchy and is represented over much of the area by boulders and gravel. As stated on a previous page, it has the appearance of having undergone much erosion, which has carried away most of the glacial debris and left behind only the coarser materials and the abundant boulders. If, as seems probable, these are all that is left of a former sheet of till which once covered the glaciated region beyond the Altamont moraine, this would indicate that a considerable period of erosion has elapsed since the deposition of the extra-morainic drift, and hence that it is an old drift. Whether it is Kansan or one of the other old drifts it is not possible to say at this time, but it may perhaps be referred provisionally to the Kansan. In the early work in this region these deposits were assigned to the Wisconsin, but evidence found later has led to the assignment of this drift to an earlier epoch.

GLACIAL BOULDERS

West of the Missouri River, in Morton County, the glacial deposits consist very largely of boulders, which are found in great numbers. (Plate VIII, Fig. 2.) Between the Heart and Cannon Ball rivers they occur as far west as range 89, or within twelve miles of the Hettinger county line, and none were observed west of this point. These boulders, which are mostly granite, thickly cover the surface in many localities, and except in rare instances no drift clay is associated with them. In some places they are scattered loosely over the ground, but in many other places they form a bed or pavement of rock in which the individual boulders are in contact with each other. These boulder deposits or boulder beds are especially noticeable on the tops of divides and on upland areas. They occur on the uplands bordering the valley of the Missouri in T. 136 N., R. 80 W., and on those which border on the east the Southeast Branch of Little Heart River; on the uplands between the South Branch of the same river and the tributaries of the Cannon Ball River and Louse Creek; on the broad divide between the Heart and Little Heart rivers, known as the Custer Flats, and on the divide northwest of Mandan between the tributaries of the Heart River and Otter Creek and the Missouri. On the narrow divide between the headwaters of the Little Heart and Heart rivers boulders occur in great numbers, heaps of them being found close to the edge of the steep eastward-facing escarpment. They are very abundant in the vicinity of New Salem and on the triangular area south of the town between the Northern Pacific Railroad, the Heart River and Big Muddy Creek. Northeast of New Salem the hills and knolls on either side of Sweetbrier Creek are thickly strewn with boulders. The great abundance of glacial boulders on the morainic hills occurring about the borders of the Little Heart basin has already been mentioned. East of the Missour River in Burleigh County boulder deposits were observed in the upland area of T. 140 N., R. 79 W., and elsewhere.

The boulders vary in size from six or eight inches to several feet in diameter, large ones measuring eight and ten feet across being seen occasionally. (Plate VIII, Fig. 2) While boulder beds are most apt to occur on the upland areas, scattered boulders are found in all parts of the region at all elevations from the bottoms of the valleys to the tops of the highest divides. They are present on areas 2,300 feet and over above sea level, or 700 feet above the Missouri River, and in valley bottoms 1,650 feet and less above sea level Boulders are reported to have been encountered in two wells at Bismarck at a depth of 125 feet below the surface or 1,545 feet above sea level.

Just north of the point where the valley of the Little Heart River enters that of the Missouri the gentle slope leading from the bluff to the latter stream is broken by low knolls and these are thickly dotted with good sized granite boulders. About seven miles southeast of here are several low hills in the valley of the Missouri which likewise carry large boulders. Glacial boulders are also found in the gravel terraces of the Missouri and Heart rivers.

STRATIFIED DRIFT

Considerable stratified drift occurs in Burleigh and Emmons counties between the Missouri River and the Altamont moraine. This is formed of the materials of the glacial drift which have been sorted and deposited through the agency of the waters flowing from the melting ice. The deposits thus have a more or less distinctly banded or stratified appearance in marked contrast to the ice-laid till which is composed of course and fine materials—clay, sand, gravel, and boulders—all mingled together in a heterogeneous mass.

While the Dakota lobe of the Wisconsin ice sheet was building the Altamont moraine, one of the important outlets for the drainage from the melting ice was Apple Creek. During the long period of time that must have been required for the formation of this massive morainic belt, the silt-laden waters of Apple Creek were making deposits in the valley of that stream. Outcrops of stratified drift which probably represent this glacial silt are found in several cuts along the Northern Pacific Railroad, where it follows the south side of Apple Creek valley.

In sec. 1, T. 138 N., R. 79 W., five feet of shale are exposed, overlain by three to four feet of yellow, finely laminated sandy clay containing near its base pebbles and small boulders of granite and other rock. In another cut one mile east of here five feet of water-laid drift appear. An outcrop in the NW. quarter of sec. 11, of the same township and range, shows twelve feet of the Lance beds overlain by seven feet of yellow, laminated, sandy clay containing lime concretions. Resting on the clay is one foot of gravel at the top of the cut. In a deep railroad cut in sec.

7 of T. 138 N., R. 79 W., twenty feet of strata are exposed. The lower fifteen feet are composed of finely laminated and fine-grained sand and clay, the laminae being much crumbled, broken and folded as though the deposit had been subjected to considerable pressure This lower portion of the section appears to be formed of much disturbed Lance beds. The upper five feet is unstratified boulder clay.

A second important outlet for the drainage of the melting ice was Beaver Creek, which has its source in western Logan and McIntosh counties, not far from the moraine. There is much outwash material along the valley of this creek, the deposit in many places being sand and gravel. These appear on the south side of the valley for many miles below Linton, and are also found on the low plain stretching away to the south of Beaver Creek.

Stratified drift, including gravel deposits, occurs north of Bismarck along Burnt and Hay creeks, where it is exposed in cuts along the Minneapolis, St. Paul and Sault Ste. Marie Railroad. In many of the cuts north of Arnold these glacial gravels appear resting on the Lance beds and having a thickness of three to six feet. Much of the gravel is very coarse, with many small boulders six to eight inches in diameter. In the vicinity of the Penitentiary seven feet of gravel are exposed along the railroad, and in a ditch beside the track, in sec. 15, T. 139 N., R. 80 W., is a deposit of gravel four feet thick containing boulders. Water-laid drift is exposed in the clay pit of the State Brick Yard near the Penitentiary. Twelve feet of clay and sand are seen here, there being three beds of clay separated by two beds of fine-grained sand.

Stratified drift is not confined to the stream valleys but is found in many places along a strip of country bordering the Altamont moraine on the west. Water-laid glacial debris doubtless underlies the outwash plain which borders the moraine, although outcrops of these deposits are rare. The Linton Branch of the Northern Pacific Railroad traverses the outwash plain between McKenzie and Moffit. The nearly level surface contains a number of undrained depressions which form marshes and alkali flats. Some of the larger basins are filled with water and form lakes, of which Long Lake is an example. Napoleon is located on such an outwash plain and the lake near town occupies a shallow depression, which is swampy in places and almost dry at times. The glacial drift here contains an abundance of fine gravel.

GLACIAL TERRACE DEPOSITS

These glacial deposits are confined to the vicinity of the streams and in their formation the materials of the drift have been sorted through the action of running water. In part at least the streams swollen by the drainage from the melting ice have been instrumental in their formation. Some of the deposits considered under this heading were perhaps formed some time after the deposition of the till, but most of them are believed to have had their origin during the Pleistocene.

Extensive gravel deposits form a terrace along the south side of the Heart River valley, and they are well shown in secs. 30, 33, and 34, T. 139 N., R. 81 W., and in sec. 25, T. 139 N., R. 82 W. The wagon road leading south from Mandan and crossing the Heart River by the new bridge near the west line of sec. 34 passes through a cut just south of the bridge, and the gravel is here well exposed. Layers of gravel alternate with beds of coarse and fine sand. Good sized pebbles of granite and other igneous rocks are not uncommon, many having a diameter of five to six inches. An extensive exposure of the gravel occurs in the large pit in sec. 30, T. 139 N., R. 81 W., to which the spur track from the Northern Pacific road extends. The terrace here has an elevation of 70 feet above the Heart River, and is composed largely of very coarse gravel and boulders eight to twelve inches in diameter, with finer gravel and a little sand. The pebbles and boulders are of glacial origin, a large proportion of the material being unlike the underlying rock, and consisting of granite, gneiss, quartzite, etc., with some local rock which is mostly the harder sandstone of the Lance beds. A number of large glacial boulders are scattered over the surface of the terrace and others are found mingled with the gravel.

In the construction of the new branch line of the Northern Pacific Railroad north from Mandan a cut was made along the edge of the terrace bordering the Missouri, about one mile north of town. In this the shales of the Lance beds are seen to rise 35 to 40 feet above the river, and resting on them is very coarse gravel and sand having a maximum thickness of twelve feet. Mingled with these materials are granite boulders two and three feet in diameter, some of them resting directly on the shales of the bed rock. Considerable coarse laminated sand is mixed with the gravel, and overlying it in places is six to eight feet of clay and fine sand, probably washed down from the slopes back from the river.

The terrace on the west side of the Missouri River south of the Little Heart and extending also a few miles north of the latter river, is formed in part of Lance beds overlain by glacial gravel and silt. These deposits are well shown in some of the railroad cuts in the vicinity of Sugarloaf Butte in the extreme northwest corner of sec. 36, T. 137 N., R. 80 W., and at a few points on the edge of the terrace. The following section, which is fairly representative, appears in one of the cuts:

	Feet
Glacial silt and wash from the bluffs	2-10
Glacial gravel	1-5
Lance beds, exposed to bottom of cut	8-10

As shown in this exposure the gravel and silt vary considerably in thickness, but they appear to be generally present on this terrace, the silt always being at the top.

Reference has been made on a previous page to the terrace at Bismarck. It lies 45 feet above normal water level, and the materials composing it are exposed a little below the steamboat landing near the Northern Pacific bridge. The terrace is here seen to be formed in part of gravel and sand, overlain by several feet of finer material, either river silt or wash from the nearby bluffs, or both. Part of Bismarck is built on the terrace, Fort Lincoln is located on it, and it extends nearly two miles farther south, its width being about two miles. Glacial terraces also occur at various points along Beaver Creek and are well shown for several miles below Linton.

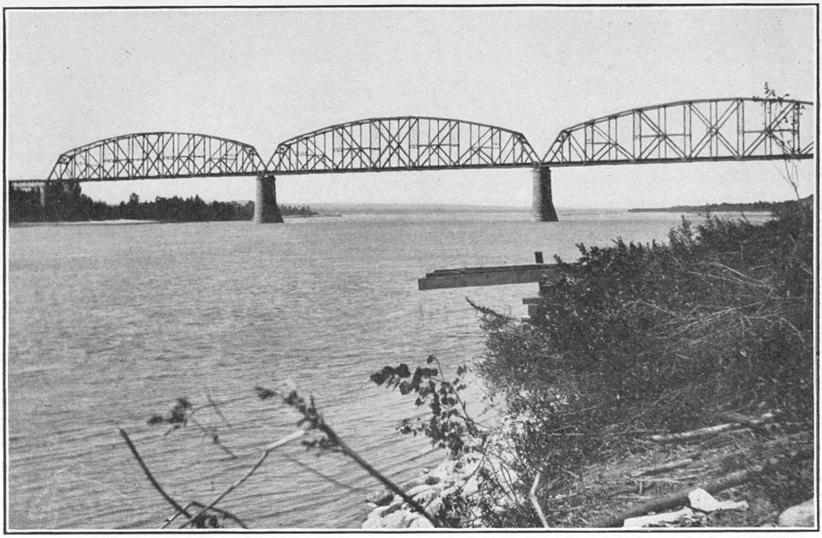


Fig. 1. Northern Pacific bridge over the Missouri River at Bismarck.

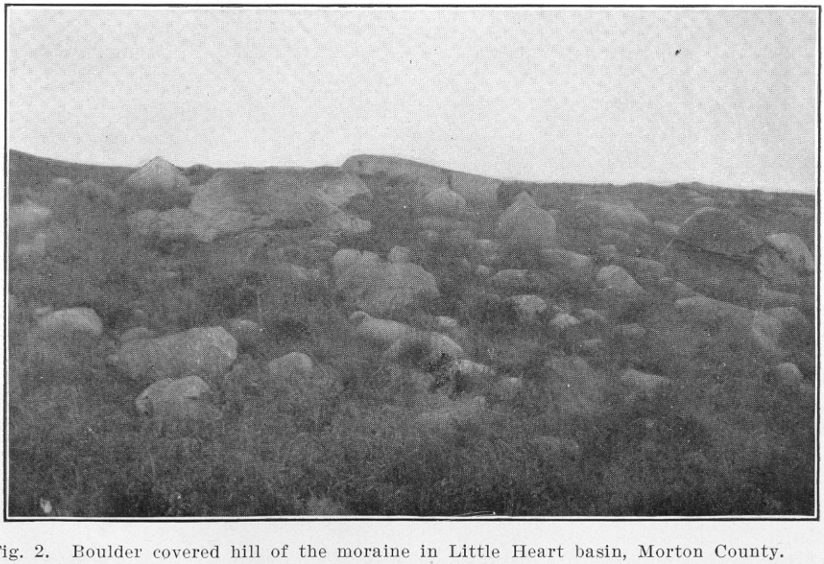


Fig. 2. Boulder covered hill of the moraine in Little Heart basin, Morton County.

RECENT SERIES

DUNE SAND

Reference has already been made in the discussion of the topography to the sandy area southeast of Bismarck in the southwestern part of T. 138 N., R. 79 W., and the northern part of T. 137 N., R. 79 W., where a deposit of sand covers eight or ten square miles. Where it has been heaped up into dunes by the wind the sand has a maximum thickness of nearly 100 feet. The area lies five or six miles east of the Missouri River, and several miles back from the bluffs bordering the valley. It does not seem at all probable that the source of the deposit was the sandy channel of the river, on account of its distance from that stream, with the bluffs between. A broad north and south depression is followed by the Minneapolis, St. Paul and Sault Ste. Marie Railroad southeast of Bismarck, and extending from near the point where this road crosses Apple Creek to the Missouri River near the Twin Buttes. As previously suggested, the source of the sand is probably this abandoned valley once occupied by Apple Creek which deposited it as sediment along its course, to be shifted later by the wind and spread out over the area now covered. The deposit rests on the drift and perhaps in places on the shale and sandstone of the Lance beds.

ALLUVIUM

Alluvium is found along practically all the streams of the area, notably along the Missouri, Heart and Cannon Ball rivers. This deposit of the rivers in recent times is spread out over the valley bottoms during periods of flood and in the Missouri valley it has accumulated to a considerable depth. It is composed of sand, gravel, and a little clay, the upper two or three feet being commonly the latter material. The belt of alluvium along the Missouri has a maximum width of three and one-half miles, with an average of about two and one-half miles.

Most of the alluvium is believed to be much more recent in origin than the terraces of glacial gravel previously mentioned, but some of the lower terraces along the Missouri and other streams are formed of recent alluvial deposits. This is doubtless true of the lower terrace between Fort Lincoln and the river, while the upper terrace, on which the Fort is built, is probably Pleistocene.

Information regarding the thickness and character of the alluvium of the Missouri River valley is afforded by the records of the borings made for the Northern Pacific Railroad prior to the building of its bridge across the river at Bismarck. (Plate VIII, Fig. 1). Through the kindness of the chief engineer, Mr. W.

L. Darling, the writer was allowed to examine these records, and the following, selected from 44 borings, are given as representative of the materials passed through.

Records of borings in channel of Missouri River near the Northern Pacific Bridge at Bismarck.

BORING NO. 21.

	Feet
Sand, fine	47.4
Gravel, clear	2.2
(At this depth struck a hard boulder and hole was abandoned)	

BORING NO. 24.

Sand, fine	33
Sand, coarse, and gravel	11
Sand, fine black	½
Sand, coarse, and gravel	10
Clay (shale) penetrated	3.9
Total thickness of alluvium	54½

BORING NO. 34.

Sand, fine	22.5
Sand, fine, and coal	7
Sand, coarse, and gravel	4
Gravel	2.5
Clay (shale) penetrated	5
Total thickness of alluvium	36

BORING NO. 13.

Sand, fine	28
Gravel	2
Sand, fine, with a little coal	19
Coal and small balls of clay	.8
Sand, coarse, gravel and coal	10.2
Sand, fine, black	.2
Gravel, coarse, and fine sand	9.2
Clay (shale), blue, and sandstone, penetrated	15.4
Total thickness of alluvium	69.4

BORING NO. 42.

Sand, fine, with gravel and coal	36.2
Sand, coarse	11
Gravel	2.2
Clay, blue	.8
Sand, fine, dark	13
Sand, coarse	5.5
Gravel, coarse	3.2
Clay (shale), penetrated	6.5
Total thickness of alluvium	71.9

BORING NO. 44.

Sand, fine	26.1
Coal	1.2
Sand, coarse, and pebbles	16.5
Sand, fine, and coal	4.5
Sand, coarse and pebbles	3.4
Clay, blue	.6
Sand, fine, dark	11
Sand, coarse,, and gravel	9

Sand, fine, and coal	6
Clay (shale) penetrated	1.5
Total thickness of alluvium	78.3

BORING NO. 9.

Sand, fine, mixed with coal and pebbles	59
Coal, mixed with lumps of clay and sand	3
Sand, coarse	3
Sand, fine, mixed with some coal	18.8
Clay (shale), blue, penetrated	10.8
Total thickness of alluvium	83.8

The first three borings, numbers 21, 24, and 34, are in the vicinity of the second pier from the east end of the bridge, while the other four borings are near the west end. The greatest thickness of river silt penetrated in any of the 44 borings was 84 feet, the deposit thickening from 30 to 84 feet in a distance of 400 feet, and being thickest at the west pier. It seems quite probable that the alluvium may extend to a considerably greater depth, since all the borings were made within 1200 feet of the east side of the valley, and the opposite side is two miles beyond the west end of the bridge. It would be interesting to know how thick the alluvium is in that portion of the valley west of the present river channel and the bridge, since the borings showed it to be increasing in thickness in that direction, and it seems reasonable to assume that it reaches to a greater depth than 84 feet, perhaps 100 or 125 feet. Borings were also made along a line one half mile below the present bridge but that site was rejected "because no hard material suitable for the foundation of the piers was found except at very great depth." The river silt was thus found to be thicker south of the bridge, how much thicker is not stated.

Reference has previously been made to two wells at Bismarck which are reported to have struck boulders at 125 feet. These were put down in the south edge of town, which is built on the 45-foot terrace. The wells, therefore, penetrated 125 feet of river silt and gravels, much of which may have been deposited during the Pleistocene, when Apple Creek was carrying such a load of glacial debris. These boulders, which rest on several feet of sand, mingled with fragments of coal, were struck at an elevation of 1,545 feet above sea level. The top of the Lance shales was reached at 1,541 feet in the deepest boring, near the west pier of the bridge.

There are a number of sand flats along the Missouri River and sand bars are constantly forming and being washed away in its channel. They are ever shifting their position and have much to do in making navigation difficult and dangerous.

Each overflow of the stream adds a little, often not more than a fraction of an inch, to the thickness of the alluvium, the materials thus deposited over the flood plains adding greatly to the fertility of these bottom lands.

STRUCTURE

The structure of the region is simple and the beds are nearly horizontal throughout the area. They have, however, a slight dip produced by a gentle anticlinal fold, the axis of which has a general north and south direction and lies not far from the Missouri River. As near as could be determined the northward dip of the strata varies from four or five feet to ten feet per mile. On Beaver Creek the Fox Hills sandstone has a dip to the east of three feet per mile, and west of the Missouri there is a westward dip of several feet to the mile. It is the northward dip of the strata which carries the Pierre, Fox Hills and Lance beds in succession below the Missouri River. On the Heart River south of Glen Ullin, at Judson, and north of Mandan and Bismarck the top of the Lance beds lies at an elevation approximately 2,000 feet above sea level. Twenty miles south of Bismarck the top of this formation is from 200 to 300 feet higher.

GEOLOGIC HISTORY.

CRETACEOUS PERIOD

During Cretaceous time the interior of the continent was depressed and the sea advanced over the land until the area now constituting North Dakota, along with the rest of the Great Plains region was submerged. At first the water was shallow and the sediments were sorted and distributed by strong currents, resulting in the formation of the Dakota sandstone. Although this sandstone lies at a depth of over 2,000 feet in this area it undoubtedly underlies the entire region, since it is known to occur to the east and south, where it is the source of artesian water in North and South Dakota.

The Cretaceous sea covered much of the state throughout Colorado and Montana time and in it were deposited the shale, chalk and sandstone of the Benton, Niobrara, Pierre and Fox Hills, with a total thickness of between 1,000 and 2,000 feet. During the formation of the shale of the Benton and Pierre the rivers brought into the sea much clay and sand from the bordering lands, while during the deposition of the intervening Niobrara beds the water was more free from sediment and marine, lime-secreting organisms abounded in countless numbers, their remains accumulating to form these calcareous beds. During Fox Hills time the sea became more shallow and strong currents sorted the materials, resulting in the formation of the cross-bedded sandstones of this epoch, which overlie the Pierre shale.

The climate during the Tertiary is believed to have been much milder in high latitudes than at the present time, the fossil floras indicating a mild temperate climate even as far north as the Arctic regions. Reference has already been made to the fact that Sequoias, similar to those found today in California, grew in North Dakota during the early Tertiary, and furnish evidence of a warm climate.

QUATERNARY PERIOD

At the close of the Tertiary period the warmth of a temperate climate gave way to the rigors of an Arctic cold. Great ice sheets or continental glaciers spread outward from several centers in Canada, until the northern part of North America was covered by a sheet of slowly moving ice hundreds or thousands of feet thick which advanced as far south as New York bay and the Ohio and Missouri rivers. At its greatest extent this ice covered all of North Dakota except the southwest corner.

The deep valley of the Missouri did not serve as a barrier to the onward movement of the ice, which extended some 60 miles farther west in the latitude of the Cannon Ball River. The Missouri does not appear to have been forced to seek a new course, at least for any great length of time, for that the present valley of the river was occupied by it previous to the glacial advance is clear from the fact that the present valley is filled to a depth of 100 feet or more by glacial deposits and late glacial or post-glacial gravels. The boulders encountered in wells at Bismarck at a depth of 125 feet and the borings for the piers of the Northern Pacific Railway bridge show that the valley was formerly 100 feet or more deeper than at present, with glacial deposits at that depth upon the preglacial surface. The filling is believed to have taken place chiefly since the Wisconsin ice invasion, though some of it may have been deposited during or after the earlier ice advance which left the sheet of extra-morainic drift over the whole region. This older drift has undergone so much erosion that in most places only boulders and residual gravel are left, the finer materials of the till having been swept away.

During the retreat of the earlier glacier an ice lobe of considerable size occupied the basin of the Little Heart River long enough to allow the accumulation of the moraines already described. This basin has a depth below the surrounding upland tracts of 200 to 300 feet, and the ice which filled it was doubtless several hundred feet thicker than that lying over the adjoining areas. It was the greater thickness of the ice in this deep depression which probably accounts for the existence of the ice lobe and its attendant moraines.

Wherever the end of the diminishing lobe remained stationary for a time terminal moraines were formed across the valley, represented by those near the head of the Southeast Branch. At the same time the silt-laden waters flowing from the melting glacier deposited their sediment to build up the valley train which forms the gently sloping plains of this basin.

It is possible that the drainage of the Little Heart basin was at one time southeastward by way of the valley now occupied by the tributary of Chanta Peta Creek, in the northeast corner of T. 135 N., R. 81 W. It is impossible to determine whether the divide between this tributary and the headwaters of the South and Southeast branches is composed in part of bedrock or is formed wholly of morainic material which accumulated in the preglacial valley, but it is certain that the divide is in part at least formed by a moraine.

The northward retreat of the ice from the Little Heart area, with the formation of a lake by the blocking of the narrow lower portion of the valley, also suggests itself as perhaps a possible explanation of the broad flats of the region. But no evidence of such a lake has been found, and the decided slope of the valley bottoms, in places nearly 25 feet to the mile, is opposed to the hypothesis of a glacial lake in this region. The deposition which has produced the flats was apparently made by streams flowing from the melting ice while the moraines were being formed.

After the earlier ice sheet had withdrawn from this region, perhaps as far north as Canada, there was a readvance, and the Dakota lobe of the Wisconsin glacier covered much of North Dakota, but did not extend as far as the Missouri River. The margin of the ice then remained nearly stationary long enough to allow the accumulation of the massive and broad Altamont moraine, which has been traced for hundreds of miles in Canada, North and South Dakota, Minnesota and Iowa. During its formation the various branches of Apple and Beaver creeks having their source in or near the moraine drained a large area of the melting ice. The greater part of the water-laid drift was deposted at this time.

The present valley of Apple Creek is broad and comparatively shallow with gently sloping sides, and the preglacial valley was probably much deeper. A deep well at the State penitentiary and another about two miles south of McKenzie each passed through about 200 feet of silt and struck a bed of glacial boulders resting on several feet of sand and fragments of lignite. This deep preglacial valley was filled with a great thickness of silt washed from the melting ice, and Apple Creek must at that time have been many times larger than today.

It was probably during the glacial epoch that the lower course of Apple Creek was changed from its former position, when it flowed through the depression extending northward from the Twin Buttes, to its present location along the base of the eastern bluff of the Missouri valley. The sand which had accumulated along its old valley bottom was heaped up into dunes by the wind and shifted a mile or two to the east.

The gravel terraces along the Missouri, Heart, and other streams were doubtless formed toward the close of the Glacial Period, when the rivers were flooded by the melting ice and their swift currents carried much coarse glacial gravel and deposited the materials along the valley bottoms. Subsequently the streams sank their channels below their old flood plains, so that the latter were left as terraces many feet above the present bottom lands.

Since the disappearance of the ice sheet the streams have spread alluvium over their flood plains and the Missouri River has deposited silt in its valley to a depth of over 80 feet. The latter river has also shifted its course from time to time, and portions of its abandoned channel are seen at various points along the valley. Much material has washed down the slopes of the area and has been spread out at their base. The fine materials of the till sheet which doubtless once covered the region have been largely swept away, leaving behind over large areas only the coarser gravel and boulders of the drift. The soils have been formed in part by the weathering of the Lance beds and Fort Union shales and sandstones, partly by the wash material carried down the slopes, and partly from the drift, both stratified and unstratified, all intermingled with decayed vegetable remains.

ECONOMIC RESOURCES.

LIGNITE

The mineral resources of the region consist of lignite, clay, gravel and sand and the resources of surface and underground water and the soil.

The coal beds of the state are confined to the Fort Union and Lance formations, and by far the greatest number occur in the Fort Union. In southern Billings County, particularly in the vicinity of Yule, and at several points in Morton County workable beds of lignite are found in the Lance formation, but throughout most of its area the latter is barren of coal with the exception of thin seams only a few inches thick.

The coal of this region, as in the rest of North Dakota, is mostly a brown lignite with a decidedly woody structure, showing clearly the grain of the wood and having the toughness of

After the Fox Hills sandstone had been deposited marine conditions came to an end and the sea withdrew from this region, never again to return. The next rocks to be formed were the Lance beds, which were probably accumulated in a fresh water lake or lakes. The fine and coarse sediment deposited in these fresh waters, and resting directly upon the Fox Hills formation, produced the alternating shales and sandstones constituting the Lance beds. In certain localities marshes or swamps were formed, due in many instances doubtless to the filling of the lake basins with sediment, and the vegetation which grew in these marshy places accumulated to form coal beds. At this time great land reptiles or dinosaurs were abundant, being represented by the massive and clumsy *Triceratops*, which must have roamed in large numbers along the shores of lake and swamp.

TERTIARY PERIOD

Deposition continued during Fort Union time, but there was a great extension of the fresh water lakes until they covered large portions of North Dakota, Montana, Wyoming, and western Canada. In the waters of these basins were deposited the sandstones, clays, and shales of the Fort Union. This was a particulary favorable time for coal formation, there being many extensive swamps in which grew and accumulated year after year the coal-forming trees and other plants. As many as 400 species of plants are known to have been living at this time, among them being a Sequoia which is related to the giant redwoods of California, and their remains were preserved in the Fort Union rocks.

At the close of Fort Union time deposition ceased in this region, although 50 miles to the west it continued into the Oligocene and fluviatile and locustrine sediments containing many mammalian remains accumulated to a thickness of at least 300 feet. Throughout most of the Tertiary period the land was rising and was subjected to long continued and extensive erosion, resulting in the removal of hundreds of feet of strata over large areas, and the formation of the broad, deep valleys of the Missouri, the Heart and the Cannon Ball, and those of their numerous tributaries. During this Tertiary erosion the Missouri River cut its valley to a depth of nearly 800 feet below the present upland surface and to a width varying from two to three and a half miles. The present relief, the topographic features of the region, including the high ridges and divides, the isolated buttes, the escarpments, and the stream valleys were all formed in large part by erosion during the Tertiary period. The surface of the greater portion of the area was thus reduced in height to the extent of from 100 to 800 feet or more.

that material. It breaks or splits readily along the grain, but is broken with difficulty in any other direction. Portions of flattened trunks and branches are often found in the beds, bearing a close resemblance to the original wood except for the brown color. The same bed is frequently more woody in some portions than others, being made up of alternating layers of tough brown lignite and black, lustrous, brittle material.

Lignite contains from 35 to 40 per cent, and over, of water, and on exposure to the air it loses part of this moisture, begins to crack, and finally breaks up into small fragments.

Many of the coal beds have burned out over large areas and there are few which have wholly escaped burning. Some were doubtless set on fire by man, others may have caught from prairie fires, but it seems probable that spontaneous combustion has been the chief cause.

This burning of the coal beds has doubtless been going on for many thousands of years, ever since the erosion of the overlying strata brought them near the surface or exposed them in the bluffs and buttes. Once started the fire slowly smoulders and works its way back farther and farther from the outcrop, the overlying clays settling down as the coal is consumed and the cracks thus opened admitting fresh supplies of air. Thus a coal bed which is not too far below the surface may continue to burn for a long period and instances are known where beds have been on fire for at least twenty years. It seems improbable that this coal can burn back very far from the outcrop when covered by any considerable thickness of rock, for after the coal had been consumed this would settle down and occupy its place, thus shutting off the air and smothering the fire. It seems likely, therefore, that those beds of lignite which have burned out over many square miles must have been near the surface, as we find them today, when they were being consumed.

The heat thus produced has changed the overlying clays, and either burned them to a red or pink clinker, or entirely fused them into slag-like masses. These clinker beds often have a thickness of forty or fifty feet and are a conspicuous feature in some parts of the region.

The coal beds of south-central North Dakota range from a fraction of an inch to twelve feet in thickness. Beds over nine feet thick are exceptional in this part of the state, while those having a thickness of six or seven feet or less are not uncommon. The extent of only a few of the coal beds of the region could be determined, but it is evident that many of them cover large areas. One coal bed in northwestern Morton County was traced over twelve miles by its clinker bed, and it probably had an areal extent of at least 200 square miles.

COAL IN THE LANCE BEDS

Coal is by no means as abundant in this formation as in the overlying Fort Union, and over extensive areas it contains no beds of workable thickness. In the region under discussion only two or three coal beds belonging to the Lance formation are of sufficient thickness to be mined. One of these workable seams is exposed in the valley of the Little Heart river and tributary valleys in the eastern portion of T. 137 N., R. 81 W. The coal lies about 100 feet above the Missouri river or a little over 1,750 feet above sea level, and has a maximum thickness where worked of 6 feet 7 inches, though in most places it is not over 5 feet thick.

At the Kipoven mine, in the NE. quarter of sec. 25, T. 137 N., R. 81 W., the section of the coal bed is as follows:

	Feet	Inches
Shale		
Lignite		2-3
Clay		5
Lignite	1	7
Clay		3-4
Lignite	5	
Shale		

The coal is mined by drifting in along the bed from the outcrop, the 5-foot coal bed and overlying clay parting are removed and the 19-inch coal bed is left to form the roof. Coal has been mined from this opening for about four years and the drift is in over 300 feet, the lignite being run out on cars. Farmers are reported to come to this mine for their coal distances of 15 to 20 miles from the south and southwest. The lignite sells at the mine for $1.25 a ton.

This coal bed has been mined by drifting into it in five or six other places along its outcrop in the valley in sections 24 and 25, T. 137 N., R. 81 W. In the SE. quarter, sec. 24, the section of the bed is as follows:

	Feet	Inches
Shale		4
Lignite		4
Clay		7
Lignite		7
Clay		2
Lignite		5
Clay		7
Lignite	4	5
Clay shale		

What is doubtless the same coal bed has been opened up along its outcrop at several points in the ravine in the NE. quarter, sec.

26. The coal is here thinner, ranging from three and a half to four feet, and the clay parting over the lower coal bed is thicker. The lignite has also been mined in the NE. quarter, section 22 of the same township and range.

All the above localities are south of the Little Heart River, but the same coal has been opened up in a number of places on the north side of the river, particularly in the south half of sec. 14, T. 137 N., R. 81 W., where the bed is at least three and a half feet thick. It is being mined at present in the NE. quarter, sec. 14, and the drift runs back several hundred feet from the face of the outcrop. The coal is brought out on cars running on wooden rails with strap iron nailed on them. The lignite bed is here 33 inches thick and one foot of overlying clay is removed to give more room for working. A prospect hole dug in sec. 12, shows 34 inches of coal.

Where the bed has been prospected to the north and northeast it is found to be thinner and the coal is split into several seams by partings of clay. It has been uncovered by stripping along its outcrop in sec. 7, T. 137 N., R. 80 W., and the lignite here measures only one foot in thickness. In the point of the bluff at the mouth of Little Heart River, on which the trangulation station was established, the following thin beds appear, representing the workable coal bed found elsewhere:

	Feet	Inches
Shale		
Lignite, shaly		4
Clay		10
Lignite		4
Shale, brown, carbonaceous		17
Lignite		9
Shale, brown, carbonaceous, with one-inch coal seam	3	
Shale and sandstone to river level	120	

It will be seen from the above section that the lignite bed is here split into three which are separated by seams of clay shale.

The mines are worked only in the fall and winter months. Little timbering is used near the entrance.

The Little Heart coal bed does not extend more than one or two miles north of the river, since it grows thinner in this direction and splits into several thin beds with clay seams between. The coal bed has been extensively eroded in the valley of the Little Heart and its tributaries, the main valley having been cut to a depth of 50 to 100 feet below the coal. South of the river it is known to extend into section 25 and 26, T. 137 N., R. 81 W., and how much farther has not been ascertained. The surface rises rapidly to the upland level, where the coal, if present, has a depth of 250 to 300 feet, and there are no well borings which have gone down to this depth. It is not improbable that the Little Heart coal bed underlies the southwestern sections of T. 137 N., R. 80 W., and the southeastern sections of T. 137 N., R. 81 W. The best place to prospect for the coal would be in the valley followed by the Telegraph Road down to the crossing of the Little Heart River, or toward the base of the slope in sec. 27, T. 137 N., R. 81 W.

In the southwestern corner of Morton County another bed is worked in the NW. quarter, sec. 5, T. 129 N., R. 88 W., on the north side of the South Fork of the Cannon Ball River or Cedar Creek. The mine is known as the McCord coal bank, and the lignite lies 250 feet above the Fox Hills.[1]

Some coal is reported to occur in the badlands along the North Fork of the Cannon Ball River in the vicinity of Stebbins.

East of the Missouri River in Emmons County a coal bed is mined near Livona, in secs. 4 and 9, T. 135 N., R. 78 W. This mine is located within two miles of the outcrop of the Fox Hills sandstone along the river and the bed lies about 1,850 feet above sea level, or not far from 200 feet above the Fox Hills. Coal has been mined here since 1891, and since 1903 the mine has been owned and operated by Mr. C. L. Parkhurst. The coal bed varies in thickness from two to three feet. The lignite is of excellent quality and sells at the mine for $2.50 per ton.

COAL IN THE FORT UNION FORMATION

Most of the coal in this region, as well as throughout the entire state, is found in the Fort Union formation. It is seldom that any considerable thickness of these strata is exposed without showing one or more coal beds. But the coal outcrops are so few and so far apart that it was found to be impossible in many instances to correlate them with any degree of certainty, and to determine the number of coal beds and the vertical distances between them. This has been done in some parts of the state, as in the Little Missouri badlands, where outcrops are so numerous that individual beds can be traced mile after mile, and their relation to the coal seams above and below determined.

The coal beds of south-central North Dakota occur in the lower portion of the Fort Union, being distributed through the 400 or 500 feet of strata which constitute the lower part of the formation. Many of the mines are located only a few miles from the boundary of the Lance beds, which disappear below the overlying Fort Union, and are mining coal which is not far above the base of the latter.

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1. Knowlton: Proceedings Wash. Acad. of Sciences, Vol. II, 1909, p. 202.

In the following discussion the southernmost mines are first described, and then in succession those occurring farther north.

COAL IN EASTERN ADAMS COUNTY

A thick coal bed is present near the top of the highest ridges and divides north of Haynes, between Hidden Wood and Cedar creeks. The coal lies well above the level of the surrounding surface, and except where preserved in these higher elevations it has been removed by erosion. Toward the top of the ridges and buttes of this vicinity there is a thick layer of burnt clay or clinker formed by the widespread burning of this same thick coal bed. This coal, which is mined in at least half a dozen different places, has a thickness of 12 to 13 feet.

The following mines are located within two miles of Haynes and all are mining the above mentioned 12-feet coal bed:

Brown Mine, owned by the Haynes Coal & Mining Co., and located in the SE. quarter, sec. 8, T. 129 N., R. 94 W. Mine was opened in June, 1908.

Farmers Coal Association Mine, located in sec. 9, T. 129 N., R. 94 W., on the opposite side of a ridge from the Brown mine.

Haynes Coal Company Mine, located in the NE. quarter, sec. 16, T. 129 N., R. 94 W.

Peterson Mine, also in sec. 16, T. 129 N., R. 94 W.

The last three mines have been opened since the summer of 1908. In all the seam is reached by a slope, up which the coal is drawn by horses. Eight or nine feet of coal are removed, and three or four feet are left to form the roof. There are 12 to 13 feet of good clean coal with no clay partings. The coal sells at the mine for $1.75 a ton. The lignite is almost black and is less woody than much of the North Dakota coal.

Two other mines in the vicinity of Haynes are working this same thick coal bed, namely, the Pinkham mine, in sec. 36, T. 130 N., R. 94 W., and the Holdridge Mine, in sec. 3, T. 130 N., R. 94 W.

This Haynes coal bed, as it may well be named, is probably not far from 150 to 200 feet above the base of the Fort Union.

At the northeast corner of Adams County a bed of coal is mined on Sheep Creek, near the east line of T. 131 N., R. 92 W. The lignite is obtained by stripping, but the bed was not well exposed and its thickness could not be determined.

COAL IN SOUTHEASTERN HETTINGER COUNTY

A coal bed 7½ feet thick is worked by stripping at the Kuntz mine, in the SE. quarter, sec. 33, T. 132 N., R. 91 W. Though the lignite has a thickness of 7½ feet in the thickest part, it grows thinner toward the east and west. From three to five feet of cover are stripped off to reach the coal, which is clean and free from clay partings. Farmers come to this mine for many miles around, some traveling as far as ten or twelve miles, for their winter supply of fuel.

Fourteen miles northwest of the Kuntz Mine a lignite bed is mined not far from the headwaters of Timber Creek, near the NW. corner of T. 132 N., R. 93 W. The full thickness is not exposed, but there is at least 5 feet of coal. A 6-foot bed of coal outcrops on the Cannon Ball River five miles east of the Hettinger County line, and it is not unlikely that this seam continues west into the latter county. Some ten or twelve miles west of the line a coal bed appears on the Cannon Ball in townships 133 and 134 of range 92. It has a thickness of 3 feet and is good lignite.

COAL IN MORTON COUNTY

In the southwestern part of the county a coal bed is present near the base of Coffin Buttes. It is 9 feet thick, contains four thin clay partings, and is mined at several points by stripping. The Corral mines are located in sec. 32, T. 132 N., R. 90 W., one on the north side and one on the south side of the section. Many farmers living to the south drive to these mines a distance of 12 to 15 miles. The same bed is mined in three places in sec. 35, T. 132 N., R. 90 W.

A coal seam near Fleak has been mined by stripping at several points. One mile north of the Post Office 4 feet of coal appear where the seam has been exposed by the removal of the overlying clay. It is probably the same bed which is worked one mile east of Fleak and also several miles to the north. This coal bed is perhaps to be correlated with the upper of the three beds of lignite which appear in the bluffs of the Cannon Ball River six miles south of Fleak.

The Fort Union formation is well exposed in the bluffs of the Cannon Ball for many miles above the boundary of the Lance beds. The position and thickness of its lignite seams are shown in the following section, exposed in the high bluff on the north side of the river, in sec. 5, T. 133 N., R. 89 W.:

	Feet	Inches
Shale	44	
Coal	4	2

Shale	23	
Coal	2	
Clay shale	1	6
Coal	2	7
Shale	10	
Coal	1	6
Sandstone, exposed above river	75	

It will be noted that the middle coal bed contains a clay seam 18 inches thick. The lower coal bed lies at or near the contact of the Lance beds and Fort Union.

Both the middle and upper beds are mined here in section 5, and a section of the former where it has been opened up is as follows:

	Feet	Inches
Shale, brown and gray		
Coal	2	4
Clay shale	1	6
Coal	3	

The lower of these three coal beds appears along the Cannon Ball about three miles to the southwest, where it is seen in a cut bank at an elevation of about 25 feet above the river, in sec. 12, T. 133 N., R. 90 W. The coal here has a thickness of 20 inches. One mile farther west, in section 11 of the same township and range, a higher coal bed, which is probably the middle one, occurs in the river bluff and has a thickness of 6 feet. The coal here does not contain the clay seam which is present in the bed several miles to the east.

It will be noted on the map that the Fort Union extends eastward many miles on the upland between the Cannon Ball and Heart rivers, and as usual the formation contains coal. A bed 4 to 5 feet thick has been mined on a small scale in secs. 2 and 11, T. 133 N., R. 88 W. A higher coal bed is mined near the north line of sec. 7, T. 133 N., R. 87 W. This varies in thickness from 4 to 6 feet and has been worked for several years by stripping off the cover

Six miles northeast of the last mentioned locality a mine has been opened just north of Carson, near the southern edge of sec. 12, T. 134 N., R. 87 W. The coal bed has a thickness of 3 feet 9 inches and a long drift has been run in along the seam. The coal occurs in a ridge which rises a hundred feet or more above the town, and the elevation of the lignite bed above sea level is not far from 2,350 feet.

The coal which outcrops on Antelope Creek below Leipzig is not far above the base of the Fort Union, and is perhaps the middle one of the three beds exposed on the Cannon Ball River seven miles to the southwest. This coal is mined in sec. 36, T. 135 N., R. 89 W., and has been worked at many points for a distance of nearly one mile, on the south side of the valley of Antelope Creek. A section of the coal bed is as follows:

	Feet	Inches
Sandstone	10-18	
Coal		10-12
Clay shale	1-5	
Coal, bottom not exposed, but at least	3	

It will be noted that the clay seam varies greatly in thickness, being only a foot in places and elsewhere thickening to 5 feet. In order to reach the coal the thick overlying soft sandstone is removed by stripping, and at some points it has been necessary to scrape off as much as 10 to 15 feet of rock before reaching the lignite.

A higher coal bed which is perhaps the upper coal bed of the Cannon Ball section is mined several miles southwest of Leipzig, in secs. 25 and 26, T. 135 N., R. 90 W. The coal is 30 to 32 inches thick and mining by stripping has been carried on here for eight or nine years.

Two coal beds are present along the Heart River valley near the western edge of Morton County. They appear in the following section which is exposed on the Heart near the east line of T. 136 N., R. 90 W., six miles from the Hettinger County line:

	Feet	Inches
Shale and sandstone		
Coal, 150 feet above river, mined at many points, contains 2-inch clay parting	4	
Unexposed	41	
Shale, yellow, forming topmost layer of the river bluff	19	
Shale, dark gray and yellow, containing two shell-bearing beds	33	
Shale, ash gray	2	4
Coal		24-30
Shale, brown to black at top	2	
Shale, gray	2	6
Sandstone ledge	1	6
Shale, yellow and ash gray, containing large calcareous concretions near base	21	
Sandstone, massive, gray, the upper sandstone of the Lance beds, exposed above river	26	

As shown in the above section the lower coal bed lies near the base of the Fort Union, which is at or near the top of the lower sandstone. The upper coal lies 95 feet above the lower. This 4-foot bed is mined by stripping in secs. 3 and 4, T. 136 N., R. 89 W. The lower 24-inch bed was traced several miles in the river bluffs, where it had burned out in places and formed a bed of clinker.

Coal Near Sims.—One of the first coal beds to be mined in North Dakota was that at Sims, where mining has been carried on for over a quarter of a century, or since 1884, when the Northern Pacific Railway opened a mine at this point. The town is located in the valley of Hailstorm Creek, which empties into Big Muddy Creek four miles to the south, and in the side of the valley the following section is found:

	Feet	Inches
Shale	40	
Coal	2	
Clay		6
Coal	2	
Shale	40	
Sandstone	3	6
Shale	60	
Coal, impure	4	
Shale	10	
Coal	7	8
Shale, exposed	12	

It is the lower coal bed which has been so extensively mined in the vicinity of Sims. It is nearly on a level with the railroad and has an elevation of about 1,970 feet above sea level. It is also not far above the base of the Fort Union, probably less than 50 feet.

The coal is mined by running a slope into the hill until the bed is reached, and then following this until the haul to the surface becomes too long, when a new slope is opened. Many old mine entries may be seen near the base of the bluffs on either side of the valley. There is only one mine in operation at Sims at the present time, the Feland Mine, located about one-half mile southeast of town and reached by a spur from the Northern Pacific road. The coal is hauled to the surface by mules and provision is made for loading directly onto the cars for shipment.

The 4-foot coal bed has been worked at some points but has never been extensively mined here.

Several lower coal seams are given in the log of the deep boring at Sims, quoted by N. H. Darton,[1] and furnished by the driller from memory. These are reported as follows:

	Thickness in feet	Depth below surface
Coal	8	10
Coal	5	70
Coal	5	136
Coal	5	330
Coal	6	710

The upper one of these beds is perhaps the seam which has been so extensively mined, though this cannot be definitely determined. The lower coal beds, with the possible exception of

1. 17th Annual Report, U. S. Geol. Survey, part II, p. 664, 1896.

the first of the four, if they are actually present, must be in the Lance beds, which as we have seen are not far below the surface at Sims. But, as has been previously stated, the Lance beds of south-central North Dakota are barren of coal throughout most of this region, and the accuracy of the above log may be questioned, particularly since it was given from memory. Thin coal beds associated with black, carbonaceous clay, may have been mistaken in the drilling for the thicker seams of coal reported by the driller. But while there is some doubt about these lower seams of workable thickness being present in the Lance beds, there is abundant evidence that a number of coal beds occur above what we may call the Sims coal bed, meaning by this the one so extensively mined at that place. These higher lignite seams are found in the vicinity of New Salem, Glen Ullin and Hebron.

Coal Near New Salem—At least two workable coal beds occur in the vicinity of New Salem. Both were struck in a wall between two and three miles southwest of town, where the section is as follows:

	Feet
Shale and sandstone, having here a thickness of	45
Coal	6
Shale	35
Coal	6
Shale	

The upper coal seam outcrops along many ravines and valleys south of New Salem, where it has been mined at a number of points. It lies about 160 feet above the Sims coal bed, and 50 to 80 feet below the elevation of the upland in this vicinity. The old mine of the Consolidated Coal Company, located one mile southwest of New Salem was in this upper 6-foot coal bed, and was for several years the largest mine in Morton County, though it is no longer operated. What is doubtless the same seam has been mined in secs. 4 and 5, T. 138 N., R. 85 W., and also in secs. 34 and 35, T. 139 N., R. 85 W.

During the past year (1911) a new mine has been opened near New Salem by the Dakota Coal Products Company. It is located northeast of town, in the SW. quarter of sec. 15, T. 139 N., R. 85 W. The coal bed mined by this company runs about 5 feet in thickness and is the lower of the two seams occurring in the vicinity of New Salem, lying 30 feet below the bed mined by the Consolidated Coal Company southwest of town. The coal is 40 feet below the surface and 65 feet below the Northern Pacific Railroad. Its elevation above sea level is not far from 2,100 feet. A spur track connects the mine with the main line of the Northern Pacific, half a mile distant. A shaft has been sunk to the coal and the mine is operated by electricity.

Between New Salem and Glen Ullin coal is reported to occur in the northern part of T. 139 N., R. 87 W., in secs. 1, 9, and 10, the bed being 6 feet thick. The bluffs bordering the valley of Big Muddy Creek (Plate X, Fig. 2) contain coal as is shown by the conspicuous clinker horizon seen for many miles above and below Glen Ullin, which was formed by the burning of a bed of lignite along its outcrop. Back some distance from the outcrop and beneath the higher ground bordering the valley the coal is undoubtedly present and has not been burned.

In the vicinity of Glen Ullin there are three coal beds. The upper is found in the highest ridges and buttes near town, where it has been largely burned out and the clinker thus formed caps these higher points. The middle bed appears to be the one which has burned out so extensively along its outcrop to produce the clinker horizon mentioned above as occurring in the bluffs of the valley for many miles. This middle bed lies from 125 to 150 feet above the railroad. Approximately 50 feet below the middle bed is the lower coal, which varies in thickness from 5 to 6½ feet. This lower bed is mined less than one mile southwest of town, in sec. 31, T. 139 N., R. 88 W., where the following section of the coal seam is seen:

	Feet	Inches
Coal		6
Clay parting		2-3
Coal	5	9

Coal has been mined here for many years by H. L. Bean to supply the local demand. Mining is carried on by drifting in along the bed, and to some extent recently by stripping off the cover. This lower coal bed is about 80 feet above the railroad, or approximately 2,150 feet above sea level. These coal beds near Glen Ullin are probably the same as those occurring in the vicinity of New Salem, although this could not be determined with certainty.

So far as known, the uppermost coal beds of the Fort Union formation in Morton County are those present four or five miles north of Hebron, in the extreme northwestern corner of the county. These probably lie over 600 feet above the base of the formation, and are believed to occur well above those found near Glen Ullin and New Salem. A 7-foot coal bed is found in the northeastern corner of T. 140 N., R. 90 W., at an elevation of about 2,450 feet above sea level. This has been mined at their clay pit in section 2 by the Hebron Pressed and Fire Brick Company, and also by H. T. Wadeson at the North Star Mine in section 3. The Mining Sub-Station of the State University at Hebron plans to open a model mine on this 7-foot coal seam in sec. 3, T. 140 N., R. 90 W.

Coal is also present in the northeastern corner of Morton County, in the western part of T. 140 N., R. 82 W., near the head-waters of one of the branches of Otter Creek. It is shown by outcrops that occur in sections 17, 20, 29, and 31. The coal bed is 4 feet thick and lies so near the surface that it is mined mostly by stripping off the cover.

From the data given above regarding the coal beds of northern Morton County it will be seen that there are at least six of these beds in the Fort Union of this region, namely, two at Sims, two at New Salem, three about Glen Ullin but two of which are thought to be the same as those at New Salem, and at least one in the vicinity of Hebron. A section showing the coal beds of this area is as follows.

		Thickness	Approximate elevation above sea level
6	Hebron coal bed	7	2,450
5	Coal bed, represented by burnt clay near Glen Ullin	unknown	2.300
4	Coal bed, the upper bed at New Salem	6	2,130
3	Coal bed, the lower bed at New Salem	5-6	2,100
2	Coal bed, exposed near Sims	4	1,987
1	Sims coal bed, the one mined so extensively	7⅔	1,970

Only one of the three coal seams occurring in the vicinity of Glen Ullin is noted in the above section, since it seems probable that the two lower beds are the same as those found near New Salem, though they are 50 feet or more higher than the latter.

Coal in Oliver County—Lignite occurs at many points in this county and it is quite likely that the New Salem seams extend north into this area. In T. 141 N., R. 86 W., a 6-foot coal bed is reported in secs. 33 and 36, and a 5-foot bed in secs. 3 and 11. Coal is said to be abundant in sec. 28, T. 141 N., R. 83 W. A bed 6 feet thick is reported in sec. 9, T. 142 N., R. 86 W., and a 7-foot bed in sec. 9, T. 142 N., R. 85 W. In the eastern part of the county, near the Missouri River, lignite is mined for local use in the northern part of sec. 7, T. 142 N., R. 81 W. In the easternmost of the small strip pits the bed measures 3 feet 6 inches, but is said to contain much dirty lignite. There are probably two beds here, the upper being mined farther west, up the draw. These beds are about 80 feet above river level.[1]

Coal in Burleigh County—Practically all the mines in this area are in the northwestern part of the county, in the vicinity of Wilton. The Washburn Mine, in sec. 1, T. 142 N., R. 80 W., is the largest and most thoroughly equipped mine in North Dakota.

1. Bull, U. S. Geological Survey, No. 381, p. 22.

The coal bed is reached by a shaft 60 feet deep. The lignite varies in thickness from 8 to 13 feet and has a thin clay parting near the bottom. The entries are unusually wide and timbering is necessary. As a rule, 6 to 8 feet of the coal are mined out first, leaving lignite for a roof, which is taken down when the pillars are pulled. The underground equipment, which is very complete and efficient, consists of electric undercutting machinery and electric motors for haulage.

A little over one mile east of the above mine, in the NE. quarter, sec. 6, T. 142 N., R. 79 E., at the Lind Mine, the coal bed is 11 feet 10 inches thick, and lies 35 feet below the surface.

The Eckland Mine is a small opening in sec. 8, T. 142 N., R. 79 W. The lignite is about 8 feet thick, with 45 feet of cover. One mile east, in sec. 9 of thè same township and range, is the Peterson mine. While it is doubtless on the same lignite bed, the coal here is 11 feet thick and under a cover 40 feet thick.

The Yiengst Mine, located in sec. 34, T. 142 N., R. 79 W., is in a 6-foot coal bed, under 60 feet of cover. Nearer the Missouri River, in sec. 3, T. 142 N., R. 81 W., a bed of lignite is partially exposed, but its entire thickness could not be determined, though two miles to the north a bed which is probably the same as in section 3 shows a thickness of 7 feet.[1]

Chemical analyses and producer gas, briquetting and steaming tests.—The following analyses and producer gas tests were made of samples taken from the Washburn Mine at Wilton and show the general nature and composition of the fuel.

Analyses of Lignite from Wilton, North Dakota.[2]

		Mine Samples		Car sample
Air-drying loss		32.30	33.50	12.70
Proximate	Moisture	40.53	41.88	35.96
	Volatile matter	27.05	26.11	31.92
	Fixed carbon	27.37	26.73	24.37
Ultimate:	Ash	5.05	5.28	7.75
	Sulphur	.76	.96	1.15
	Hydrogen	——	——	6.54
	Carbon	——	——	41.43
	Nitrogen	——	——	1.21
	Oxygen	——	——	41.92
Caloric value determined:				
Calories		3.691	——	3,927
British thermal units		6,644	——	7,069

These analyses were made at the fuel-testing plant of the United States Geological Survey at St. Louis.

Another consideration that adds materially to the value of the lignite is its surprising success in the producer gas plant. The

1. This information regarding coal in Burleigh County is from Bull, U. S. Geol. Surv. No. 381, pp. 22 and 23.
2. Bull, U. S. Geol. Survey, No. 290, 1905, p. 138.

following statement has been made concerning the efficiency of North Dakota lignite in the gas-producer and gas engine:

"The result of the steam test was so unsatisfactory that there is nothing by which a direct comparison can be made of the efficiency of the fuel used in the producer gas plant as compared with the efficiency developed in the steam plant. Never-the lignite is its surprising success in the producer gas plant. The following statement[3] has been made concerning the efficiency theless a comparison of the results obtained on other coals under the steam boiler is instructive. * * * to produce one electrical horsepower hour in the producer gas plant required 2.29 pounds of dry North Dakota lignite, whereas to produce the same result in the steam plant required 3.39 pounds of the best West Virginia coal. This means that North Dakota lignite, with the moisture eliminated, will do more work when used in a producer-gas plant than the best coal of the country will do in a steam plant."

A number of tests have been made recently by the fuel-testing plant of the United States Geological Survey and by the Bureau of Mines to determine the best methods of briquetting North Dakota lignite. It has been found that the lignite can be briquetted, some of it without a binder, and that its efficiency is thereby materially increased. The briquetted product also stands weathering and handling much better than the raw material.

Steaming tests have also been made with specially constructed fire boxes and grates, and the results are highly satisfactory, as the efficiency of the lignite when properly fired is so increased as to compare very favorably with that of fuel of higher grades. The details of these tests are set forth in Bulletins 2 and 14 of the Bureau of Mines.

CLAY

South-central North Dakota, like the rest of the state, contains extensive deposits of valuable clays. Both the Fort Union and Lance formations yield materials suitable for a variety of clay products, such as front and fire brick, stoneware, and sewer pipe. The North Dakota clays have been described at length in a previous report[1] of the State Geological survey, the location of the high grade Fort Union clays being shown on a map accompanying the report. The following information concerning the clays of this region is largely derived from this volume.

Six plants in the state are already using the Fort Union clays, these being located at Dickinson, where there are two, Hebron, Wilton, Kenmare, and Burlington. Some of the shales

1. Prof. Paper U. S. Geol. Survey, No. 48, Part 1, 1906, p. 111.
2. Fourth Biennial Report, North Dakota Geol. Surv., 1906, pp. 1-324.

and clays of the Lance formation are also known to be suitable for clay products.

Clays of the Lance Formation—These are well exposed in the bluff of the Missouri River valley near Bismarck. About 50 feet above the river, near the eastern end of the Northern Pacific Railroad bridge, about six feet of shaly, laminated clay outcrops. The upper part is gray in color and contains a little fine sand. Below this is a fine-grained, more plastic, chocolate colored clay almost free from sand. The color is due in part to the presence of carbonaceous matter. On burning this clay it becomes a light red, and when baked it possesses a hard, compact, ringing body. The bricklets made from it were strong, burned without checking, and with almost no warping. An analysis of this clay shows:

Analysis of Lance Clays from Bismarck

	Per cent.
Silica	58.73
Alumina	14.98
Iron oxide	5.63
Lime	2.10
Magnesia	.74
Potash	.16
Soda	.988
Water as volatile matter and other matter by subtraction	16.672

This clay would doubtless be of value for several uses. It would make a good brick, and might also be suitable for a porous, red earthenware, but could not be vitrified or burned very dense. It could be mixed with the clay above and would then probably make drain and sewer pipe and a good ornamental building material.

The clay which was used at the old State Brick Yard, one mile west of Bismarck, was a glacial drift which overlaid the Lance beds.

Fort Union Clays.—The brick plants at Hebron and Wilton make use of these clays, and the plant formerly operated at New Salem also employed them.

The white, high-grade clays of the Fort Union formation are well shown in the vicinity of Hebron, and so far as known, this is the easternmost locality for these beds. They occupy the buttes north of town and lie at an elevation of nearly 300 feet above the railroad. In sec. 11, T. 140 N., R. 90 W., there is a fine exposure of these clays, which are here mined by the Hebron Pressed and Fire Brick Company. The following section is shown at this point:

	Feet	Inches
Sand, with carbonaceous clayey layers	10	
Impure limonite		2
Clay, shaly, impure, dark gray and blue, carbonaceous and ferruginous	4	
Clay, sandy, impure, ferruginous	10	
Clay, carbonaceous, gray to black, spotted	5	6
Clay, sandy, light gray and almost white, contains very little iron, most plastic near the top, grows more lean and sandy toward the bottom	50	

Twenty feet of sandy clay similar to the lowest member of the above section is said to occur below its base, exposed in a well near by.

A sample collected from near the top of the fifty-foot layer, which contained considerable fine, pure sand, was analyzed with the following results:

	Per cent
Silica	73.90
Alumina	16.49
Ferric oxide	1.25
Lime	.29
Magnesia	.46
Soda	.22
Potash	1.20
Water and other volatile matter	5.52

The fifty-foot bed of clay shown in the above section is used for fire and pressed brick. It is quite refractory, the bricks made from it probably not fusing until a temperature is reached considerably over 3,000 degrees F. It is also suitable for stoneware and white earthenware, as is shown from the fact that these products have been made from it at the Hebron plant. For dense and vitrified wares such as stoneware it would have to be mixed with clays of lower fusibility.

The plant of the Hebron Pressed and Fire Brick Company was established in the spring of 1905. The clay is mined five miles north of town and is hauled to the plant by a steam tram. The clay is stored and sweated in bins before using, and is then crushed in a dry pan. With the exception of the fire brick, the brick are manufactured by the dry-press process. They are burned at high temperatures in Flood rectangular down-draft kilns with lignite for fuel. Buff, mottled, gray and flashed face brick are made. Fire brick are moulded by the soft-mud process and repressed by hand. The excellent grade of products from this plant find a ready sale over a large territory.

The high grade sandy fire clays outcrop for a distance of about two miles north of the pits of the Hebron Pressed and Fire Brick Company. They are usually overlain by a thick layer of sand and an impure carbonaceous clay. This fire clay is from 15 to 50 feet thick two miles north of the pits but thins out rapidly to the east and north. Toward the west the continuation of the same clay horizon is seen for several miles along both sides of Farmer's Valley, about 300 feet above the flat. Samples collected from the south side of the valley, between three and four miles west of Hebron, were tested and showd the clay to be suitable for the manufacture of pressed brick, terra cotta, the cheaper grades of stoneware, and possibly vitrified wares, such as paving brick.

Between five and six miles northeast of Hebron 10 to 15 feet of cream white, pure sandy clay outcrop near the tops of the buttes and represent the horizon of the high grade fire clays. Only a few miles farther east in the broad valley of Elm Creek the clay seems to disappear, the elevation of the country being probably below that of the clay horizon. Tests of a sample from the last mentioned locality showed the clay to be suited for an excellent grade of brick, and for stoneware.

The Fort Union clays are used in the manufacture of brick by the Washburn Lignite Coal Company at Wilton. The clay underlies the coal bed, eight to ten feet of clay being mined and the coal used for a roof. The clay, which like the coal is mined by the butt entry system, is undercut by electric coal cutting machines and then shot down. It is trammed out to the shaft by mules and after being hoisted is dumped near the crushing machinery. It is crushed in a dry pan after being dried and weathered on the dump pile for three or four days. From the dry pan the clay is elevated and screened, the oversize returning to the pan and the remainder going to the machines. Both dry-press and stiff-mud brick are made. The stiff-mud, side-cut brick are dried in open yards and burned in permanent up-draft kilns, lignite being used for fuel. The dry-press brick are burned in rectangular down-draft kilns of the Flood type. This plant at Wilton began operations in 1906 and its products find a ready market.

Pleistocene clays are used for making brick at the State Brick Yard, located near the Penitentiary at Bismarck. The material used is a stratified drift, and twelve feet of clay and sand are exposed in the pit, there being three beds of clay free from pebbles separated by two layers of fine sand. Both the clay and sand are used in making the soft-mud brick. The plant is operated by the state with convict labor.

Alluvial clay is used by the Mandan Brick Company, whose plant is located near the bank of the Heart River just west of town. The brick are moulded by hand. The clay is tempered over night in a soak pit and is then further prepared in a short, vertical pug-mill. The brick are dried in open yards and burned in scove kilns with wood fuel. They are red and porous, but quite strong.

GRAVEL AND SAND

Gravel and sand suitable for building and other purposes occur along many of the streams of the region, where they form the terraces already described. The most extensive deposits of these materials are probably those along the Heart River valley. They appear across from Mandan, on the south side of the Heart, where gravel and sand pits have been opened in the terrace at many points in sections 33 and 34. Two and one half miles west of Mandan, in the south half of section 30, a spur track runs into a large gravel pit where the railroad secures rock for ballast. The material is here mostly a very coarse gravel, containing many small and some good sized boulders. That there is a large supply of gravel here is shown from the fact that this terrace deposit extends along the valley for nearly two miles, with a width of over a quarter of a mile and a thickness of 40 to 50 feet. Near Bismarck an abundance of material for building purposes, for surfacing roads and streets, and for other uses, is found in the terrace of sand and gravel which extends west of town to the Missouri River and south to Fort Lincoln and beyond. The spur track running to the steamboat landing follows near the edge of this terrace. Other deposits of gravel and sand occur along the Cannon Ball River and Apple, Burnt, Hay, and Big Beaver creeks, as well as in many other localities. Extensive gravel beds are found along the south side of the latter creek just below Linton, in the northern part of T. 132 N., R. 77 W. West of the Altamont moraine, particularly in the vicinity of Napoleon and south to Wishek and beyond, there is much gravel and sand which represent outwash materials from the moraine.

WATER RESOURCES

SURFACE WATERS

The surface waters include streams, lakes, and springs. The area is well supplied with streams and these furnish water for stock throughout most of the year. These surface waters are for the most part unfit for drinking purposes, but the Missouri River supplies the cities of Bismarck and Mandan with excellent water, and Fort Lincoln obtains its supply from the same source.

The determination of the surface water supply of any area depends (1) on a knowledge of what is the total annual run-off per square mile for the region, and (2) on a knowledge of how the run-off is distributed through the year. For an excellent discussion of the surface water supply of North Dakota the reader is referred to a paper by Professor E. F. Chandler in the Third

Biennial Report of the State Engineer.[1] This paper has been freely drawn upon in the preparation of the following pages dealing with the surface waters.

The usual seasonal distribution of flow in the ordinary streams of this region is as follows: Through the winter the flow is steady but very small, reaching a minimum in February or thereabouts, when the ice covering is from one to three feet in thickness. In March or early April every coulee and ravine is filled from the melting snow and the early spring rains, the larger streams are raised, and the ice breaks up and melts. Later the June rains may be expected, which may or may not be heavy enough to again cause noticeable rise in the rivers, but which not infrequently brings as great flow as in the early spring. Following this, unless floods are caused by violent storms, the rivers sink lower and lower through the summer, usually reaching the lowest stage of the year in August or September. With the cool weather of the fall evaporation becomes less and there is some increase in flow; the streams remain at a rather low stage until the cold of winter, closing the small tributaries, cuts off the supply so that the river shrinks again to the winter minimum.

These streams depend almost wholly on the flow from the surface of the ground that follows rain or melting snow, and receive but little from the small springs or seepage. Hence in dry seasons the flow even of large rivers shrinks surprisingly and the minimum may be only a hundredth or a thousandth as great as the maximum.

The distribution of flow of a stream fed by a country of a different nature is unlike this. A river like the Missouri, which comes from the mountain snow fields, reaches its maximum at the time of most rapid melting of the snows by the heat of the June sun; for this reason the June flood of this river, which reaches North Dakota in the latter half of that month, may be expected to far surpass the spring rise both in height and duration.

Of the water falling on the surface, part runs immediately off into the water courses and is carried away; part sinks into the ground and after traveling below the surface a greater or less distance escapes as seepage or springs into streams and thus flows away; while still a third portion of the rainfall is evaporated. The evaporation and the run-off together are equal to the rainfall, and the ratio between these depends in each locality upon a great number of topographic and meteorologic conditions. Among these conditions affecting the percentage of run-off may

1. "The Relation Between Rainfall and Streamflow in North Dakota." Third Biennial Report of the State Engineer, 1908, pp. 53-66.

be mentioned the following: steepness of slopes, amount and character of vegetation, the character and depth of the soil, and the geologic structure. In the same locality in different years the run-off varies with the climatic influences, such as the amount of rainfall, whether the latter is in form of torrential rains or gentle showers, the temperature of the air and earth, and the wind velocity.

The amount of water carried by many of the streams of the state has been determined and their stream flow is known. This is expressed in "second-feet," by which is meant the number of cubic feet of water flowing past a given point in one second. From this the total quantity discharged in a year can be found; and then by division by the total number of square miles drained by the river above the point of measurement the average quantity of water that flowed during the year from each square mile of the drainage area is found. Definite knowledge of the mean flow of any stream is necessary that the quantity of water available for any purpose, such as irrigation or water power, may be determined.

In comparing the rainfall and run-off it is more convenient to express the latter as the total depth in inches from the drainage area in a year.

Of the total rainfall of the region, how much finds its way into the streams and constitutes the run-off?

The mean annual rainfall for south-central North Dakota is between fifteen and seventeen inches. During the seventeen years from 1892 to 1908 the average rainfall at Bismarck was 16.10 inches, the minimum being 13.67 (1898) and the maximum being 18.22 inches (1906). Nearly the whole of this is evaporated since the average annual run-off is less than an inch, as shown by the following table:

Total Run-off of Heart and Cannon Ball Rivers, Showing the Depth in Inches on Drainage Area.

	1903	1904	1905	1906	1907	1908	1909	1910
Heart River at Richardton	0.6	1.2	0.3	1.5	0.8	0.5	1.4	1.1
Cannon Ball River at Stevenson	0.6	0.6	0.6	1.1	0.6	0.9		

The mean annual run-off for the years 1903 to 1908 inclusive expressed in inches, was seven-tenths of an inch for the Knife and Cannon Ball rivers and eight-tenths of an inch for the Heart River.

The normal distribution of the total annual flow among the months of the year is illustrated by the Cannon Ball River, which may be taken as typical of the other streams of the region.

Mean Monthly Run-off of Cannon Ball River, Expressed in Inches.

Cannon Ball River at Stevenson—

Jan.	Feb.	Mch.	April	May.	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
.00	.01	.10	.11	.12	.26	.04	.02	.01	.00	.00	.00

Comparing this latter table with the one showing the total run-off during a series of years it will be noted that the seasonal flow varies relatively much more than the total annual flow.

Variations of stream flow are to be expected, since the rainfall is much greater in some years than in others, and a considerable amount of the excess rainfall must reach the streams, in fact a much greater part of the excess than of the normal rainfall.

Further discussion of the streams of south-central North Dakota will be found in the chapter on drainage in the earlier pages of this report.

Springs are of rare occurrence in this region and the amount of water they furnish is too small to be of importance as a source of supply. In many places the water seeps out slowly and may afford a supply for stock and domestic use, but little use is made of such seepage and it serves chiefly to furnish a constant source of water to the streams, and enables these to maintain a continuous flow throughout the year. If it were not that the ground water thus reaches the streams by seepage they would continue to flow only during and shortly after a rain and their channels would be dry much of the time between rainfalls.

The lakes of the area are found only east of the Missouri River, where they occupy depressions in the glacial drift, including the outwash material from the Altamont moraine. The unequal deposition and accumulation of the drift left many depressions in its surface and these gave rise to the numerous ponds, lakes, and marshes of the region. Some attain considerable size, as for example Long Lake and the large lake near Napoleon, but the great majority are small, while many have already dried up or become marshes. During much of the year these lakes furnish water for stock, but in many instances it is not suitable for domestic use.

SHALLOW DUG WELLS

Shallow dug wells furnish sufficient water for farm and domestic purposes throughout much of the region. These are supplied with water from the surface which has soaked down through the soil and subsoil and has in most instances not traveled far before reaching the wells. West of the Missouri River the water of these wells is found either in the shales and sandstones of the Lance and Fort Union formations, or in the silt of the stream valleys. When in the clay shale the water generally seeps slowly into the wells and if much is drawn off at one time it may require several hours for the water to reach its former level. If the water is in sandstone or silt it moves more freely and enters the well almost as fast as it is pumped out. Most of the wells sunk in the flood plain of the Missouri or its larger tributaries go down only 15 or 20 feet before reaching a good supply of water.

East of the Missouri River the water of many of the shallow wells occurs in the glacial drift and the gravel and sand layers of this deposit commonly yield an abundant supply.

The waters of the surface wells vary greatly in composition, but they are for the most part suitable for domestic purposes except that some are quite hard and others contain more or less alkali.

TUBULAR WELLS

Bored or tubular wells with a depth of 75 to 250 feet are common in the region under discussion and form one of the principal sources of water supply. The wells of the Electric Light Plant and Creamery at Bismarck are 130 feet deep and the water occurs in a bed of coarse sharp sand containing fragments of lignite. Resting on the sand is a bed of granite boulders which were encountered in sinking the wells. At the Penitentiary this boulder bed was struck at 200 feet. The two wells bored some years ago at Fort Lincoln and which for a time furnished the water supply of the post, had a depth of 98 feet and were 10 inches in diameter. They doubtless went down into the sand layer at the base of the river silt, the same sand bed as that encountered at Bismarck.

In western Burleigh County most of the bored wells have a depth varying from 150 to 240 feet, the water occurring in a soft sandstone. The supply is abundant and the water is very soft. The well at Sather is 150 feet deep and another two miles north, in sec. 5, T. 140 N., R. 80 W., which is on the upland, has a depth of 210 feet. A well in sec. 10, T. 140 N., R. 79 W., reaches water at 112 feet, and one two miles to the south is 240 feet deep. In sec. 10, T. 138 N., R. 79 W., water is found at 90 feet, and many of the wells in southwestern Burleigh County outside the Missouri bottoms have a depth of 200 feet and over.

The water of most of the tubular wells of the area under discussion is found in the soft sandstones of the Lance formation and occurs at several horizons within 250 to 300 feet of the surface. In northern and western Morton County, and in some townships in northwestern Burleigh County water is struck in the sandstone beds of the Fort Union, while in much of eastern Burleigh and the greater part of Kidder County the supply comes either from these same Fort Union sandstones or in some cases from the sand or gravel layers of the glacial drift overlying this formation.

DEEP WELLS

Deep borings have been made at Bismarck, Mandan, and Sims in an attempt to reach artesian flows, but the results were unsatisfactory. None of these wells penetrated deep enough to reach the Dakota sandstone, which is the source of most of the artesian water of eastern North Dakota. In the central part of the state this sandstone lies over 2,000 feet below the surface, as is shown by the fact that the Mandan well did not reach it, though it attained this depth.

The Bismarck well found no flows, though it is reported to have reached a depth of 1315 feet, passing through shale with occasional thin limestone beds. It fell far short of reaching the water-bearing beds of the Dakota sandstone. The deep well at Mandan went down 2,000 feet but was apparently not quite deep enough to reach the Dakota sandstone. The only water obtained is a small flow from a depth of 357 feet, estimated at three gallons per minute, but it is soft and clear. Below the thin bed of loose sandstone which supplies this flow another sand rock with a small flow was reported from 410 to 470 feet. This lower sandstone with a thickness of 60 feet probably belongs to the Fox Hills formation. From 470 to 1,500 feet the material was chiefly gray and blue shale, while from 1,500 to 2,000 feet the boring was mostly in shale, as near as could be learned.[1] The Dakota sandstone at Mandan, therefore, lies more than 2,000 feet below the bottom of the Missouri River valley, or over 350 feet below sea level.

In the deep boring at Sims, which reached a depth of 1,311 feet, no water was found. The record of this boring is published by Darton, in the report just referred to, as given from memory by the driller. The log is as follows:

		Feet
9.	"Drift"	10
8.	Sandstone and shale, with three coal beds, the upper 8 feet and the lower two 5 feet thick. The upper bed is at the top and lower is at base of this number	120
7.	Sandstone, soft	200
6.	Coal	5
5.	Sandstone, soft, with hard bed at base	40
4.	Shale, with sulphur	260
3.	Sandstone, soft	69
2.	"Coal," good	6
1.	Shale, with sulphur	600
	Total	1,310

1. N. H. Darton, "Preliminary Report on Artesian Waters of a Portion of the Dakotas," 17th Annual Report, U. S. Geol. Survey, part 2, p. 63.

Number 8 of the above section probably belongs to the Fort Union, while numbers 4 to 7 are doubtless to be referred to the Lance formation. Numbers 2 and 3 are perhaps likewise to be included with the latter, in which case the Fox Hills sandstone is absent in this locality and the thickness of the Lance beds is 580 feet. The lower 600 feet of the section (No. 1) is Pierre shale. It will be noted that two workable coal beds (Nos. 2 and 6) are reported as occurring in the Lance formation. As stated on a previous page, the presence of thick coal seams in this formation is rare and it may be that the thickness of the coal was overestimated, since a correct estimate is difficult when the ordinary churn drill is used.

SOILS

Soils are produced by the decay or breaking down of pre-existing rocks through the action of the various weathering agencies, and the mineral constituents are mingled with the carbonaceous matter derived from the many generations of plants which have lived and died on the surface, thus contributing their organic material to the superficial layer.

Considered with reference to their origin the soils of this region may be grouped in two main classes: (1) those which are residual and (2) those which have been transported.

RESIDUAL SOILS

These soils cover by far the greater portion of south-central North Dakota west of the Missouri River. They are formed by the weathering and decomposition in place of the shales, clays, and sandstones of the Lance and Fort Union formations. These rocks break down quite readily to form a sandy clay or loam which is mixed with vegetation and produces an excellent soil. Although a portion of this area west of the Missouri River was covered by the continental glacier and undoubtedly received a deposit of drift, the finer portions of this glacial debris have been almost wholly removed from most of the region, leaving behind the gravel and boulders of the drift, resting directly on the bed rock. The soils of this glaciated portion of the area are thus largely residual and formed chiefly by the weathering of the bed rock in situ, although there is in places an admixture of foreign material brought by the glacier.

In localities where the bed rock is chiefly sandstone the soils are composed largely of sand, while in other localities underlain by shale the soil contains a large proportion of clay. But for the most part it is a mixture of sand and clay in varying proportions, forming a loam.

TRANSPORTED SOILS

These soils are composed of materials brought from a greater or less distance through the transporting agency of ice, rivers, and the wind.

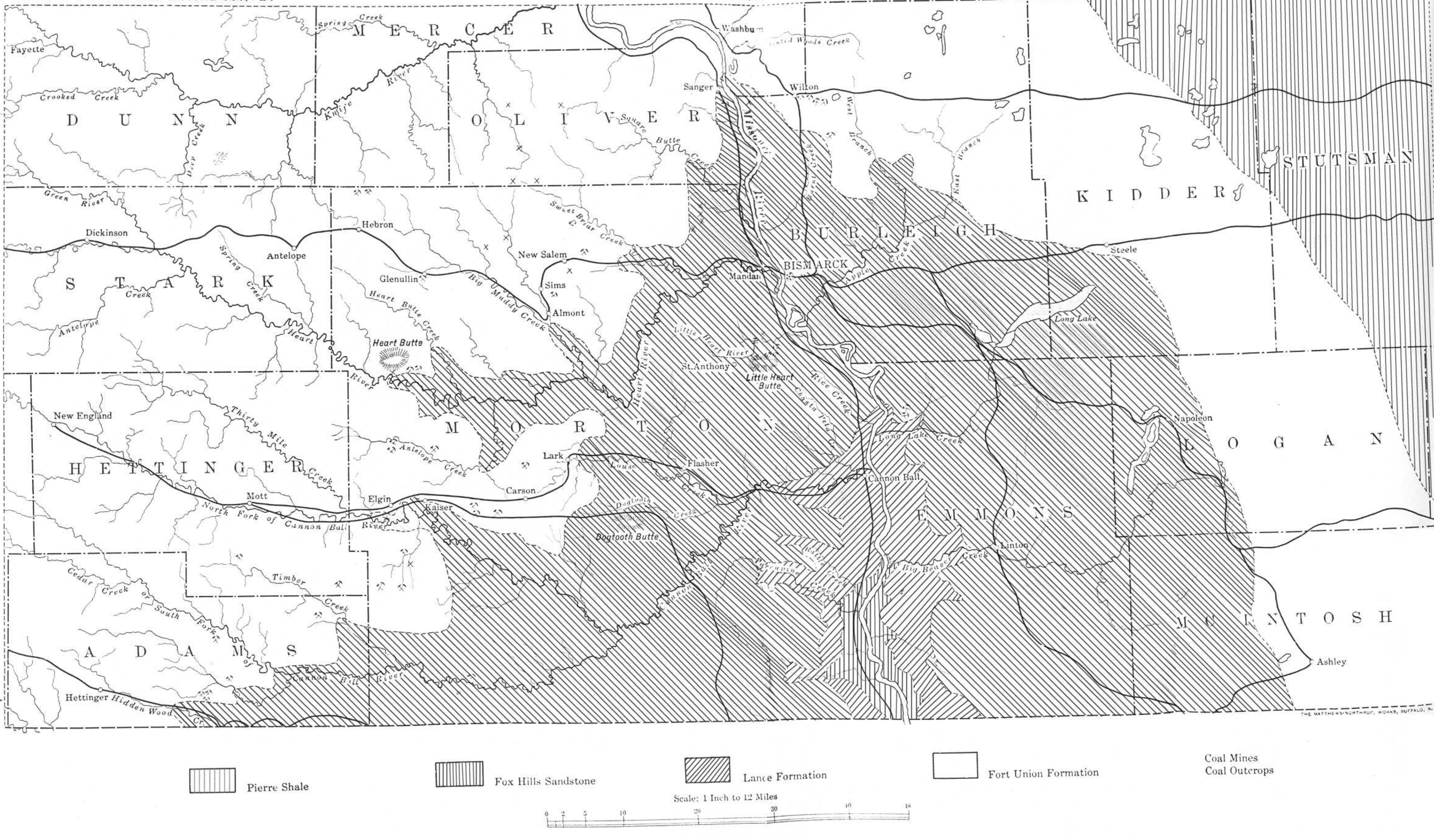
Glacial Drift Soils.—The soils of the drift are formed of clay, sand, gravel, and boulders which were gathered by the glacier during its advance and deposited beneath and at the margin of the ice. The materials have been derived in part from the granites, gneisses, and limestones far to the northeast, and in part from the clays, shales, and sandstones nearer at hand, all mingled together to form a soil containing a variety of constituents. During the formation of the massive Altamont moraine the waters flowing from the melting ice spread a layer of silt, composed of the finer materials of the glacial debris, over a belt of considerable width west of the moraine.

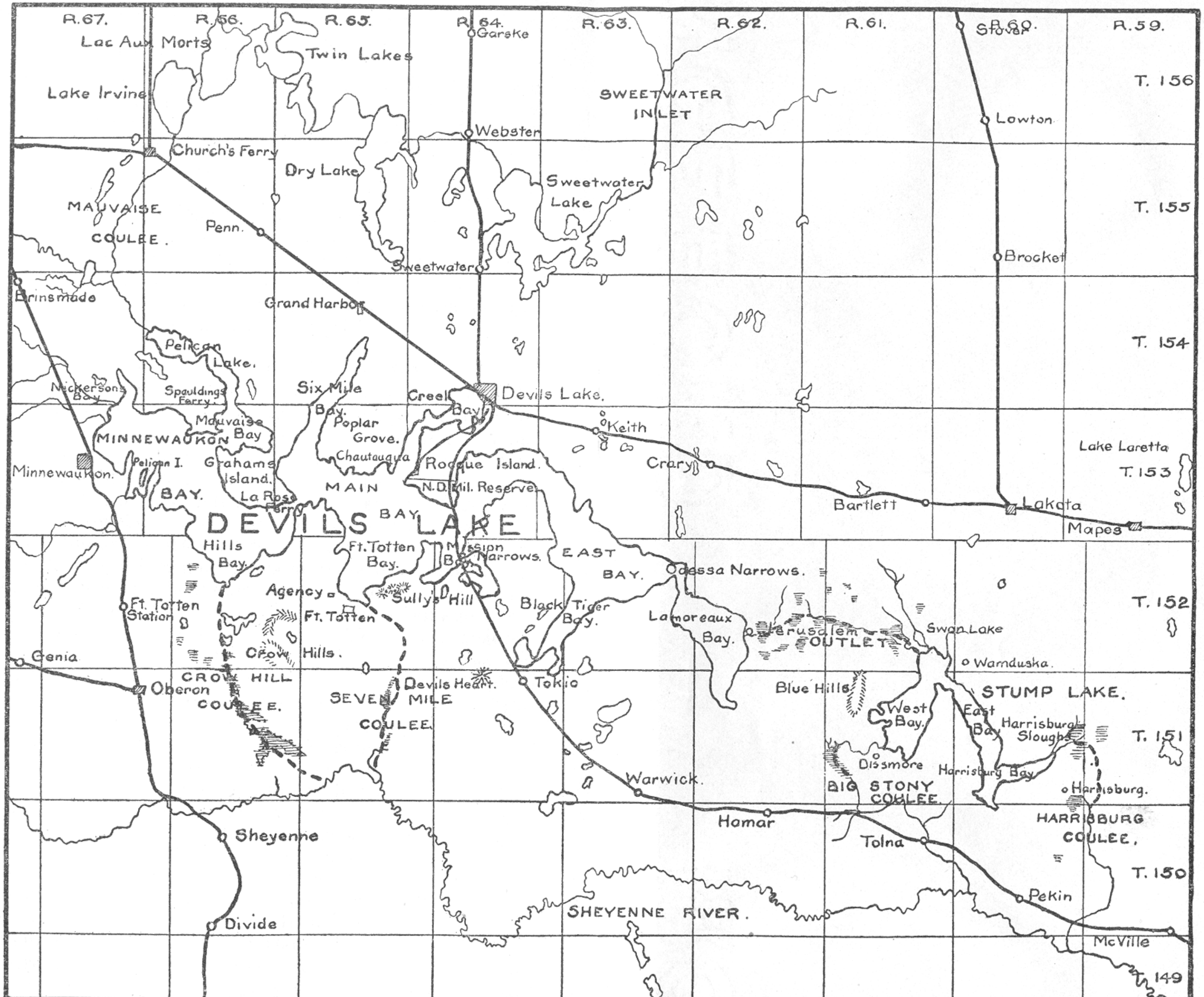
The glacial drift soils are confined mostly to that portion of the area lying east of the Missouri River, since west of the river they are thin and patchy, and merge into the residual soils of the region.

Alluvial Soils.—Rich alluvial soils occur in the valley bottoms of all the larger streams, including not only the broad valley of the Missouri but those of the Cannon Ball, Heart and Little Heart rivers, and Beaver, Apple, Big Muddy, and Square Butte creeks, with their larger tributaries. These alluvial soils consist in part of the flood plain deposits formed by the streams in recent times, and in part of the glacial gravel, sand and silt deposited by the streams during the Glacial Period and forming terraces which have an elevation of 15 to 30 feet above the present flood plains. In places these alluvial soils are very sandy, appearing as broad sandy flats along the Missouri River, but for the most part they are composed of fine silt, which on the flood plain is being added to from time to time by the overflow of the river. The soils of the stream terraces generally have a subsoil of gravel and sand.

Dune sand soil.—Reference has already been made to the dune area southeast of Bismarck, where the sand covers 8 or 10 square miles. The soil of this and other small tracts is thus composed almost wholly of quartz sand, which has accumulated to a considerable depth through the action of the wind.

GEOLOGICAL MAP OF SOUTH-CENTRAL NORTH DAKOTA
BY A. G. LEONARD, STATE GEOLOGIST.





MAP OF THE DEVILS-STUMP LAKE REGION, NORTH DAKOTA.

Scale 0 1 2 3 6 12

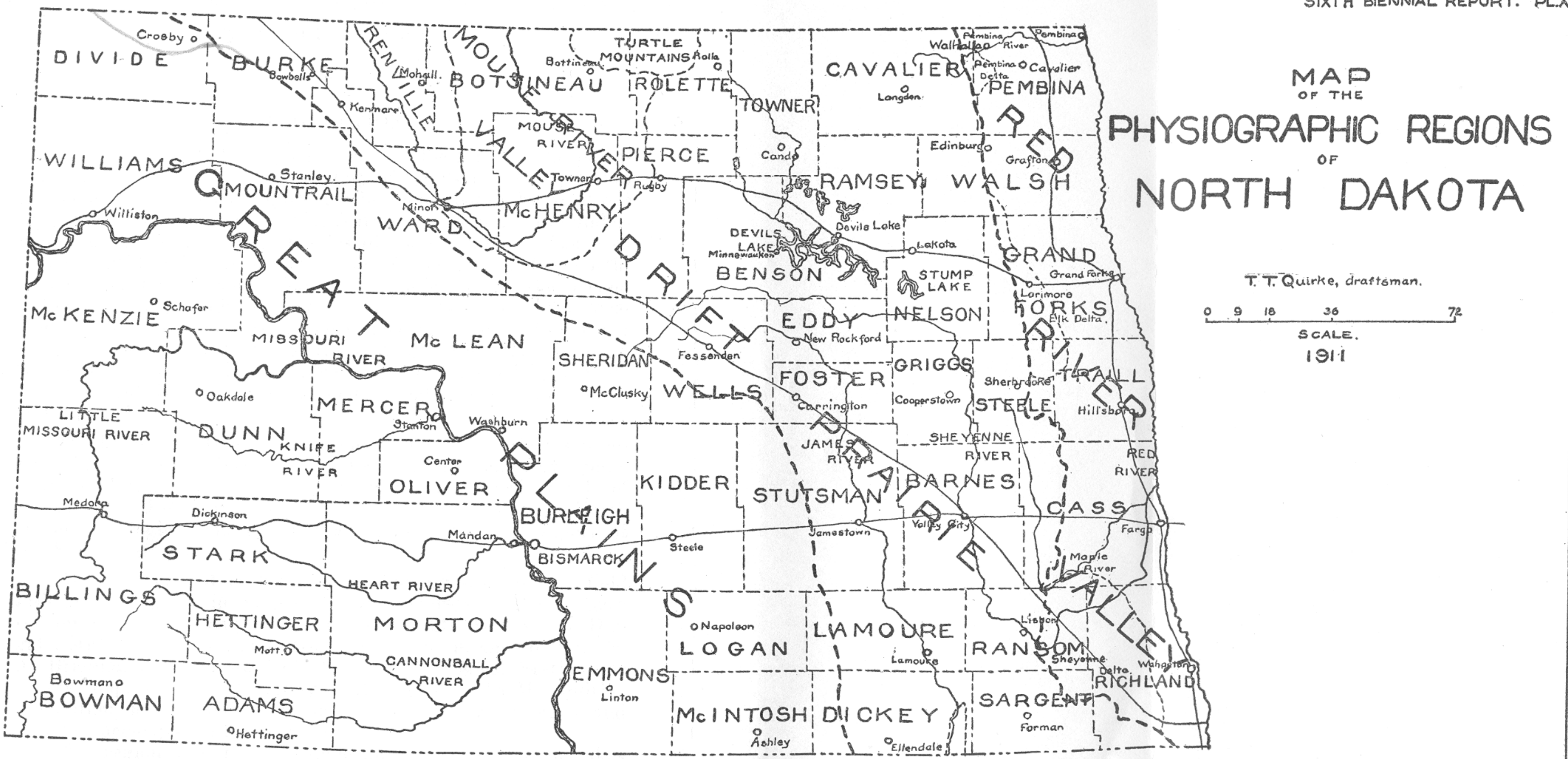
Shorelines from U.S. Survey of 1883.

1911.

T.T.Quirke, Draftsman.

N.D. GEOLOGICAL SURVEY.

SIXTH BIENNIAL REPORT. PL.X.



THE PHYSIOGRAPHY OF THE

DEVILS-STUMP LAKE REGION

NORTH DAKOTA

BY

HOWARD E. SIMPSON

THE PHYSIOGRAPHY OF DEVILS-STUMP LAKE REGION, NORTH DAKOTA.

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By Howard E. Simpson.

INTRODUCTION.

The purpose of this report is to describe some of the physical features of the immediate vicinity of Devils and Stump Lakes in North Dakota, explaining their origin and geographic relations and at the same time using these features as an aid to the understanding of the general principles of physiography. The area under consideration is located near the center of the northeastern quarter of North Dakota, as indicated on the accompanying physiographic map of the state, Plate XII. The location of the more important places mentioned in the text are shown on the detailed map of the region, Plate XIII. It is expected that this preliminary paper will be followed by a more complete and detailed report as soon as the survey of the region is completed.

In the preparation of this report the few earlier sources have been freely drawn upon, especially the scholarly monograph of Upham,[1] the more popular work of Willard,[2] the brief report of the Fish Commission,[3] the several reports of the North Dakota Geological Survey[4] and a recent manuscript report of the State Engineer.

Acknowledgment is due to the following students for field assistance rendered in connection with courses in the summer session of the University of North Dakota: Mr. Windsor R. Holgate, Mr. T. T. Quirke, and Miss Inga Knudson, and to Prof. M. A. Brannon and the staff of the State Biological Station for hearty cooperation in the study of this region. To Mr. Quirke, the author is also indebted for the draughting of maps and sketches accompanying this report.

This region is of physiographic interest because these lakes

1. Warren Upham, The Glacial Lake Agassiz, Mon. 25, U. S. Geol. Survey, 1895.
2. Daniel E. Willard, The Story of the Prairies, Rand McNally & Co., 1902.
3. Thomas E. B. Pope, Devils Lake, North Dakota, U. S. Bureau of Fisheries, Document No. 634, 1908.
4. First, Second, Third, Fourth, and Fifth Biennial Reports, North Dakota Geol. Survey, University, North Dakota.
5. Survey of the Proposed Division of the Mouse River to Devils Lake, T. R. Atkinson.

are typical in their origin of unnumbered thousands of glacial lakes in the northern part of the continent of North America and in their present brackish condition of another less numerous but widely distributed group in the western portion of our country. Of especial interest is this region to the people of the state of North Dakota because of its beautiful woods and waters, its rolling hills, and its abounding legendary and historic associations.

GENERAL PHYSIOGRAPHIC FEATURES

NORTH DAKOTA PLAINS

The Devils-Stump Lake region lies within the broad uplifted portion of the plain which in North Dakota forms the transition between the physiographic provinces of the United States known as the Prairie Plains and the Great Plains Plateau. The transitional character of the plain in this state is very marked, but in its origin, relief, and physiographic form, it is clearly a portion of the Prairie Plains and is so classified. So striking are the drift features throughout this plain that it may properly be called the Drift Prairie Plain. Within North Dakota this plain is, therefore, the middle one of three well marked plains which rise successively from east to west by distinct escarpments, these being the Red River Valley, the Drift Prairie Plain, and the Great Plains Plateau. (Plate X.)

THE RED RIVER VALLEY

The Red River Valley is not a true valley but an old lake plain, northward along the axis of which flows the Red River of the North. This plain is remarkable for its large level areas and its fertile soil-lacustrine deposits of silts and clays formed on the floor of an ancient glacial-marginal lake, Lake Agassiz, remnants of which are known today as Lake Winnipeg, Lake Manitoba and Lake of the Woods. That portion of this plain which lies within North Dakota has a breadth of thirty to forty miles, except at the southern end where it narrows to ten miles, and an elevation of from about 800 feet at Pembina to about 975 feet near Wahpeton. The boundary between the Red River Valley and the Drift Prairie Plain is an escarpment so abrupt and rugged in the north, where it passes just west of Walhalla and Mountain, as to receive the local name of Pembina Mountain. The wooded and dissected character of the bluff undoubtedly accents the contrast with the old lake floor and lends character to the local name. This same escarpment is even more conspicuous in Canada where it is termed the Manitoba Escarpment from the province through which it passes, and this is the general name by which this remarkable feature is best known. Near the middle of the state, and west of Larimore, it fades into a gentle and inconspicuous slope, becoming somewhat more marked again near Sheldon and Milnor, as the south state line is approached, and again so conspicuous in South Dakota as to receive the well-known name of the *Coteau des Prairies.* Throughout the entire distance across North Dakota the escarpment bordering the Drift Prairie Plain on the east rises 300 to 500 feet above the Red River Valley floor, in some places the slope is abrupt, in others gentle, but always is it conspicuous in this country of low relief.

THE GREAT PLAINS

On the western border of the Drift Prairie Plain rises the similar and even more abrupt escarpment of the Great Plains known in this region at the *Coteau du Missouri.* This escarpment trends from northwest to southeast, passing near Kenmare, Minot, and Steele, and rises 600 to 700 feet. This plateau occupies fully one-half of the state and is a characteristic portion of the Great Plains. Its irregular surface varies in elevation from 1,800 to 2,700 feet above sea level, the relief being due chiefly to the erosion of nearly horizontal beds of shale of varying composition and hardness. Only in the eastern portion, where lies the broad hilly belt forming the terminal moraine of the great North American ice sheet, known as the Altamont Moraine, is the surface form the result of ice action.

THE DRIFT PRAIRIE

The Drift Prairie Plain, lying between the two escarpments mentioned above, varies in width from about 200 miles at the north to 100 miles at the south and has a general elevation of from 1,500 to 1,800 feet above sea level. This plain has a gradual but gentle slope eastward from the *Coteau du Missouri* to the Pembina escarpment and *Coteau des Prairies* and southward from the international boundary line to the South Dakota line. This double slope determines the direction of the drainage, causing the several main streams to take a general southeasterly course. The topography of this plain is that of the young drift type characteristic of all that portion of the prairie plains which lies within the limits of the latest ice invasion, and varies from gently undulating through rolling to hilly, the form being due almost entirely to the original disposition of the unmodified glacial drift upon a nearly level plain. The soft, shaly character of the underlying rocks is such that they do not influence the surface topography to any marked extent, except where occasional groups of low well-rounded hills or full bodied ridges rise above the plain, and these are so well veneered with drift that only their form reveals their origin. Crow Peak, Sullys Hill, and the Blue Hills to the south and east of Devils Lake are all of this type, being mesa-like remnants of older and once continuous formations now all but eroded away.

More important because more numerous, though less conspicuous, are the groups of hills and knobby, irregular ridges which stretch across the prairie in a northwest to southeast direction. At times the ridge effect is pronounced and they lengthen out into long looped curves, and again there seems to be simply a confusion of low rounded hills, both types being so characteristic as to suggest at once to the student of physiography their origin in glacial moraines. This prairie is otherwise a gently rolling drift plain cut by a few abnormally deep and well defined valleys such as those of the James, the Sheyenne, and the Maple rivers, trending southward and eastward, marked by many shallow, irregularly winding coulees and dotted by thousands of small lakes and marshy areas, occupying numerous sags and swales, which testify to the undrained condition of the land.

Such topography is characteristic only of a drift region in which the irregularities of the earlier plain have been obscured by the filling up of the valleys, the smoothing down of the hills, and the spreading over all of a mantle of drift the inequalities of which remain today almost unmodified by the agents of erosion. The time which has elapsed since the completion of the work of the ice has been insufficient for but the slightest beginning of the erosive processes.

Two features of especial importance deserve mention in connection with this Drift Prairie Plain, since they stand in marked contrast to its general topography. These are the Turtle Mountains and the Mouse River Valley. Each of these resembles one of the other physiographic regions of the state and their location within the bounds of the Drift Prairie Plain and their peculiar relation to one another still further emphasizes the transitional character of this middle plain.

THE TURTLE MOUNTAINS

The Turtle Mountains are a rough, moraine covered tableland, lying midway on the Canadian boundary line. With an area of 600 to 800 square miles, they rise mesa-like 400 to 800 feet above the surounding plain, their margin forming a gentle though conspicuous escarpment on all sides. The "mountain" character is suggested not only by the elevation of this plateau above the plain, but also by the very rough morainal character of the surface. Lakes abound and this upland is, on the whole, well timbered and well watered, but very poorly drained. The Turtle Mountains are the most conspicuous illustration of that group of isolated residuals scattered here and there over the western portion of the Prairie Plains Province which are remnants of younger horizontal strata elsewhere eroded back to the *Coteau du Missouri* of which they may be considered an outlier.

THE MOUSE RIVER VALLEY

The Mouse River Valley is a glacial marginal lake plain, similar to that of the Red River Valley, the floor of which was formerly covered by the waters of Lake Souris. This plain lies between 1,100 and 1,600 feet above sea level. Like the Red River Plain, it also is drained northward through the eastern portion of the "Loop" of the Mouse River. The position of this low flat lake plain between the *Coteau du Missouri* and its eastern outlier the Turtle Mountains, accentuates the separation of these two features, formerly united, and shows by strong contrast the relative amount of work performed in this region by the agents of erosion in preglacial time as compared with the meagre work done since the close of the glacial epoch.

THE DEVILS-STUMP LAKE BASIN

With the possible exception of the Turtle Mountains and the Mouse River Valley, the most striking physiographic feature of the Drift Prairie Plain and one of the most interesting and important of the state is Devils Lake. This lake together with Stump Lake lies just within the southern border of the large interior drainage basin to which it gives its name.[1] This basin extends from the southern slopes of the Turtle Mountains and the Canadian boundary southward to a series of prominent hills lying between Devils and Stump lakes and the Sheyenne River. The eastern and western boundary lines are more vague and indistinct, but the theoretical area of the entire drainage basin is estimattd at about 3,500 square miles.[2] There is a gradual slope throughout the basin southward to these two lakes; the fall is so slight, however, and the surface so irregular that the drainage is but very imperfectly developed. Small lakes and ponds abound, especially in the southern portion. Coulees are few and very shallow, rarely containing running water except in wet seasons. Formerly these coulees and the chains of lakes connected by them emptied considerable water into Devils Lake through Mauvaise Coulee and by several converging coulees into both the eastern and western arms of Stump Lake. Mauvaise Coulee was the most important drainage line of the entire basin. Its headwaters were gathered beyond the international boundary line and in its course southward it drained the Sweetwater chain of lakes by Lake Irvine through which it passed, and entered Mauvaise Bay of Devils Lake as a large and permanent stream. Today no surface streams flow into either Devils Lake or Stump Lake except very minor flows during

1. E. J. Babcock, Water Resources of the Devils Lake Region, Second Biennial Report, North Dakota Geological Survey, 1903, page 208.

2. E. F. Chandler, The Red River of the North, Quarterly Journal University, North Dakota, Vol. I, No. 3, April 1911, p. 248.

spring thaws and after excessive falls of rain. Both lakes, however, undoubtedly receive extensive underground seepage from the drift cover of the large drainage basin, the waters of which move slowly down the slope from the north over the impervious floor of Pierre shale and through the lower sandy portions of the drift. Little of the surface drainage of this inland basin ever reaches either of these lakes. In fact, but a very small fraction, almost negligible, of the rain falling in the basin reaches the lakes by running off over the surface. The amount that reaches the lakes and the Sheyenne River by underground seepage is no doubt greater, but this amount cannot satisfactorily be estimated.

THE DEVILS-STUMP LAKE REGION

The larger physical features of the state and of the Drift Prairie which have been briefly reviewed are of interest in this report only as a setting for the physical features in the immediate vicinity of Devils and Stump lakes. These features will now be considered in some detail in the following order: the Plain; the Hills; the Moraines; the lakes, Devils Lake, Stump Lake, Sweetwater chain of lakes; the Sheyenne River.

The Plain.—The plain in the vicinity of Devils and Stump lakes is but typical of the larger area of the Drift Prairie Plain already described except in its more strongly marked morainal character. It is essentially a moderately rolling plain sloping gradually southward, and owes its origin primarily to the erosion and base leveling of a higher plan, as evidenced by the scattered residual hills which dominate the landscape between the Devils and Stump lakes and the Sheyenne River, and secondarily to the accumulation of a mantle of glacial drift to the variations in thickness of which are due all minor inequalities of relief.

So abundant are the ridges and belts of hills characteristic of recessional moraines and so pronounced is the heavily rolling topography of the ground moraine that the whole region might well be characterized as morainal. The common sag and swell topography of the drift prairie is here so accentuated that it approaches the knob and kettle type of moraine. The depressions of an intermediate type between the sag and the kettle are especially common and are here termed pans. (Plate XII, Fig. 2). The term seems especially appropriate to one who, passing through the country in spring, sees the broad landscape dotted with these depressions partly filled with water. Practically all of these pans dry out during the summer, many become excellent small hay meadows, while the floors of others somewhat deeper are coated with a thin crust of alkali salts which at a short distance has every appearance of standing water unless some man or

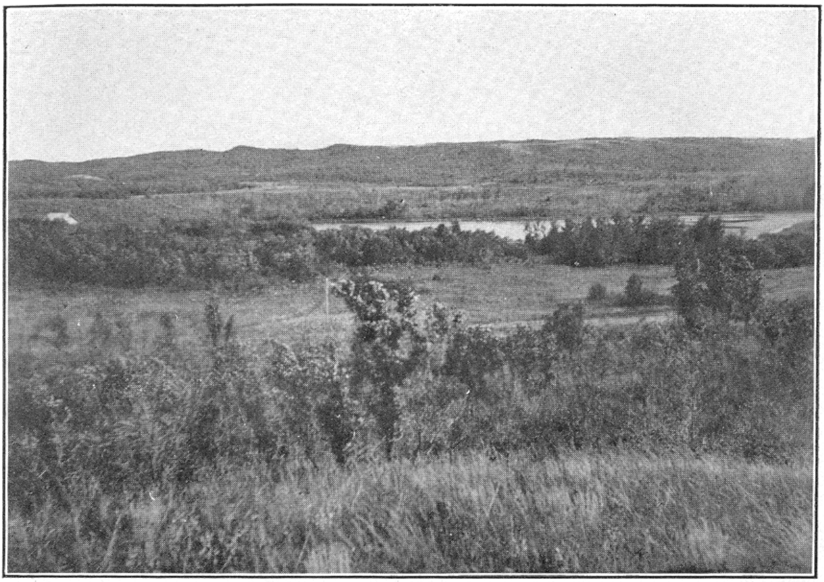


Fig. 1. Morainic topography south of Mission Bay, Devils Lake. Residual ridge veneered with recessional moraine in background, deep irregular basin in foreground. Indian house on left. (Knudson.)

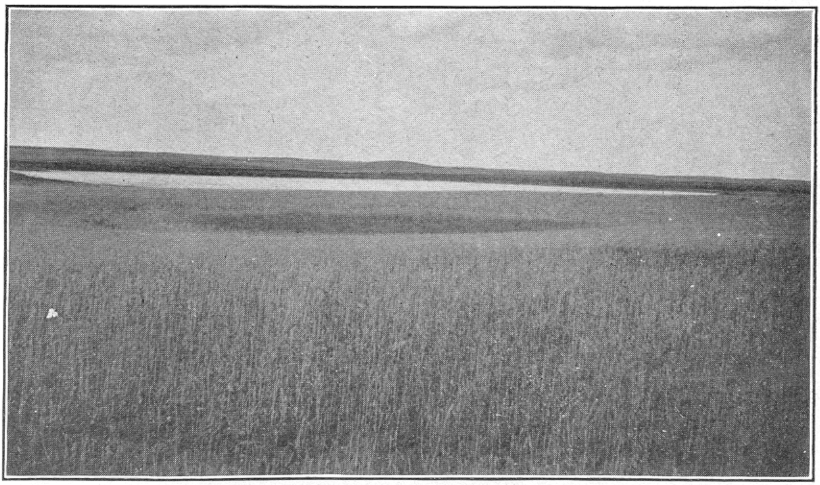


Fig. 2. Morainic topography north of East Bay, Devils Lake, characterized by gentle swells and shallow pans. Smaller pan in foreground is grassed over, larger one in rear is encrusted with alkali (August, 1910.) Isolated kame in background.

animal has happened across leaving a distinct trail. Clumps and fringes of small trees, of which poplar is perhaps the most common, are found in these moist depressions in some localities in such numbers as to add variety to the landscape and suggest in this country of low relief an odd type of inverted topography. This is particularly true of the neighborhood known as Poplar Grove, between Creel Bay and Six Mile Bay north of Devils Lake.

To another type of depression found occasionally upon the prairie interest attaches out of proportion to its physiographic significance. These are the "buffalo wallows," from which the earth has been carried away as mud on the bodies of these animals or has been stamped and pawed by their hoofs into dust and then blown away by the winds. In the center of each depression is usually found a large boulder in the presence of which may be seen the indirect cause of the depression. The boulder is generally well polished on its edges and projecting corners by the rubbing and scratching of the buffaloes of which there were formerly in this region many herds of countless thousands.

The best illustration of the buffalo wallow noted was near the southeast corner of the West Bay of Stump Lake on the farm owned by Mrs. Jennie Thatcher. This wallow was 108 feet in diameter and three feet deep. A large red granite boulder seven and a half feet long by seven feet wide and four and a half feet above ground stood in the center. The smooth sides and highly polished corner gave indirect but unmistakable evidence of the origin of the depression.

Occasional drift hills or groups of knobs more conspicuous than the rest are found capped with sand and gravel indicating their kame like origin.

The region is almost unmarked by drainage lines except a few well-marked coulees, through which little or no water flows today and which are very evidently channels of glacial drainage. The only exception to this general absence of recent drainage channels is to be found in the immediate vicinity of the Sheyenne River whose deeply eroded valley gives outlet to some short tributaries which are not now being pushed rapidly backward into the upland, owing to the short season in which they contain water and the hardy growth of grass found during the summer season.

The plain is typically prairie, yet in the immediate vicinity of Devils Lake is found a large portion of the good hardwood timber of North Dakota. The woods are close to the lake and chiefly on the north and south sides near the middle. Excellent oak, elm, ash, and a large variety of other trees are found here.

On the southern side they are limited chiefly to the northern slopes of Sully Hill range, where wind and temperature conditions are most favorable for protection from excessive evaporation. The best growths were undoubtedly on Grahams and Roque islands, for here "wood reserves" were early created by the Government to supply Fort Totten with fuel and timber.

The Hills—Residual hills, remnants of horizontal strata elsewhere eroded away, are found more frequently between Devils and Stump lakes than elsewhere in the Drift Prairie region. Of these, Mauvaise or Big Butte, Crow Hills, Sullys Hill, and Blue Mountains are striking examples, as they rise from 200 to 300 feet above the prairie. All of these, judging from their massive full bodied form and smooth outline, consist of shale veneered over with glacial drift.

The Moraines.—Probably in no region of the state, if indeed in any portion of the United States, are the recessional moraines better shown than in the vicinity of Devils Lake. Both types before mentioned, the long curving, irregular ridges and the confused masses of hills are here well represented.

To the north of the lakes and paralleling them at a distance of from six to ten miles is the long, ridge-like series of low rounded hills known as the Itasca Moraine,[1] the tenth in succession from the south formed during the retreat of the glacial ice in this region. This moraine is well shown between three and four miles north of the city of Devils Lake, where the hills have an elevation of 50 to 75 feet above the general level of the plain. The Sweetwater group of lakes lies just to the north of this moraine, originating probably in the low flat land behind the morainal dam which lay across the natural drainage slope to the south.

Numerous small and narrow belts often of very modest swells and knolls extend southward from the Itasca Moraine and have an almost north and south trend. The fact that these are nearly parallel to each other and normal to the trend of this larger belt, and that they all terminate in it to the northward suggests that after a rather rapid eastward retreat of the margin of the ice in this immediate vicinity that it again advanced from the north, which theory seems to be further suggested by the general arrangement of the several larger belts of the Itasca Moraine bebetween Devils Lake and Pembina Mountain.[2]

Between Devils and Stump lakes and the Sheyenne River is found the most remarkable union of morainic belts to be found in North Dakota. Here the fifth, sixth, seventh, eighth and

1. Warren Upham, The Glacial Lake Agassiz, Mon. 25, U. S. Geol. Survey, 1894, p. 173.
2. Ibid, Plate XX.

ninth of the series known respectively at the Waconia, Elysian, Dovre, Fergus Falls, and Leaf Hills moraines unite in a confusion of morainal topography. Most important of these several moraines however, are the eighth and ninth, which immediately border both Devils and Stump lakes on the south and are indistinguishable (Plate XII, Fig. 1).

"Along the entire south side of Devils Lake, extending more than thirty miles from Jerusalem to Minnewaukan, this compound morainic belt is magnificently developed, in many portions forming hills, knobs, and ridges of till, very rough in outline and bristling with multitudes of boulders of all sizes up to 10 feet in diameter, on a width that varies from one to five miles. Most of these hills rise 50 to 150 feet above the lake, and appear by their small area and glacial features to consist wholly of drift."[1]

"Perhaps the most striking feature of the morainic belt south of Devils Lake is the overwashed gravel and sand which generally border the southern side of the hills, descending from them in graceful slopes. The deposit is most grandly exhibited three or four miles east of the Fort. The upper edge of the overwashed slope, there consisting of gravel and sand, with rounded and subangular cobbles of all sizes up to a foot in diameter, rests, at about 225 feet above the lake, upon the southern side of the morainic hills, with their vast accumulation of boulders, which rise only from five to ten to forty feet higher. The gravel and sand form a flat tract that declines from the moraine at the rate of 30 or 40 feet per mile; and these fluvial beds have a considerable thickness, as is shown by water courses which have become channeled to depths of 50 or even 100 feet without disclosing boulders."[2]

DEVILS LAKE

Devils Lake is characterized by broad, shallow, and irregular bays, connected by "narrows" and entered by many "points," from which radiate several long narrow arms, the whole producing a strikingly irregular form with great extent of shore line. It belongs to that class of lakes, numerous in the northern United States, formed during the retreat of the glacial ice in the irregular depressions left in the blocked and partly filled valley which had been eroded in the bed rock during preglacial times. In some of the bays, notably those having a general north and south trend, the valleys may have been deepened somewhat by the erosive action of the ice and thus resemble in origin the Finger Lakes of New York State. Judged by its long,

1. Warren Upham, The Glacial Lake Agassiz, Mon. 25, U. S. Geol. Survey, 1894, p. 169.
2. Ibid, p. 170.

narrow form, parallel and fairly steep sides, the Six Mile Bay best illustrates the class to which this scooping action of the ice probably contributed. The main body of the lake when first surveyed in 1883 consisted of six large, shallow bays connected by "narrows," presenting a decidedly meandering form or an arrangement of bays almost *en eschelon* with a general northwest to southeast trend. The length of the lake from Minnewaukon on the west to Jerusalem on the east was approximately thirty miles, while the greatest width, between Chautauqua and Sullys Hill, is four and one-half miles.

The number of secondary bays extending in a direction nearly normal to the trend of the main lake adds much to the irregularity of the form and tends to confirm the theory of origin above mentioned. The area of the lake in 1883 was approximately 125 square miles, and, on account of the strikingly irregular form of its many narrow bays and long slender arms, the shore line exceeded 180 miles in length. Geologic as well as historic evidences all point to a much larger lake and a more complicated shore line than this. Since 1883 no complete survey of the lake has been undertaken, but through the lowering of the lake level and the process by which the bays are cut off to form separate lakes the shore line has been greatly simplified and the area much reduced. The present area of the lake is not precisely known, but is estimated as "not more than half of the 120 square miles formerly seen."

Devils Lake is not of great depth, and is in fact a relatively shallow lake. Upham reported it "75 or 80 feet in the eastern portion of its broadest area,"[1] probably meaning the eastern central portion of the Main Bay; but this is probably excessive, as soundings made in 1907 by the Bureau of Fisheries[2] revealed a maximum depth of 25 feet. The surface elevation at this time was 1,428.58 feet above sea level. Since the known surface in 1883 was 1,439.08[3] its depth at this earlier date must have been about 10.5 feet more than in 1907, or 35.5 feet, the greatest depth since the settlement of the region. Since the soundings made by the Bureau of Fisheries the lake has lowered to 1,424.98[4] or about 3.6 feet, which gives a present depth of about 21.4 feet. The maximum of soundings taken in 1911[5] was 23 feet, showing a fairly close approximation of the calculated depth.

Observations on the floors of the old bays now dry, together with inference from the fact that there is no inlet to the lake, lead to the belief that there is little filling being done in the larger bays and that decrease in depth from this cause need not

1. E. F. Chandler, Surface Water Supply of the United States, Part V, Water Supply Paper No. 245, U. S. Geol. Survey, 1907-8, p. 52.
1. Warren Upham, The Glacial Lake Agassiz, Mon. 25, U. S. Geol. Survey, 1894, p. 170.
2. Thomas E. B. Pope, Devils Lake, North Dakota, U. S. Bureau of Fisheries, Document No. 634, 1908, p.
3. U. S. Geol. Survey, B. M., Chautauqua.
4. Reading, June 21, 1911.
5. Soundings by Mr. Marshall Brannon, of the State Biological Station staff.

be taken into account. Further observations on the shores indicate that even in the earliest historic times the depth of the lake did not reach 50 feet.

Sources of the Water of the Lake.—There is today neither inlet nor outlet of Devils Lake. Previous to 1889 the Mauvaise Coulee drained the Sweetwater group of lakes through Lake Irvine into Mauvaise Bay at the northwestern corner of the lake. This Sweetwater group consisted of an important chain of lakes including Sweetwater Lake, Dry Lake, Twin Lakes, Lac aux Mort, and Lake Irvine, all connected, at least in times of high water, by a series of small coulees. Into these near the eastern end flowed the waters of Sweetwater Inlet, and near the western end those of Mauvaise Coulee, both of which drained considerable areas to the north. Thus, through Mauvaise Coulee alone, Devils Lake received the waters of a considerable inland drainage system. Of such volume was this stream that an important wagon ferry was maintained at Churches Ferry, a point a short distance below the outlet of Lake Irvine.

Since 1889, however, Mauvaise Coulee has had a dry bed except during spring thaws, and within the last few years even these have not caused it to flow. No natural stream of water is now known to flow into Devils Lake by this or any other channel.

The present sources of water of Devils Lake are, therefore, three: (1) the rainfall upon the surface of the lake; (2) the run-off from the small, uncertain and very irregular area sloping toward and immediately surrounding the lake; and (3) the ground waters coming into the bed of the lake, chiefly in the form of seepage. No considerable springs are known to feed the lake.

The amount of rainfall in the Devils Lake region is well known from long continued observations at several stations by the United States Weather Bureau and its forerunner, the Signal Service. The records of these stations show that the normal annual rainfall is approximately 18 inches.

The inflow by run-off from the land immediately about the margins of the lake is small, uncertain and very irregular. Comparatively little water enters the lake in this way because of the morainal character of the land immediately surrounding it. Sags pans, kettles, and other undrained depressions are common among the hills and on the prairies. The subsoil of glacial drift contains

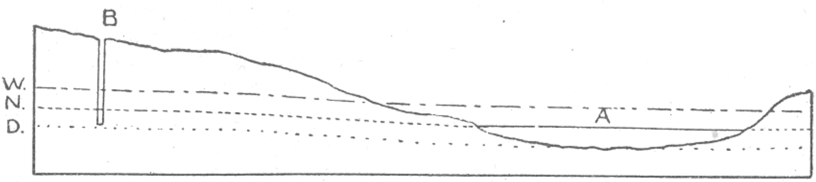


Fig. 1.—Diagram showing the relation of lakes and wells to the ground water table: N. normal level of the water table; W, Watertable in wet years; D, water table in dry years; A, lake in normal or wet years or marsh in dry years; B, well, with abundant, scant or no supply of water according as year is wet, normal or dry.

much gravel and sand and is relatively porous, while over a considerable portion of the area a heavy forest cover prevails. All of these conditions favor evaporation or absorption of the rain water and decrease the run-off. When we remember that, "the total run-off for the entire year as found at river stations of this state is rarely more than two inches, and often only a fraction of one inch,"[1] we realize that very little of the run-off can reach Devils Lake under conditions mentioned.

The chief source of the water of Devils Lake is undoubtedly to be found in the ground water. The surface of the lake is but a continuation of the ground water table which extends underneath the shores of the lake and gradually rises into the surrounding plains and hills. Water falling in rain upon the lands percolates downward through the soil and subsoil until it reaches a horizon below which there is saturation, or an impervious rock stratum. Owing to capillarity this water table, as the upper surface of the ground water is called, is higher under the hills and lower under the depressions, such as valleys and lake basins, but where these are so low as to pass below the ground water table the water seeps down along the table into these open areas until they are partially filled. In this way the level of the lake is maintained, subject to variations from evaporation and rainfall.

The Escape of the Waters of Devils Lake.—Since there is no visible outlet to the lake, the only way that the water can pass from the lake is by: (1) evaporation into the air; and (2) by underground outflow in the form of ground water. The ground water level is in general higher than the lake level and the lake is the lowest part of the great inland drainage basin, so it is improbable that water actually flows out from the lake underneath any part of the surrounding country. The lake occupies rather the bottom of the basin into which the ground water from the surrounding country drains, particularly from the great prairie area sloping from the north. The escape of water from Devils Lake today is probably almost entirely by evaporation, and in times of normal rainfall the evaporation slightly exceeds precipitation and inflow, thus accounting for the gradual lowering of the lake since the earliest settlement in this region. The amount of water in the lake today, therefore, depends chiefly on the elevation of the ground water table on the one hand (Fig. 1), and evaporation on the other. Both of these depend to a large degree upon rainfall and the humidity of the atmosphere. We see, therefore, that the lake level is dependent primarily upon climatic control. It is subject to many fluctuations directly or indirectly associated with the weather, and to some important modifications which are

1. Chandler, ibid. p. 51.

the result of human agencies, such as drainage and the cultivation of the soil, but in general the size, depth and permanency of the lake depends on climate.

The Shore Line.—The remarkable length and irregularity of the shore line of Devils Lake have already been noted. The present shore is almost everywhere covered with boulders and cobbles (Plate XVII) generally incrusted with a white alkaline deposit, or consists of gravelly and sandy stretches which slope down to the water's edge in series of belts (Plate XV, Fig. 2) or more rarely steps, from the ancient cliffs or beaches well above and often far back from the present shore. The succession of slopes and beaches, each marked by its characteristic vegetation, and the heavy forest growth which prevails upon the upper levels and the upland are very striking. (Plate XV, Fig. 2.)

Floor of the Lake.—The form and character of the floor of the lake was studied in detail by the Bureau of Fisheries in 1907, when a hydrographic survey of the Main Bay was made and observations taken on all other portions. In his report of this survey Thomas E. B. Pope says:

"The floor of the lake is practically level, rising from a depth of 25 feet to the shallow portions near the shores or forming sand bars and stony reefs at the mouths of bays. In general the deepest area is that of the southern side under the lee of the morainal ridges of Sullys Hill and Fort Totten, while the entire western section beyond LaRose Ferry (Minnewaukon Bay) is but three feet deep, with underlying soft black mud supporting an abundance of weeds and inaccessible to all but the lightest draft boats."

The sandy and gravelly beaches of the steeper littoral portions, the muddy character of the main floor and of all the larger bays and rapidly shoaling shores, together with the abundance of water weeds now growing in shallow bays, was attested by many observations in the field. Owing to lack of inlet and to the absence of cliff cutting by the waves, filling upon the floor of the lake is extremely slow and unimportant, and only in the most shallow bays is there a noticeable accumulation of vegetable matter. Over the broad head of Creel Bay, dry since 1889, not over six inches of filling is found overlying the drift floor.

Composition of the Waters of Devils Lake.—The waters of Devils Lake may be termed alkaline and brackish since they show a salinity of about one per cent, of which magnesium and sodium salts constitute a considerable portion. Analysis by the U. S. Bureau of Chemistry shows the following composition:[1]

ANALYSIS OF THE WATERS OF DEVILS LAKE, 1907

(Parts per million.)

Carbonic acid ion	125.1
Bicarbonic acid ion	538.9
Silica	26.6
Chlorine	900.3
Iron	14.8
Calcium	26.3
Magnesium	530.5
Sulphuric acid ion	4,977.9
Sodium	2,108.3
Potassium	199.7
Total	9,448.4

HYPOTHETICAL COMBINATION

Potassium chloride	380.5
Sodium chloride	1,187.3
Sodium sulphate	5,058.8
Magnesium sulphate	1,955.1
Magnesium carbonate	179.9
Magnesium bicarbonate	505.9
Calcium bicarbonate	106.3
Ferrous bicarbonate	47.1
Silica	21.0

This analysis shows the Devils Lake water to have almost one-third the salinity of sea water. It is therefore not suitable for drinking or for boiler use, though stock have not infrequently been observed drinking it. Two varieties of fish, stickleback and minnows, live in the water, the former in great numbers, and form an important food supply for the thousands of gulls and other water loving birds which inhabit the region. Frogs and salamanders also find the water congenial.

The character of the water is further shown by the fact that the boulders and gravel of the lower beaches are encrusted with "white alkali" and in the dry summer of 1910 broad strips of the beach and shallow portions of the lake from which the waters had but recently receded were covered with a grayish white efflorescence. In 1911, however, with the normal amount of rainfall and a higher lake level, this latter feature was entirely wanting.

BAYS OF DEVILS LAKE

The main body of the lake is divided into four well-marked sections generally termed bays. These, in their order from west to east, are as follows: Minnewaukan Bay, Main Bay, East Bay, Lamoreaux Bay.

1. Thos. E. B. Pope, Devils Lake, North Dakota, Bureau of Fisheries, Document No. 634, 1907, p. 15.

Minnewaukan Bay.—This large bay, scarcely second to the Main Bay in size, formerly extended from the village of Minnewaukan 11 miles eastward to LaRose Ferry at the southeast end of Grahams Island. At the time of the Bureau of Fisheries Survey in 1907 no point was found more than eight feet in depth, and it was in most places much less, while the soft black mud on the flat bottom supported such an abundance of weeds as to make it inaccessible for all but the lightest draft boats. During the years 1910 and 1911 only skiffs and a single launch drawing 18 inches of water have been able to pass the narrows at LaRose Ferry, and the launch succeeded only in early spring. The western half of the bay is almost dried up and covered with grass and weeds. Occasional ponds and a small channel extending up to the mouth of Mauvaise Bay, are the only remnants of this recently broad expanse of water.

From Minnewaukan Bay only one secondary bay of importance leads off. This is Mauvaise Bay, or Pelican Lake, which opens at the northwest end of Grahams Island and extends north and northwest about six miles. Into the head of this formerly emptied the only known inlet of Devils Lake, Mauvaise Coulee. Two or three small detatched bodies of water, connected in early summer by a narrow, shallow channel, is all that remains of this once important stream.

Main Bay.—The Main Bay is today the only section of importance in Devils Lake. It extends from the LaRose Ferry to the Narrows, five miles south of Devils Lake City, across which the Great Northern Railway Bridge and a causeway carrying a public highway have been built, entirely cutting off all connection with the eastern portion of the lake. This bay is, therefore, about eight miles long and at its widest point, from the mouth of Creel Bay to Sullys Hill, four and a half miles in width. According to the Bureau of Fisheries survey it embraced a total area of 34.5 miles in 1907. Here was found the maximum depth of 35 feet in 1883, which by 1907 had been reduced to 25 feet, and this to 23 in 1911. The deepest area extends from the middle of the bay to the lee of the Sullys Hill range. The bottom is a very level floor of soft black mud gradually ascending to sandy, gravelly, or even bouldery shores.

Several important bays open into the Main Bay, chief of these being Creel Bay in the middle of the north shore, Six Mile Bay in the northwest end, Mission Bay and Black Tigers Bay to the southeast, and the broad open Fort Totten Bay opposite Creel Bay on the middle south shore.

Creel Bay.—Most important of all the smaller bays of the lake is Creel Bay. At the time of the original survey in 1883, this extended in a northeasterly direction for about three and one-half miles with an average width of about one-half mile, then turned sharply to the east through a "narrows" and opened out into a broad, shallow bay two and one-half miles in width, on the northeast shore of which was located the city of Devils Lake.

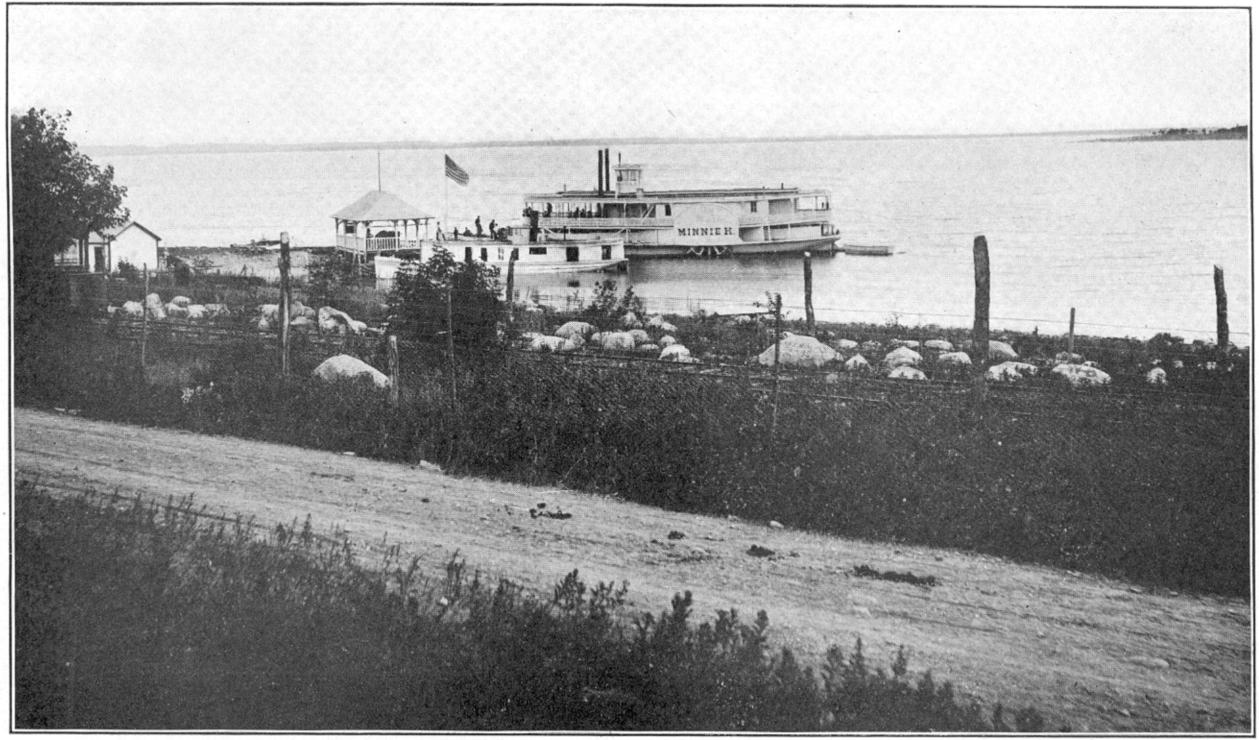
In 1889 this shallow upper portion, which in 1884 had a depth of about seven or eight feet,[1] dried up, and in 1907 the lower portion of the bay that remained showed a maximum of twenty-three feet near its mouth and fifteen feet for the then major portion. The depth in the middle of the bay off the Biological Station was found to be thirteen feet in 1911.[2] The shores of the bay are all sandy, gravelly, or boulder covered except for the mud and marsh portion at the extreme end.

On the eastern shores of Creel Bay at North Chautauqua is located the State Biological Station conducted under the direction of the Board of Regents of the University of North Dakota. Just south of the Biological Station grounds, in the yard of Captain. E. E. Heerman, the veteran master and pilot of the fleet of steamers that formerly plied on the waters of this lake, stands the permanent bench mark of the United States Geological Survey, established in 1883. This bench mark consists of an iron post three inches in diameter driven deep into the ground, on the top of which is a brass cap with inscription.

A painted wooden tablet standing beside the bench mark bears the following inscription: "This bench mark is 1,439.08 feet above the sea and represents height of lake in June, 1883. Zero of gauge 22.90 feet below the bench." The gauge referred to is a staff tide gauge, established by the United States Geological Survey at the time of the setting of the bench mark and is attached to the piles of the pier at the Chatauqua landing for Captain Heerman's steamers at the foot of the yard. (Plate XIII.) This gauge has been read occasionally since 1883 by Captain Heerman and since the establishment of the Biological Station regularly during the open season by members of the Biological Station staff. The records will be found in connection with fluctuations of lake level.

Six Mile Bay.—Whether this bay received its name from its length or its distance from the site of the city of Devils Lake at the head of Creel Bay is a mooted question, and either may be correct. The bay trends northeasterly from the western end of Main Bay and parallels Creel Bay and like it is probably formed in a north tributary of the main valley, the blocking of which has

1. From interview with Captain Heerman.
2. Soundings by Mr. Marshall Brannon, State Biological Station staff.



Devils Lake looking southwest from Chautauqua (Photo by Kitchen, 1903.)

formed Devils and Stump lakes. While the bay is not deep, but ten feet being reported in 1907, the direction and linear form, the straight, smooth, and steeply sloping sides suggest more strongly than in any other bay the scooping action of the glacial ice, after the manner of the formation of the well known group of Finger Lakes of New York, including Cayuga, Ithaca, and others. The northern end shoals less rapidly than Creel Bay and the water has retreated not to exceed a mile. Otherwise the shore lines differ but slightly from those shown on the map of 1883. (Plate XI.) A causeway with but one small wooden bridge crosses the bay from east to west about one-third of the way from the northern end anticipating at this part of the bay the natural formation of a bay head bar, the two spits at either end of which were well developed before the causeway was commenced.

Mission Bay.—This very irregular bay extends from the southeast corner of the Main Bay and in 1883 was subdivided into Mission Bay and Little Mission Bay. The longer and more irregular portion extending in a southeasterly direction has been cut off by bars, much of it has dried up, and the portion remaining is known as Mission Lake. Little Mission Bay has also been reduced by bay head bars to what is now termed Misson Bay and Little Mission Lake. (Plate XX, Fig. 2) The former trends southwesterly, has a length of less than a mile with a breadth of less than one-half mile. In 1907 the deepest water reported in the bay was eleven feet, with but five and one-half feet in the channel over the bar across the mouth. The bottom is covered with soft black mud into which an oar can be sunk at least two feet, and in the shoal south end the water weeds grow in such a mass as to make progress with a light launch very difficult, as weeds repeatedly entangle the propeller. The shores are uniformly sandy and gravelly.

Fort Totten Bay.—This historically important bay on the south side of the Main Bay is so broad mouthed as to be regarded by many as but a portion of the Main Bay, yet of such interest is it that it is well deserving of emphasis. It is about a mile deep and a mile across. The crest of Sullys Hill, the highest point in the region, commands the entrance on the east side. From its base a boulder-covered point juts out into the gateway. Extensive shale beaches on the western side of the bay mouth led to the discovery there of outcropping ledges of Pierre shale, the only known bedrock exposure in the lake, which have determined the location of this side of the mouth. (Plate XVIII, Fig. 1.) The bay is undoubtedly deeper than most of the bays, but soundings are wanting.

The beautiful little spring-fed body of water known as Little Sweetwater Lake, which lies in behind the hills to the northeast of Fort Totten, is a former head of this bay, now long seperated by a broad bar overgrown with tangled growth of forest and vine.

Eastern Bay.—This section of Devils Lake trends northeastward and then southeastward, forming a strongly marked bend, and is approximately fifteen miles long from the Narrows at the Great Northern Railway bridge to the Odessa Narrows, across which is the causeway known as Lamoreaux Bridge. This bay is uniformly shallow, about twelve feet in 1907, and shoals rapidly on both sides and toward the east. During the dry year of 1910 much of the eastern arm of the bay was an alkali incrusted mud flat, and a series of soundings in 1911 revealed no point over eight or nine feet in depth.

Lamoreaux Bay.—The extreme southeastern section of Devils Lake, about six miles in length and a maximum of two in breadth, is known as Lamoreaux Bay. It has relatively even sandy shore lines. The depth is unknown, but the comparatively narrow beaches indicate fair depth and less shoaling in this than the Eastern Bay. On the eastern side of this bay at Jerusalem is found the ancient outlet to Stump Lake.

STUMP LAKE

Stump Lake is located eight or ten miles southeast of Devils Lake and in the line of its general trend. The location suggests a glacial origin similar to that of Devils Lake and in the lower portion of the same valley. It also lies in the southern margin of the same inland drainage basin and during geologic times at least was a part of the same drainage system. So closely is it united physiographically with Devils Lake that it is included in the title head of this paper. Its area in 1883 was about sixteen square miles and its shore line about thirty-five miles in length. This lake is fully as irregular in form as Devils Lake and consists of three bays: the East Bay, Middle Bay, and Harrisburg Bay.

The West Bay is largest of all, being three miles broad in the southern portion and tapering to one mile at the northeast end. In this bay are located the three islands set apart by the Government as the Stump Lake Reserve for the protection of the large numbers of game birds which nest upon these islands.

East Bay is six miles long and approximately one mile wide and trends southeasterly from the north end of West Bay. This is probably the deepest portion of the lake and while a reported depth of 100 feet or more was accepted by Upham,[1] soundings

1. Warren Upham, Glacial Lake Agassiz, Mono. 25, U. S. Geol. Survey, 1894, p. 170.

by Mr. Marshall Brannon of the Biological Survey in 1911 reveal but a depth of thirty-nine feet. The trend and general shore character of this bay suggests considerable scooping action of ice in central and north portions. Extensive springs in the southern end of this bay supply a considerable amount of very pure water to the lake. Here also are the remains of an ancient forest, the stumps of which, until recently submerged, have given the name to the lake. (Plate XIX.)

Harrisburg Bay extends in a general easterly direction from near the southern end of Eastern Bay and while three-fourths of a mile in width near the mouth narrows to a point in a distance of three miles.

Swan Lake.—Swan Lake is a small detached portion of Stump Lake lying north of the extereme northern portion of the lake and connected by a coulee with the larger lake, and into this end as well as into the extreme eastern end of Harrisburg Bay several coulees, now generally dry, formerly poured their waters.

The Sweetwater Chain of Lakes.—Lying about ten or twelve miles to the north of Devils Lake and having a general direction parallel to it is a chain of lakes sometimes known as the Sweetwater group from the largest and best known of the chain. This series of lakes owe their origin to glacial agencies chiefly of the constructional type, since they lie in the flat lowland behind the ridge of hills known as the Itasca moraine, where the drainage down the natural slopes from the north is checked and the depressions in many of the moraines filled with water form lakes of a broad, shallow, irregular type characteristic of such an origin and location.

Lying as they do in this position, they form a sub-drainage basin with a down slope to Devils and Stump lakes which lie in the lower southern portion of the same natural basin. They formerly received the drainage, both surface and subsurface, from a large area, but are today without apparent inlet except in wet seasons, and are subject to great fluctuation with the years. Formerly these lakes were all connected by coulees in the following order from east to west:

Sweetwater Lake, Cavanaugh Lake, Dry Lake, Chain Lakes, Lac aux Morts, Lake Irvine, and thence through Mauvais Coulee with Devils Lake, into which they poured a considerable body of water. Not only is there now no outflow into Devils Lake, but the connections between the lakes is rarely made. Some of the lakes, notably Dry Lake, are dry beds or grassy meadows most of the time.

Attention has been called to the fact that Sweetwater Lake, Dry Lake and Twin Lakes, Lac aux Morts and Lake Irvine lie directly north of the three bays of Devils Lake: Creel, Six Mile, and Mauvaise, and the suggestion has been made that the lakes lie in the same tributary valleys in which these three large arms of Devils Lake lie and that the Itasca Moraine which crosses these tributary valleys in an east and west direction dammed their courses and so caused the lakes to gather above where the valleys are filled.[1]

Of these lakes Sweetwater, which lies about five or six miles north of the city of Devils Lake, is the largest, being ten or twelve square miles in area, and the most important. Its maximum depth in 1907 was seventeen feet. The water is fresh and the margins are largely lined with rushes. Sweetwater Inlet, a coulee formerly of considerable size, enters the lake at its eastern end. Like Devils Lake, this very unique lake is broken up into detatched lakes by building of points out into bars and the lowering of the lake level. A series of beaches also indicate former higher levels.

The Great Northern Railway obtains its water supply at Devils Lake from this lake by means of a pipe line, and connection is made with the Devils Lake city waterworks, though it may be used by that city only in case of fire or other emergency. So soft and fresh is the water that it makes an excellent water for steam purposes.

The other lakes of this series are shallow, so much so that they are often frozen solid in winter. Their depth, however, varies greatly with the season. All are slightly brackish.

THE SHEYENNE RIVER

Only one permanent stream is to be found in the vicinity of Devils and Stump lakes. This is the Sheyenne River, the source of which lies to the west near the great "Loop" of the Mouse River. From here it flows eastward, passing about ten miles south of and parallel to Devils and Stump lakes, after which it flows 100 miles southward and enters the Lake Agassiz basin, thence northeastward to the Red River ten miles north of Fargo. This river forms the southern boundary of the area under consideration and is of interest in this connection chiefly because of its geologic relation to the lakes. The great irregular moraine just south of the lakes forms the divide between inland drainage basin of the lakes and that of the Sheyenne River, though in the ancient history of these lakes they all belonged to one system, Devils Lake having outlet into Stump Lake and Stump Lake into Sheyenne River.

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1. Daniel E. Willard, Story of the Prairies, 1907, p. 160.

The chief interest in Sheyenne River lies, therefore, not in the present stream but in the history of that earlier Sheyenne, doubtless much larger than the present stream, first formed by drainage from the great ice sheet when it stood with its front along the great morainal divide south of Devils Lake and the outlet of glacial Lake Souris and the earlier and greater Devils and Stump lakes.

It was during this period of the greater Sheyenne that this great valley, far too large for the work of the small stream which flows through it today, was carved. That the carving went deep into the original bed rock underneath the drift may be seen from the plentiful exposures of the Pierre shales where the high bluffs of the old valley are undercut by the present stream. In places where the valley is sunk to the depth of 150 to 200 feet below the upland one-half to three-fourths of the depth may be in dark gray shale. Terraces in the train of gravels deposited in the valley during the retreat of the ice are remarkably well developed.

THE BED ROCK

In the region about Devils and Stump lakes the glacial drift is so thick and so uniformly distributed that few exposures of the underlying strata are found. There is, therefore, little opportunity for the study of the bed rock. The few known outcrops occur in widely separated localities in the deeper valley walls, the margins of the lake basins, and in deep road cuts. From these and from the samples and logs of the deeper wells we may, however, learn much of the underlying strata, especially when this data is correlated with that of the more extensive exposures farther east, where the larger rivers have cut deep valleys through the Pembina escarpment as they flow down to the Red River plain.[1]

CRETACEOUS SYSTEM

THE PIERRE SHALE

All evidences point to the fact that but one formation immediately underlies the drift of this entire region, and probably of the whole of the Drift Prairie plain. This formation is everywhere readily recognized as the Pierre shale, the name being derived from Fort Pierre, South Dakota, where it occurs in a characteristic outcrop and is exposed over a large area.

Shale is composed of particles of mud pressed and cemented together into a compact mass. Such rock in a widespread area indicates that the mud from which it was derived was deposited in large bodies of water, the thin and very uniform thickness of

1. For a brief, but comprehensive, account of the general geology of the state, see A. G. Leonard, The Geological Formations of North Dakota, Third Biennial Report, N. Dak. Geol. Survey, 1904, pp. 140-177.

the layers indicates sedimentation in very quiet waters, and the presence of salt water fossils indicates marine conditions. Such conditions are found today in moderately deep off-shore seas, and from this may be inferred the general conditions under which the Pierre shale was deposited. This shale is locally known as slate, though it lacks the hardness, texture, and characteristic cleavage of this more indurated and metamorphosed rock.

The Pierre shale is generally of a dark blue-gray color, and thin laminae unite to form strata of very uniform character and of great thickness over large areas. In the deeper portions somewhat sandy layers are occasionally found. In the outcrops where exposed to the air the shale is well jointed and readily weathers into small flaky fragments which have little spots or blotches of pale yellow color, due to the iron oxide which they contain. They also occasionally yield small brownish yellow limonitic concretions..

Good exposures of the bed rock have been found in but few places. The best of these outcrops occur in the banks of the Sheyenne River where, owing to the deep post-glacial cutting of this stream, the shale is exposed in sections many feet in thickness. The same conditions prevail in the lower valley sides of the major tributaries of the Sheyenne, notably on both sides of the Big Stony Coulee where the wagon road crosses it one-half mile east of Tolna.

The extensive shale beaches on the south shore of the Main Bay of Devils Lake just west of the broad entrance of Fort Totten Bay led to the discovery of ledges of this shale just at the water's edge at this point, from which the waves had washed a large portion of the beach material. (Plate XVIII, Fig. 1.)

Bed rock is also found below two feet of drift in a spring a few rods southwest of Court Lake, and is reported as forming the lake bed in the south end of Mission Bay three or four feet below the surface of the water, where it may be found by wading.

In all of these outcrops the character of the shale is essentially the same and, though no fossils were found, all may undoubtedly be referred to the Pierre stage of the Cretaceous system.

CRETACEOUS FORMATIONS BELOW THE PIERRE SHALE

It has already been stated that no rock other than the Pierre shale outcrops in this region. Older beds of rock lying beneath the Pierre have been penetrated by many artesian wells within the state, one of the most important of which is the well located in the city of Devils Lake. A study of the record of this well in the light of the records of the other deep wells and of the outcrops throughout the state makes it possible to describe the strata passed through and the geologic history of the region which they present with a fair degree of certainty.

The Devils Lake artesian well was drilled in 1889 to a depth of 1,511 feet, the elevation of the curb being 1,470 feet above sea level. The section of the well is as follows:[1]

SECTION OF DEVILS LAKE WELL.

	Feet
Glacial drift, till as on the surface	25
Dark shale, nearly alike through its whole thickness, including Fort Pierre and Fort Benton formations, with no noticeable calcareous beds at the intermediate Niobrara horizon	1,043
Gravel, of granitic pebbles up to half an inch in diameter, firmly cemented with nodular pyrite	3
Dakota sandstone, or rather a bed of loose sand, very fine, white, or light gray, the base of which was not reached	80
Total	1,511

1. Warren Upham, Glacial Lake Agassiz, Mon. 25, U. S. Geol. Survey, 1895, p. 529.

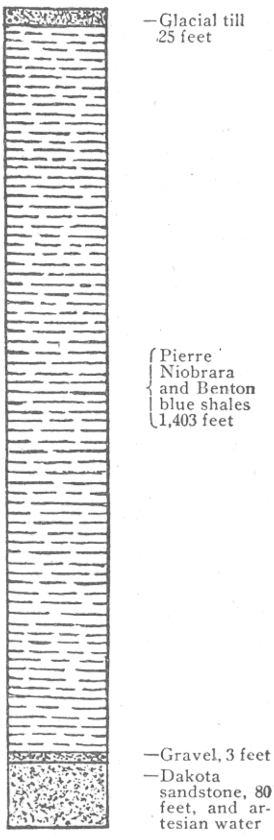


Fig. 2. Section of artesian well at Devils Lake, showing geological formations of region (Babcock).

The 1,403 feet of dark gray shale beneath the drift and above the Dakota sandstone was not differentiated by the driller but it undoubtedly included the Pierre, Niobrara, and Benton shales. In outcrops in the Pembina escarpment near Walhalla both the Niobrara and the Benton are well shown. The Niobrara is somewhat lighter in color than either of the others and quite calcareous. The Benton is darker, almost a jet black in large part, and not infrequently contains pyrite nodules and gypsum crystals.

The lowest member of this section is the Dakota sandstone, penetrated at a depth of 1,431 feet and which at 1,470 feet, just at sea level, yielded a strong flow of brackish water carrying much fine white sand in suspension. No outcrops of this formation are known within the state, but since it is the chief artesian water horizon it has been reached by the drill many times and is well known from drill samples. This important water bearing sandstone probably underlies the entire state except a portion of the Red River Valley, where granite is reached at comparatively shallow depths. Westward it extends to the Black Hills and the foothills of the Rocky Mountains where it rises to the surface and gathers the waters which gush forth so plentifully in the artesian wells of the eastern part of the Dakotas.

All of the formations shown in this well section, which extends 41 feet below sea level, belong to the Cretaceous system, so called from the large amount of chalk contained in its rocks in some portions of the world, notably southern England and Texas. Something of its characteristics is shown at Concrete, where an attempt has been made to utilize the Niobrara beds in the manufacture of cement.

GEOLOGIC HISTORY.[1]

During the time in which these rocks were being deposited a great inland sea stretched from the Gulf of Mexico northward to the Arctic Ocean, separating the North American continent into two parts and covering a large portion of the great interior plain, including this region, with deep water. On this sea floor were deposited the same kind of sea muds that are being deposited in the moderately deep off-shore seas of today.

In the western portion of the state are found a few outcrops of a sandstone overlying the Pierre shale known as the Fox Hills sandstone. This is the youngest formation laid down by the great inland sea which covered this region during Cretaceous times. No occurrence of the Fox Hills or any younger formations is known in the Devils Lake region. Whether these forma-

1. For a more complete account see A. G. Leonard, The Geological History of North Dakota, Fifth Biennial Report, N. D. Geol. Survey, 1908, pp. 229-243.

tions ever extended as far east is not known. If so, they have, in all probability, long since been eroded, for with the closing of the Fox Hills epoch the uplift of the land caused the sea to retreat from this region to which it never again returned and, in the beginning of Tertiary time, this old sea floor become a land surface and has remained such down to the present time.

With long exposure to the wash of rain and the wear of streams deep valleys were carved and hills formed. The process of erosion went on through the long period of Tertiary time until the hills were nearly all worn down and the country reduced to a general base level above which rose a few remnants of the earlier and higher levels, mesas, and buttes, such as Turtle Mountains, Sullys Hill, Crow Peak, and Blue Mountains. The trend of the valleys across this plain was from west to east probably into a great pre-glacial Red River. The valley of at least one of these streams will be referred to again as determining the present location of Devils and Stump lakes.

INFLUENCE OF BED ROCK ON TOPOGRAPHY

Comparatively little influence is exerted on the topography of the region today by the bed rock and the old preglacial topography. The old hills and ridges which dominated the preglacial landscape are subdued and covered with a heavy mantle of drift, the valleys are largely filled with glacial debris, and only in the more prominent features such as Sullys Hill and the Devils-Stump Lake valley may the old valleys, now greatly modified, be seen.

THE GLACIAL PERIOD

THE DRIFT MANTLE

The Devils-Stump Lake region is a drift covered prairie. As indicated on a previous page, the bed rock surface of this entire region is covered with a mantle of clay, sand, gravel, and occasional boulders to an average depth of thirty to sixty feet. The topography of the bedrock has been entirely concealed, except in the higher ridges and deeper valleys, and even here it has been greatly modified.

The materials that make up the drift are occasionally found separated in more or less distinct beds extending over considerable areas, but most generally they ocur in a confused heterogeneous mixture showing no particular proportion nor constant relation. These materials are in part derived from the bed rock beneath and are in part entirely foreign to it. The finer the material the greater the proportion of that which bears close resemblance to the bed rock, and the coarser the material the greater the proportion of foreign matter. In the case of the boulders, all are foreign not only to this locality but to the state as well.

The intimate intermingling of the various materials is such that it may be easily seen that the drift is not the result of the disintegration and decay of the underlying rock in situ, and that it has in fact no direct relationship to the bed rock on which it rests. (Fig. 3). This fact is emphasized by a study of the mantle

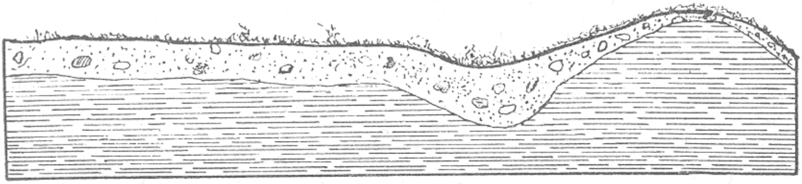


Fig. 3. Diagram showing the relation of drift to bedrock in a glaciated region.

rock and the bed rock where it outcrops on the sides of the Sheyenne River valley and the few other places noted in the preceding pages. If this mantle rock were formed in place it would grade by almost imperceptible degrees from the surface soil downward through the subsoil, and the more and more completely disintegrated rock into unaltered bed rock, and the residual soil thus formed would be free from foreign matter except that of an organic nature. (Fig. 4.) Such gradation from bed rock into

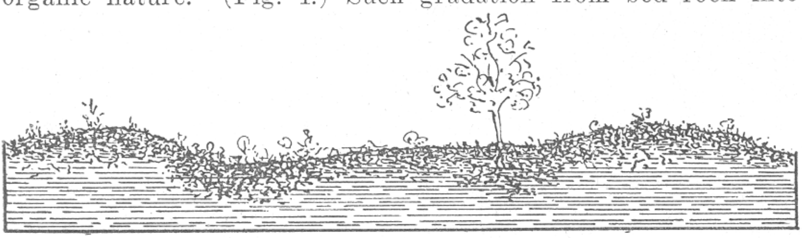


Fig. 4. Diagram showing relation of residence soil to bed rock in an unglaciated region.

residual soil would be the combined result of the work of weather, ground water, the roots of plants and burrowing animals, acting upon the country rock and causing its decay. The absence of this gradual transition and the presence of abundant foreign matter leads us to infer that the mantle rock is transported material. The occurrence of this material over a large portion of the state, as well as over an immense area in the northeastern part of North America suggests uniform conditions over widespread areas. The early belief that the agent of the transportation and deposition was water and that the material had drifted into its present position gave rise to the name which it still bears—the drift. This opinion was sustained to a degree by the occasional evidence of assortment and stratification of these materials in more or less well defined beds covering considerable areas, and these beds were found not only at the surface of the drift but within and beneath it.

GLACIAL ORIGIN OF THE DRIFT

A study of that portion of the drift which is entirely unassorted and unstratified, and which is known as till is of interest as throwing some light on the nature of the transporting agent. (Plate XXI, Fig. 2.) The till consists of many kinds of rock of all sizes thoroughly mixed. Most of the larger stones are sub-angular, or with slightly rounded corners and edges, and some have flat faces which are often well polished and covered with many parallel scratches and grooves. The larger stones and boulders are, as before suggested, of a kind which do not occur as bed rock within the state and many are known to have come from southern Canada. The transporting agent was capable of gathering its material from a large area, transporting the largest boulders as well as the finest sand and clay for great distances and depositing the whole in a most heterogeneous mixture as an unequal mantle over a large area. In addition to this it must have been able to give a portion of the transported stones the subangular character and the polished, grooved, and scratched appearance noted above.

That wind could not have transported this material is obvious from the size and relation of much of the material. That running water did not is evident from the fact that the weight of the larger boulders is far beyond the transporting power of ordinary currents, and their widespread distribution on the plains precludes any belief that they were carried by torrential streams. Besides, stream-laid deposits are assorted in layers and the material is smooth and well rounded from wear. That the drift is not, as some early supposed, the deposit of sea water, is also easily proven by the angular form of the material, the unstratified and unsorted condition of most of it, and above all by the irregular form assumed by the till in contrast to the smooth, nearly even surface of marine sediments, whether in form of boulder beach or beds of deep sea ooze.

The drift materials do, however, possess all of the characteristics of the deposits of glacial ice such as may be observed in process of formation in Alaska and Greenland today. From the comparative studies of the deposits of the northern United States and the deposits of many glaciers it is now known that the till was deposited by glacial ice and that the stratified materials associated with it are from the same source, but they have been assorted by the streams and deposited in the waters which arose from the melting of the ice. The old name, however, is still retained, and the unassorted till together with the assorted and coarsely stratified materials associated with it are known collectively as the drift.

EXTENT OF THE GLACIATION

The glaciation must have been as extensive as the drift is widespread. Glacial ice is therefore known to have covered at its maximum development an area in North America approximating 4,000,000 square miles, or about ten times that of the present ice-field of Greenland, and fully the size of the ice sheet now capping the Antarctic region. This area includes practically all of Canada and in general that portion of the United States north of New York Bay and the Ohio River and east of the Missouri River.

Within this great area once covered by ice there is an area of several thousand square miles in southwestern Wisconsin overlapping into northeastern Iowa and southeastern Minnesota where there is no drift. This region, for some reason, remained uncovered by ice, though evidences of glaciation are found in the region entirely surrounding it.

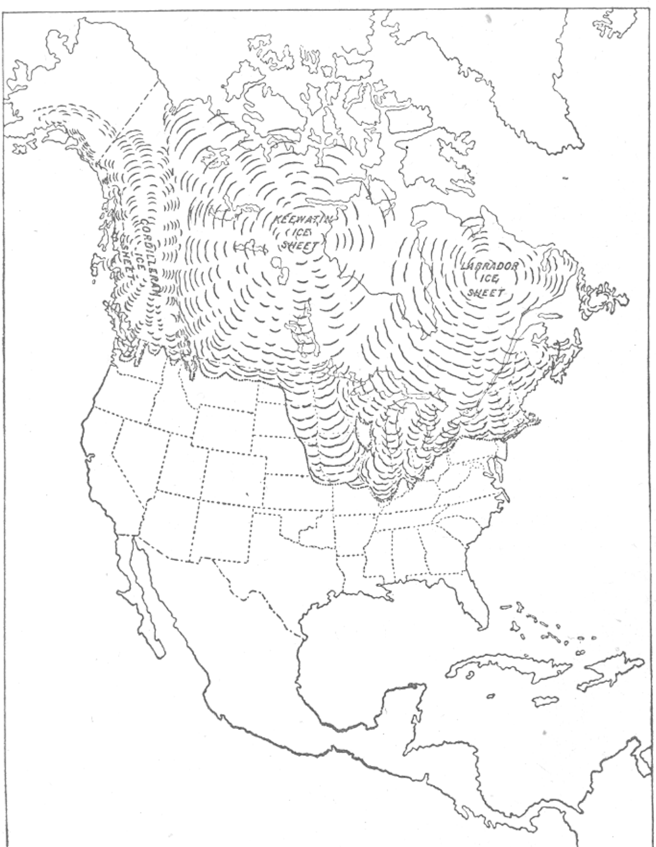


Fig. 5. Map of North America showing maximum extension of glaciation and centers of accumulation. (U. S. Geol. Survey.)

Fig. 5 shows the limits of the ice advance in North Dakota. It will be seen that this state was invaded by two of the distinct lobes into which the southern edge of the North American ice sheet was divided. These are known as the Daktoa lobe and the Minnesota lobe, and their line of contact was along the series of hills known as "The Ridge," which lies between Larimore and Edinburg. This ridge is formed of material deposited along the line of slight movement between these two great lobes and is therefore a medial moraine. The region under discussion lies to the west of this moraine and north and east of the terminal moraine and is therefore in the area covered by the Dakota lobe of the ice sheet. It is known that this state was at least twice invaded by an ice sheet and many of the surface features of the region are the result of the latest of the ice invasions, or that of the Wisconsin epoch.

CAUSE OF THE GLACIAL PERIOD

It must have been an extraordinary change in climate that led to the development of the great ice field over a large part of northern North America. Why such an enormous ice sheet was developed so far from either pole has never been satisfactorily explained, but it was probably due to some very marked geologic or geographic change. That this change was one which produced widespread climatic effects is seen from the fact that a similar sheet with its center on the Scandinavian peninsula covered all of northwestern Europe and most of the British Isles, while another independent cap covered the Alpine highlands, Greenland, lying between these two continents, was covered even more completely than now by an ice cap. The chief climatic factor in the development of these great ice sheets was undoubtedly a reduction of temperature, yet the fact that Alaska and Siberia were free from ice indicates that not only low temperature but an abundance of snow was an essential condition.

The hypothesis which at present seems best to explain these changes of climate refers it to a change in the composition of the atmosphere, probably to a lessening of the amount of carbon dioxide gas.[1]

FORMATION OF THE ICE SHEET

With the change of climate more snow fell each winter over certain portions of Canada than melted and evaporated during the ensuing summer. The resulting accumulation of snow thus formed a snow field which grew thicker with each succeeding winter. As the climatic change grew more marked the snow field was extended, and "This extension of the snow field itself promoted a lowering of the temperature of the surrounding at-

1. Chamberlin and Salisbury, Geology, Vol. III, pp. 432-446.

mosphere, thus inviting an increased proportion of the precipitation in the form of snow, and at the same time retarding melting and evaporation.''[2] In time the snow field attained great area and thickness.

During this extending and deepening process the snow field became an ice field in the same way that the snow banks of late winter become ice banks. (1) The weight of the snow itself tended to make the lower layers so compact that they formed ice. (2) Water from the melting snows of the surface during the warmer periods or from rains percolating downwards froze in the open spaces between the snow and ice crystals below and formed more solid ice. (3) The snow crystals became more granular in form and icy in character, as do all of our winter snows toward spring. In all of these ways and perhaps others the snow field changed into an ice field.

The great ice sheet, with its cover of new fallen snow, had its greatest thickness near the center, diminishing toward the margins where the evaporation and melting balanced snowfall. The pressure upon the lower ice was greatest near the center, decreasing toward the edges. The result of this great pressure was to cause the ice to spread slowly in all directions under its own weight. The ice field was thus transformed into a glacier of great magnitude.

GLACIAL INVASION OF NORTH DAKOTA

The great ice sheet which overrode the greater portion of North Dakota developed in two distinct centers of glaciation; one east of Hudson Bay in the Labrador peninsula, known as the Labrador, and the other west of Hudson Bay, known as the Keewatin. A third, known as the Cordilleran, originated in the Rocky Mountains of northern British Columbia, but this in no way affected the prairie region.

The Keewatin glacier centered near the western edge of Hudson Bay, from which point the ice moved out in all directions, as indicated by the striae on the bedrock. From this great, nearly circular ice sheet, occupying all of the central portion of Canada, there extended a long lobe southward through North and South Dakota, deflected, no doubt, by the high escarpment of the Coteau du Missouri, which terminates the Great Plains on the north and east. The Labrador glacier sent lobes far to the southward and westward from its center, and one of these, known as the Minnesota lobe, deflected southward, in part at least, by the Pembina Mountain escarpment, filled the Red River Valley and extended on through Minnesota into the central part of Iowa.

These two lobes of the great ice sheet met along the general line of the Pembina escarpment and the medial moraine formed

1. Chamberlin and Salisbury, Geology, Vol. III, pp. 432-446.

of the debris heaped up along the line of contact is distinctly seen just south of Edinburg and west of Park River, Conway, Inkster, and Larimore, and is locally known as "The Ridge."

The direction of movement of the ice and the form and relation of the ice lobes in this state are not clearly represented by striae and grooves upon the bedrock, since this is of a soft and yielding character throughout the area and does not well retain such impressions, but they have been determined largely by the directions and relation of the morainal ridges, the trend of the glacial hills, and the direction in which material of the drift was transported. There is abundant evidence to show that the Glacial Period was marked by the advance and retreat of several successive ice sheets rather that that of a single one.

So far as definitely known, the Drift Prairie region of North Dakota was invaded by the ice more than once, the last and most important stage of glaciation being known as the Wisconsin, and the drift is known, therefore, as the Wisconsin drift. There is, however, some evidence that an earlier sheet, perhaps the second or Kansan, reached the maximum limit of glaciation in this state south and west of the Missouri River, and that the Wisconsin's farthest advance is marked by the great Altamont moraine, which follows in a general way the trend of the Coteau du Missouri east and north of the river of the same name.

The evidence of the greater age of the extra-morainal drift is chiefly the deeply trenched character of the area, trenching that has been brought about not only by the larger streams, but by the branching system of valleys that have developed since the glacial deposits were laid down, the removal of most of the till by erosion, the abnormal proportion of boulders, and the generally weathered character of the materials which remain.

No evidences of an older drift have been found in the region under consideration. The Wisconsin drift in the Devils Lake region has been laid down so recently that the streams have scarcely begun the work of trenching and erosion. Lakes, marshes and undrained areas abound, and the topography of the numerous moraines formed during periodic pauses in the recession of the ice remain practically unmodified.

THE WORK OF THE ICE

The topography of the Prairie Plain before the advance of the ice has already been described in connection with the bed rock. This topography was shaped, so far as details were concerned, by rain and river erosion, and the bedrock was then covered by a layer of soil and mantle rock which originated in the decay of the formation beneath. When the ice sheet melted away a wholly new topography appeared. These changes of topography were brought about in two distinct ways: (1) through erosion of the preglacial surface by the ice, and (2) through the deposition of the drift.

The relatively thin edge of the ice crept very slowly over the surface of the ground. It probably pushed up a little of the soil in front of it, but the water-saturated soil was undoubtedly frozen as the ice advanced over it. The solid mass of soil and partly decayed rock was broken, crushed, and frozen into the ice, became in effect a part of the mass, and was carried along with it. Much of this material was worked up into the lower part of the ice and the continental glacier thus holding fast great quantities of clay, sand, pebbles, and coarse stony material in its powerful grasp, bore down with tremendous power and weight upon the bed rock and residual waste beneath, tore up and carried along all the loose fragments within the zone of surface decay and disintegration, plucked angular blocks of stone and ground, scraped and rasped the bedrock below until the surface of the latter was reduced in some places many feet below the former surface.

In the rougher country crags were removed and the higher elevations scoured and rounded off, and valleys trending in the direction of the ice movement were scoured out and deepened as in the case of the so-called "finger lakes" of New York.

Owing to the soft, yielding character and the horizontal attitude of the bedrock in the Devils-Stump lake region, the erosive work of the ice is not marked. The surface was probably not greatly reduced, but was stripped of the loose soils and disintegrated rock and then generally overridden, the ice being unable to get foothold on the shales. The ancient mesas and buttes remaining above the old Tertiary peneplain were rounded and reduced, but otherwise retained their general form as seen in Big Butte, Sullys Hill, and Blue Mountains. Evidence of valley deepening may be seen in the bays of the lakes having a north and south trend, notably East Bay of Stump Lake, Six Mile Bay and perhaps the lower end of Creel Bay in Devils Lake, but in none is the effect very striking.

On the whole the major topographic forms were not, however, greatly modified by erosion; they were simply reduced and rounded by the ice. The minor topographic forms were, however, highly modified and frequently obliterated by the mantle of debris spread over them. Valleys were blocked, partly filled, or completely buried with drift, those lying across the line of glacial movement being most affected. The smaller hills were changed in contour, and often completely covered.

In the prairie regions, where the bed rock was soft and yielding and the topographic relief mild in character, the effects of erosion and deposition together almost obscured all earlier topographic forms, leaving a new topography composed chiefly of the irregularities of the drift itself. Such was the case in the Devils Lake region.

The topography retains the primary form of the preglacial peneplain modified by glaciation into a drift plain with relief both decreased by the filling of the valleys with glacial debris and increased by the irregular deposition of the drift in the form of morainic hills and ridges marking pauses in the retreat of the glacial ice. These hills and ridges rise from 50 to 150 feet above the surrounding surface and have a remarkable looped form due, no doubt, to the lobate character of the ice margin. This lobate character appears to have been the result of the irregularities of topography of the plains over which the ice passed, deflection being caused in the case of the two ice lobes represented in this state by the two well marked escarpments, the Coteau du Missouri and the Pembina Mountains. The lines of maximum flow followed the axes of depressions, notably the Red River Valley in the case of the Minnesota lobe. This looped character of the moraine systems is perhaps best developed in the region south of the Great Lakes.

The till plains between the recessional moraines are of the youthful rolling type characteristic of the Wisconsin drift, the thickness of the drift ranging from a few inches to sixty or eighty feet in thickness and probably in many cases very much deeper.

The drift of these till plains is chiefly a blue clay derived from the crushing of the underlying Pierre shales, but it contains many fragments of indurated rock and some boulders, chiefly of granite, gneiss, and limestone, derived from points north of the international boundary line.

Most striking of all of the topographic features of the plain are the massive rounded buttes and mesas and full bodied ridges, the monadnock like remnants on the old preglacial peneplain, which still retain the outlines of the old bed rock topography though so veneered with drift as to obscure the minor details of dissection. Of this type are the Blue Mountains lying to the south of and between Devils and Stump lakes. In some cases where these preglacial ridges lay across the path of the glacial ice, in such a way as to retard and check its movement these ridges are bordered and crowned by morainic ridges, thus combining the preglacial and glacial hills as in the Majestic Sullys Hill range immediately south of Devils Lake.

DRAINAGE MODIFICATIONS

Among the most interesting effects of glaciation was the modification of drainage by the diversion of streams from their former courses. During the long period of erosion between the uplift of the new land, at the time of the withdrawal of the Cretaceous inland sea, and the invasion of the glacial ice, the cutting of stream valleys had been going on, much material had been removed from the surface of the land as indicated by the well marked escarpments of the Coteau du Missouri and its distant outlier, the Turtle Mountains, which indicate a former extension of the formations far to the east, and the great central portion of the state, including the Devils Lake region, had been worn down to a broad, nearly level lowland plain. The preglacial Red River had worn out the wide valley now known as the Red River Valley, which was later filled in part by a thick layer of drift and overlain by the sediments deposited in the bed of Lake Agassiz, on the surface of which the present river now flows. The Red River Valley is, therefore, not a true valley, but a lake plain within an old partly filled valley. The escarpment known in the north as the Pembina Mountains and in the south as the Coteau des Prairies is the western border of this valley.

One of the old valleys of an eastward flowing stream, partly filled by glacial drift, is occupied by Devils and Stump lakes and is thought to extend northwest along the line connecting Ibsen, Hurricane, Grass, Island, and Long lakes nearly to the Turtle Mountains. The Blue Hills, Sullys Hill, Crow Peak, and Big Butte, probably formed a series of buttes on the divide south and west of this valley. The south side of the old valley trough is, in general, the southern margin of Devils Lake, as indicated by the outcropping bed rock at the west entrance of Fort Totten Bay and in the south end of Little Mission Lake, and the character of the hills mentioned above. The number, form, and altitude of many of the secondary bays indicate that they are but tributaries to this main valley.

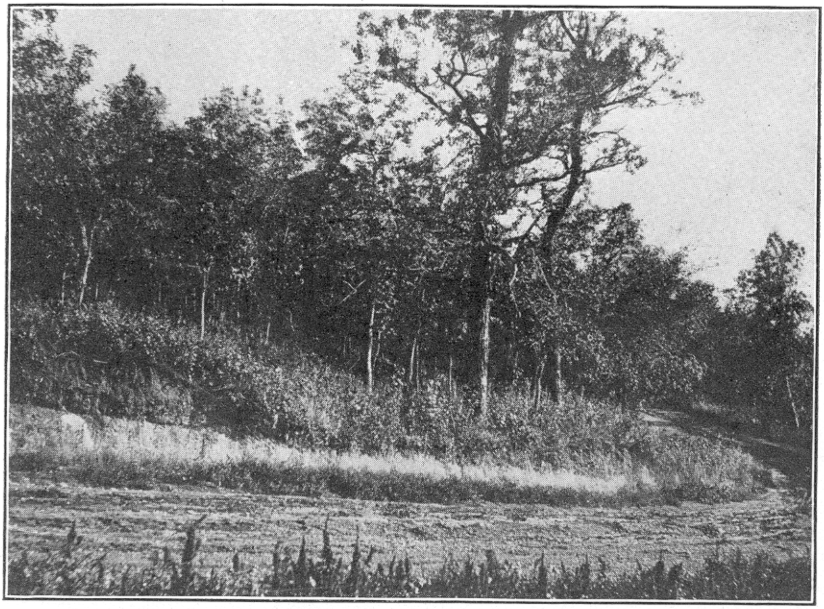
More conspicuous is the influence of glaciation upon the postglacial streams, especially those formed during glacial times along the margins of the ice. The Sheyenne River in portions of its valley evidently had its course determined by the temporary ice margin from which it received a large supply of its waters. This is true for much of its course to Valley City.

Throughout the Drift Prairie Plain the drainage, such as it is, is distinctly governed by the morainal topography. The morainal ridges constitute the chief divides between the headwaters of the minor streams and determine the parallel relations of the larger streams. The coulees are notably irregular and connect many lakes and temporary ponds, very unlike the well-organized drainage which probably existed before the ice invasion.

THE HISTORY OF DEVILS LAKE.

ORIGIN OF DEVILS LAKE

The history of Devils Lake began with the retreat of the margin of the great ice sheet from the range of hills about Fort Totten. During the retreat of the ice front to the north across this region it paused, as we have seen, for a considerable time



Abandoned beaches on Chautauqua road, east shore Creel Bay. The large tree stands on the A beach midway between the A and B cliffs.

within the area now lying between the Sheyenne River and Devils and Stump lakes. The retreat at this point was slower, perhaps, than at any other point in the general line of retreat within the state, as indicated by the massing of the moraines in this narrow belt. The retreat across this short distance occupied as much time as that from far beyond the state line on the south and the James River on the west to a curved line on the north passing through Caledonia, Larimore, and Aneta, more than one-half of the distance across the state.

This long pause resulted in the accumulation of great heaps of morainal debris in the region already marked by the high residual hills of bedrock which formed the southern divide of the preglacial valley in which Devils and Stump lakes now lie.

During this period of slow retreat the water from the front of the ice was being drained away southward through several well-marked spillways to the Sheyenne River. Notable among these are two leading from Devils Lake, Seven Mile Coulee from Fort Totten Bay and Crows Hills Coulee from Minnewaukan Bay, and the Big Stony Coulee and Harrisburg Coulee from Stump Lake. All of these emptied into the Sheyenne River and thence through Lake Agassiz and the River Warren (occupying the present Minnesota River valley) into the Mississippi River and the Gulf of Mexico, rather than into Hudson Bay, where the Sheyenne drainage now goes.

When the ice retreated northward from this great divide of hill and moraine the depression between the ice front on the north and the morainal ridge on the south was filled with water from melting ice and a glacial marginal lake was formed where before glacial times there had been an open valley trending slightly south and east.

Judging from the lobate character of the northern side of the moraine, it is probable that for a very short time there may have been several small marginal lakes in the southern bays of the present lakes, draining through the glacial spillways above mentioned. As the edge of the ice which formed the northern shore of these small marginal lakes retreated still farther northward they were merged into two large lakes, the remnants of which are Devils and Stump lakes. Even these were connected through the broad shallow coulee, probably a part of the preglacial valley, which extends almost due eastward from Devils Lake at Jerusalem to Stump Lake, and had outlet into the Sheyenne through a similar coulee known as the Big Stony which leads past Dissmore and Tolna. (Plate XVIII, Fig. 2.) The elevation of the crest of this outlet is 1,460 feet above sea level and corresponds to the general level of the highest beach line which surrounds both lakes. This is 35 feet above the level of Devils Lake at present, and 50 feet above that of Stump Lake.

GLACIAL LAKE MINNEWAUKAN

So much larger were the glacial lakes than the present lakes, and so different in form, that it seems advisable, in order to avoid confusion, to give them distinct names. To the glacial lake of which Devils Lake is the remnant is restored, therefore, the original Sioux Indian name for this body of water, Minnewaukan, meaning "spirit water," a name which has suffered much in translation, due to the white man's conception that all spirits are of the evil one. The original name has fortunately been retained for the town formerly on the shore of the western bay but now unfortunately some distance inland. The glacial ancestor of Stump Lake will similary be called Wamduska, the Indian name for this beautiful body of water. This term means serpent in the Sioux language and is thought to have been given on account of the fancied resemblance of the form of the lake to that of a great serpent crawling westward. This name is still retained for the township in which the larger portion of the lake is found and was applied to the now abandoned townsite on its northern shore.

THE OUTLET OF LAKE MINNEWAUKAN

Lake Minnewaukan, unlike its smaller successor, had at least one well defined outlet, that by Jerusalem eastward to Lake Wamduska and thence past Tolna to the Sheyenne. Undoubtedly the several temporary marginal lakes formed between the ice front and the irregular moraine which forms the divide between the basin of the lakes and that of the Sheyenne River each had outlet over the lowest col of the morainal southern rim into one of the great glacial spillways. The crest of the divide in each of the four great spillways before mentiond is so reduced and so inconspicuous as to make it highly probable that each was used for a time as an outlet for a considerable body of ponded water.

Seven Mile Coulee which leads almost directly south from Fort Totten Bay through Little Sweetwater Lake, was evidently thus occupied, but not long. The Crow Hills Coulee to the west of Crow Hills, leading from the southeastern corner of Minnewaukan Bay was probably used longer but with the elevation[1] of its crest at 65 feet above the present lake level and thirty-three feet above the highest well-marked shore line this outlet was short lived. Others are thought to lead from Mission Bay or Black Tigers Bay, but they are not well defined. These spillways cannot, however, be considered as outlets of the modern Devils Lake since all are distinctly higher than the outlet eastward past Jerusalem.

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1. T. R. Atkinson, Report on the Survey of the Proposed Diversion of Mouse River to Devils Lake, 1912, (profile).

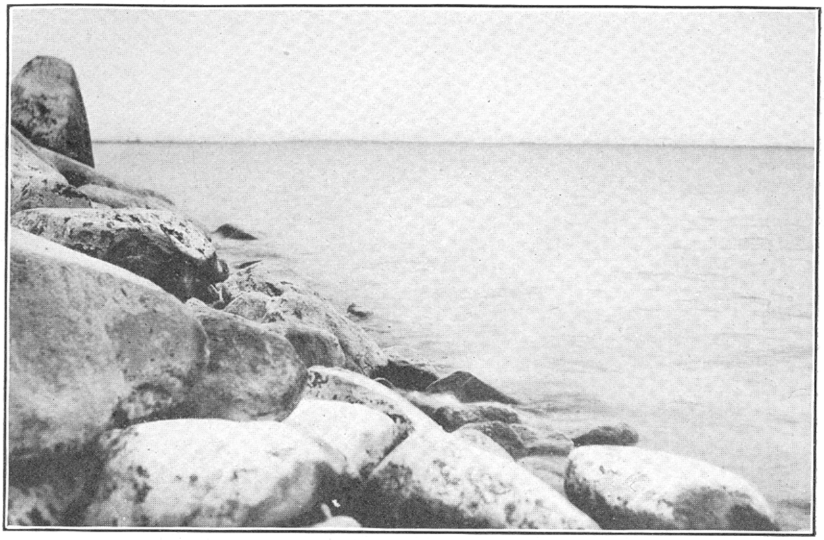


Fig. 1. Natural sea wall, ice built, on north shore "Rock Pile" Island. (Henderson.)

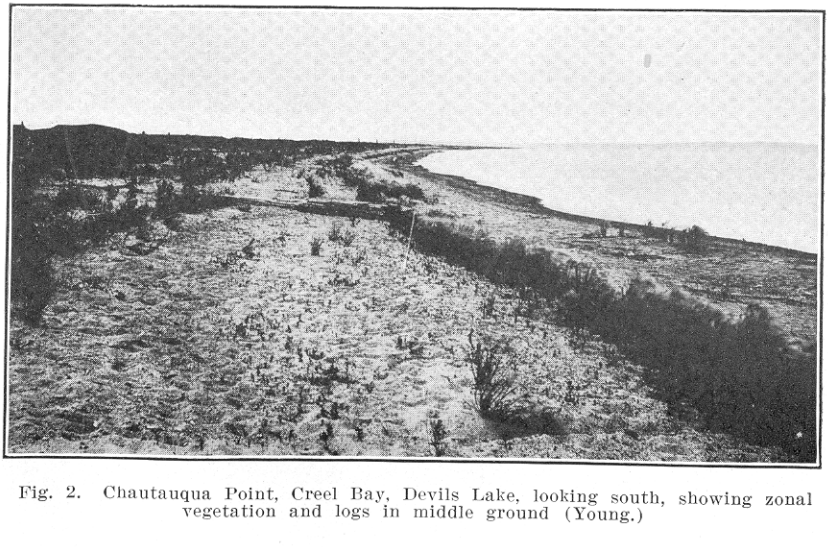


Fig. 2. Chautauqua Point, Creel Bay, Devils Lake, looking south, showing zonal vegetation and logs in middle ground (Young.)

One of these could have been retained as the outlet of the larger lake only provided the Jerusalem outlet was blocked by an ice barrier, a tongue or lobe extending southward between the two lakes after the retreat of the main ice sheet. Some indication of such an ice dam is to be found in the small lobate moraine which loops southward past Odessa, practically uniting the moraines to the north of the lakes and those to the south. Such outlets were, however, so shortlived as to be unimportant, since no lake was maintained at such an elevated level sufficiently long to develop shore features. These "big coulees" are, therefore, considered important in this study not as outlets of Devils Lake, but as glacial spillways cut by the great floods of water passing from the front of the ice when it lay immediately to the south of Devils Lake. They are either unoccupied today, or occupied by ponds, lakes, or small streams entirely unequal to the task of carving these great valleys in the drift.

The Jerusalem outlet was occupied as soon as this portion of the old valley was uncovered by the ice and was maintained throughout glacial times and until the inflow was exceeded by evaporation and the water level was reduced below the elevation of the outlet. This outlet is today entirely without permanent water, and throughout most of its course is so broad, over one-half mile wide, as compared with its depth, and length of six miles, as hardly to be recognized as a valley. Its direction and its relation to the basins of the two lakes and to the hills on the south suggest that the water in this course followed the old valley developed in preglacial times. When, therefore, it carried the great flood of waters from the ice front far to the north as they passed between these lakes, this outlet stream must have resembled a strait more than a river.

The elevation of this outlet is approximately 1,454 feet above sea level, or twenty eight and one-half feet above the present level of the lake. This corrsponds to the second series of beaches about Devils Lake, the constancy of elevation of the water of which at this level was maintained by this outlet. In any case the outlet prevented any marked rise above this level, though it may have fallen below many times before the outlet was finally abandoned. The absence of any well marked cliffs below this level is suggestive in this connection.

The waters of Lake Wamduska had an outlet in turn through another flat bottomed spillway known as Big Stony Coulee, leading past Dissmore and Tolna into the Sheyenne River. The fact that this outlet has an elevation of 1,460 feet above sea level and is fully six feet higher than the inlet from Lake Minnewaukan indicates that the outflow by way of Tolna ceased long before the inflow by way of Jerusalem.

GLACIAL DRAINAGE RELATIONS

The size of these outlets just described appears strikingly out of proportion to the lakes drained, even when the large size of the earlier lakes is considered. The key to the solution of this problem is found in the almost equally large inlet into the northwestern end of Devils Lake known as Mauvaise Coulee. The relations of Lake Agassiz and Lake Souris to the glacial drainage of the western margin of the continental ice sheet form one of the most interesting chapters in the glacial history of North America. That portion involving Devils Lake region will be briefly outlined.[1]

Lake Souris had outlet southward, as did all of the other marginal glacial lakes, first from a point near Velva through a well marked channel west of Dogden Butte, in which lie Strawberry, Long and Crooked lakes, to the Missouri River. This channel is well defined and was probably occupied for some time Later a lower outlet was uncovered eastward by way of Big Coulee, one of the head streams of the Sheyenne, and Girard and Buffalo lakes to the James River, the lower valley of the Sheyenne being still buried beneath the ice. When, however, the edge of the ice had retreated so that it stood on the high hills south of Devils Lake and poured a flood of waters through the spillways before described into the present Sheyenne Valley, thereby rapidly cutting and deepening it, the Lake Souris waters were diverted from the James River and entered Lake Agassiz through the Sheyenne River.

Still later, when the ice had retreated sufficiently to uncover the Turtle Mountains, and the great lowlands west and north were covered by the waters of Lake Souris, a still lower outlet was found across the international boundary and east of the Turtle Mountains by way of Mauvaise Coulee into Lake Minnewaukan and thence through the Jerusalem outlet, Lake Wamduska, Big Stony Coulee and Sheyenne River into Lake Agassiz.

We can little comprehend the vast flood of water which passed this way from the southern and western front of the great ice sheet. From the far northwest, including even the basin of the great Assiniboine River and glacial Lake Saskatchewan, 300 miles to the northward, came the flood of glacial waters through this great chain of lakes and their connecting rivers, which must have somewhat resembled straits, to the Mississippi River and Gulf of Mexico. This was flood time in the Devils-Stump Lake region, when Lakes Minnewaukan and Wamduska stood at their highest level.

1. Warren Upham, Glacial Lake Agassiz, Mon. 25, U. S. Geol. Survey.

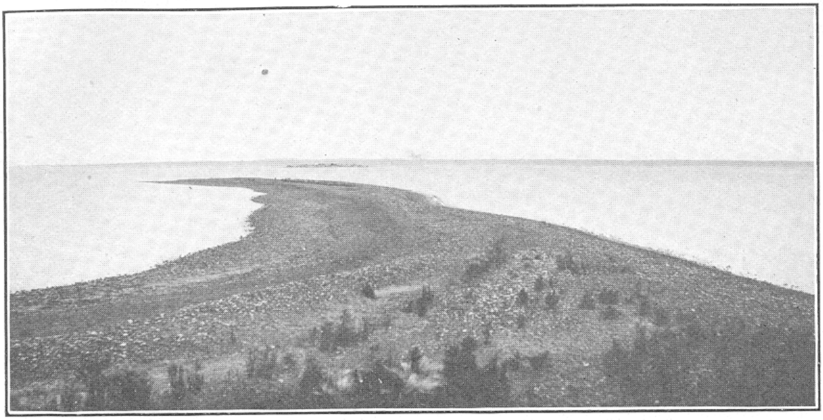


Fig. 1. Rock Pile Island looking north from spit building toward it from south shore of lake (Henderson).

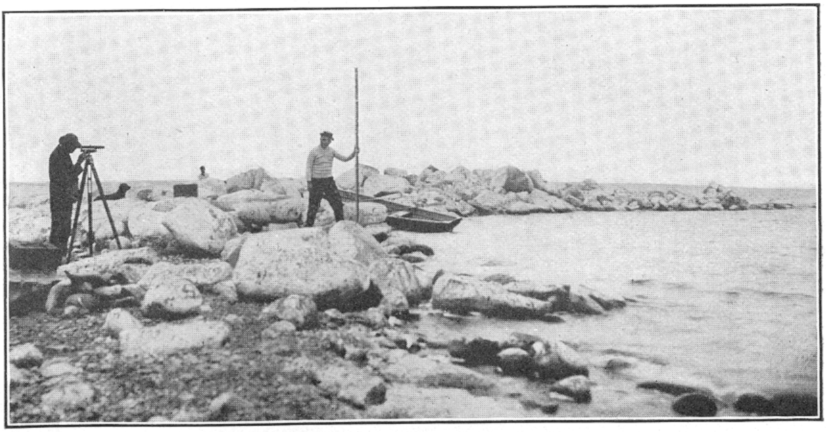


Fig. 2. Eastern shore of Rock Pile Island, looking north.

With the final retreat of the last lingering tongue of ice across the present international boundary, still lower and more direct connection was made between Lake Souris and Lake Agassiz by way of the Pembina River. With the loss of this great flood of water the level of Lakes Minnewaukan and Wamduska rapidly fell, while through the newer and lower outlet Lake Souris was rapidly drained and passed out of existence though Lake Agassiz was yet at its highest stage.

STAGES OF LAKE MINNEWAUKAN

There were two distinct stages in the history of Lake Minnewaukan, as indicated by two well-marked lines of beaches and cliffs. These two stages, together with the corresponding abandoned shore lines, are termed A and B. After these stages had passed the waters ceased to overflow the basin and assumed a general form approximating that of Devils Lake today, though the area was considerably larger.

Slight indications of earlier stages at higher levels are found in a few places, but they are indistinct and inconclusive. Such stages were in any case so temporary that no well marked evidence may be expected.

Early Glacial Stages.—Mention has already been made of the probable occurrence of small marginal-glacial lakes in the southern bays of the Devils-Stump Lake basin, held in between the high hills and moraines on the south and the retreating front of the ice sheet on the north. In such case outlet southward was found by each individual lake. Also, that the form of the moraine in the vicinity of Jerusalem suggests a prolongation of a tongue of ice southward from the main body, between lakes Minnewaukan and Wamduska, after it had cleared the present basins of both of these lakes, in such a way as to form an ice dam across the Jerusalem outlet. Such a dam would cause the water in Lake Minnewaukan to rise until it found outlet through one of the southern spillways already described direct to the Sheyenne River. These spillways not only indicate that they carried a vast quantity of water from the ice front when it stood on the morainal hills in the vicinity of Sullys Hill and Crow Hill, but the col which forms the divide in each one indicates the passage of a considerable quantity of water through them after the retreat of the ice front from their immediate vicinity.

Slight indications of these earlier stages and higher beaches are found in washed slopes which appear to be wave chafed and in small cliffs and wave-cut terraces at elevations of 7 to 20 feet above the level of the A beach. An illustration may be found on the west side of East Bay, Stump Lake, just southeast of the home of Gustav Schindele. Such an earlier stage at this point can only be accounted for by the presence of the ice wall across the north end of East Bay, cutting it off from West Bay, and forming a small glacial-marginal lake in its southern end. If such were the case the retreat of the ice front but a short distance would unite the two bays with outlet at the A level through the Big Coulee at 1,460 feet. The evidence of earlier stages at level higher than 1,460 feet are, however, fragmentary and inconclusive and tend only to strengthen the hypothesis of the presence of small marginal lakes in the southern bays. The life history of such must necessarily have been brief and unimportant.

The A Stage.—The first definite stage in the history of Lake Minnewaukan is termed the A stage. During this stage the waters of the lake stood at an elevation of 1,460 feet above sea level, thirty-five feet above the present level of the lake, and found outlet past Jerusalem into Lake Wamduska and thence by way of the Big Coulee into the Sheyenne River south of Tolna. The elevation of the beach line corresponds with the elevation of the bottom of the outlet at it highest point about one mile west of Dissmore. This outlet prevented great fluctuation of level, at least upwards, and held the water surface constant so long that the waves and currents did a remarkable amount of work. Where shores were steep against the sides of the morainal hills, strong cliffs were developed, (Fig. 6) from the wave-cut ma-

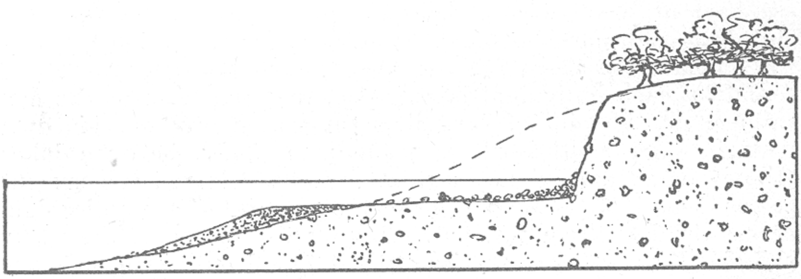


Fig. 6. Cross section of cliff and wave cut terrace.

terial of which much fine clay and silt was derived and spread over the lake floor, thus tending to fill it, and enormous quantities of sand and gravel, transported by waves and currents along shore, were worked into beaches where the shores were more shelv-

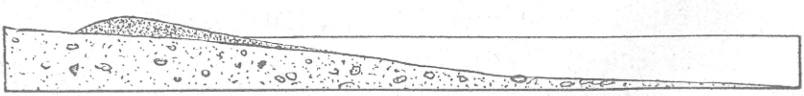


Fig. 7. Cross section of a beach.

ing. (Fig. 7). That winter ice played an important part in this work is evidenced by the large quantities of glacial boulders worked into boulder walls, beaches, and shore pavements. The irregular

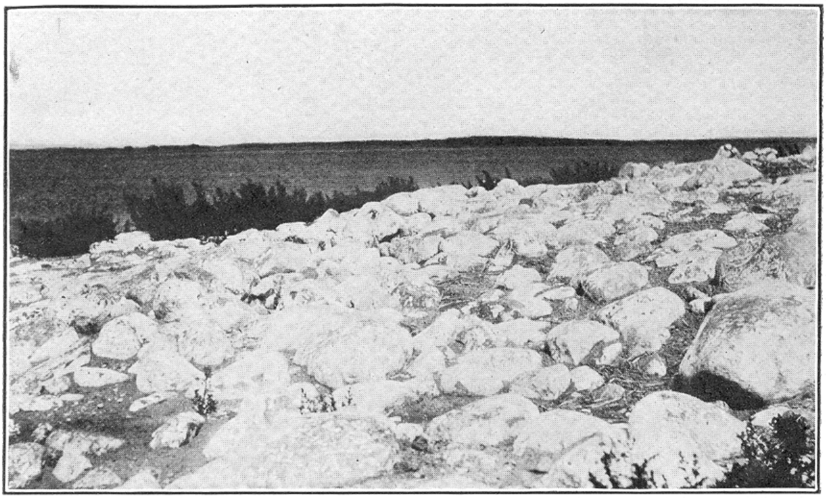


Fig. 1. Boulder pavement on north shore of Bird Island, Devils Lake. Old cormorants nests among alkali incrusted boulders. (Henderson).

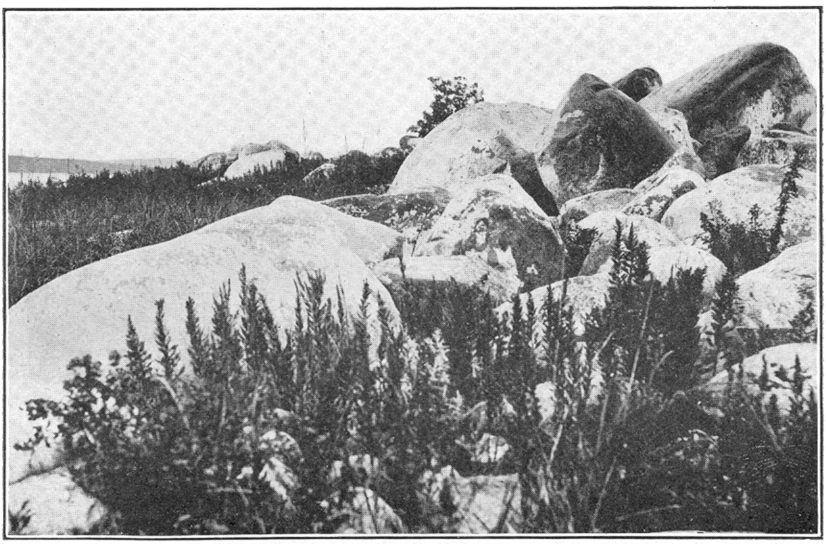


Fig. 2. Abandoned sea wall on "Rocky Island" looking east. Near view of wall. (Henderson).

and embayed character of the lake is such that many spits were formed from islands and points just as the process is going on today, spits from opposite points united to form bars and bars developed into barrier beaches, changing the bays into detatched lakes. This work was frequently anticipated by the formation of bayhead bars cutting off the heads of the bays and forming them into small lakes. This latter process was in some cases several times repeated before the mouths of the bays were closed, thus forming series of small lakes or lagoons in successive stages of dessication.

The A Beach.—The two distinct levels at which the waters of Lake Minnewaukan stood for a considerable length of time are indicated by well defined shore lines. These shore lines are marked by strong cliffs where the relief is strong (Plate XVI, Fig. 1) and where the form of the lake and the direction of the storm winds are such as to render the wave attack most effective. In places of slight relief and on low shelving shores, beach ridges of sand and gravel and even of large boulders are found—the latter due undoubtedly to the work of shore ice.

The position of the highest beach has been located by reconnaissance on the north side of Devils Lake between the north end of Six Mile Bay near Grand Harbor and Indian Head, the extreme southeast end of the lake, also through Jerusalem outlet and about Stump Lake. Evidence of ice shove in delta material at the stock yards on the Great Northen Railway one mile west of Devils Lake city seems to offer conclusive proof that the ice still formed the north wall of at least a portion of the lake and was active during the A Stage.

The water of the first stage, therefore, stood at the 1,460 foot level outlet, and being held there for a considerable period of time formed the very distinct A series of cliffs and beaches. This shore line is well developed on the west side of Chautauqua grounds as a cliff and in the nursery just east of the city of Devils Lake is marked by a strong beach. In fact, the transition from a low cliff to a good beach which fades out eastward in a spit is readily seen and interpreted from the north window of an eastbound train as the track parallels the shore line on the south for a short distance.

In some places the evidences of this shore line have been obliterated by the retreat of the cliffs of the next younger or **B** stage. This is strikingly illustrated along the north side of the Main Bay adjoining the parade ground of the Military Reservation. Here the strong wave work during the B stage has driven the B cliff back until it obliterated all traces of the higher A, leaving the most conspicuous cliff to be found at any point on the lake shore.

This A shore line may be traced through the Jerusalem outlet and forms as conspicuous a feature along the shores of Stump Lake as it does about Devils Lake. It may also be traced into the Big Stony Coulee outlet to the level of which it approximately corresponds.

One of the most interesting sections of this shore line is revealed in the extensive cut the Great Northern Railway has made near the stock feeding yards a mile or so west of the city of Devils Lake. This cut is made in an extensive morainal and outwash deposit of gravel which passes into a delta deposit, the maximum elevation of which corresponds to the A stage of the lake and into which the A beaches come on either side. This delta material shows unmistakable evidence of ice shove after formation and before the lowering of the lake waters below the A stage, thus indicating the presence of the ice margin as a portion of the northern shore line of the lake during the A stage.

Time and Duration of the A Stage.—That the A stage was in its beginning coincident with the retreat of the ice across its immediate basin seems evident not only by analogy but by the direct evidence of ice shove in the delta deposits shown in the stock yards cut mentioned above. The length of the Tolna outlet and its character as an old glacial spillway was such that but little down cutting could have been accomplished by the relatively pure clear water flowing from the lake. Little evidence of such cutting is seen at the crest of the divide in the outlet. Probably not more than five to six feet may be credited to outflow from the lake after retreat of the ice and as this is above the A stage it was probably cut by the waters of a small marginal lake first found in the West Bay of Lake Wamduska and before the general lake level of the A stage was established.

The duration of the A stage is not known. The closing came when the inflow of waters into lake Minnewaukan and Wamduska was exceeded by the evaporation from their combined surface, thus causing the level to fall below the Tolna outlet. No lower outlet from either lake is known and it is believed that none exists. That this was some time after the retreat of the glacial ice across the international boundary and the diversion of Lake Souris drainage eastward seems certain, for the surface flow of the Devils Lake drainage basin must have been considerable and have exceeded surface evaporation from the lakes until something like the present climatic conditions were established. It is possible that this condition was reached and that the outlet was restored many times before the level was permanently reduced below the outlet. This effect of fluctuation, however, seems less probable in the case of the A stage than of the B stage of Devils Lake, since the surface area of the combined lakes offers a condition of greater stability of level than that of one.

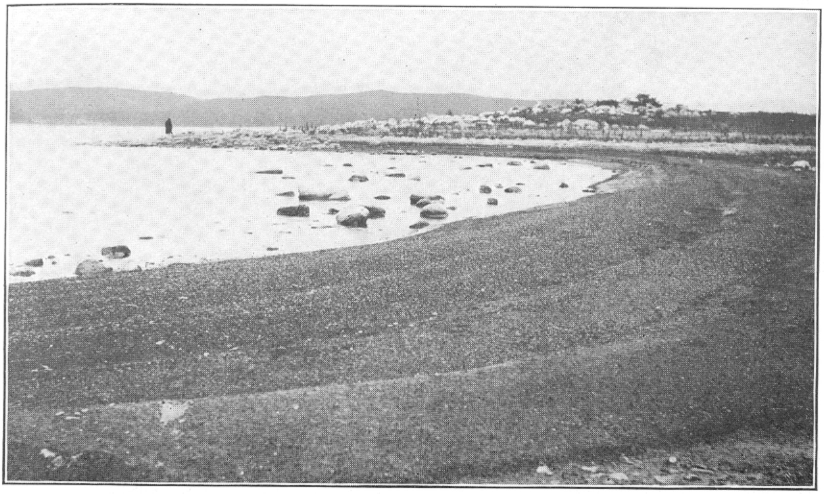


Fig. 1. Land-tied "Rocky Island," west side Fort Totten Bay, looking east. Pierre shale beach in foreground. (Henderson.)

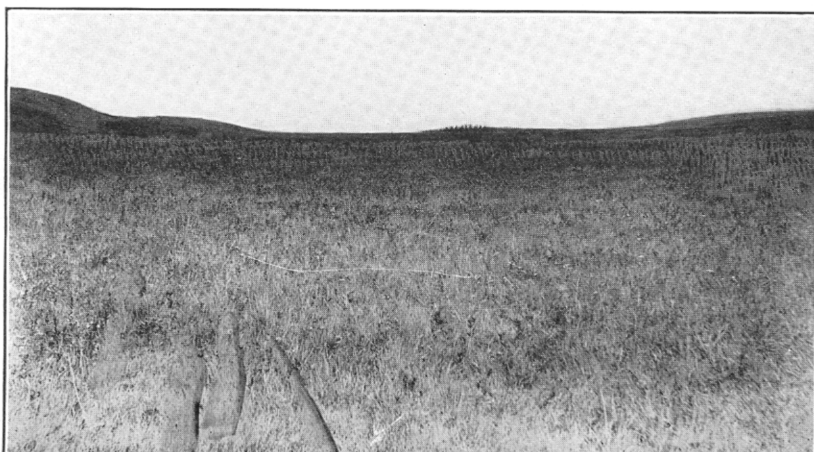


Fig. 2. Old Tolna outlet of Stump Lake, looking east from present divide between Big Stony Coulee and Stump Lake drainage.

The only additional evidence as to the time length of the A stage is to be found in the amount of wave work done upon the cliffs during this stage. This seems, on the whole, to be less than that during the B stage, and it must be remembered that the waters of this stage were less hampered by the boulders accumulated on the beach than later stages increasingly were. Little may be learned from deposits save negative evidence of the shallow kettles in the drift beneath the A beach, which in places were unfilled during this period.

The B Stage.—The second stage of Lake Minnewaukan is known as the B stage. During this time the waters of the lake stood at an elevation of 1,453.5 feet, 28.5 feet above the present lake level and 6.5 feet below that of the A stage, and had outlet by way of Jerusalem into Lake Wamduska, though the flow of the waters of the two lakes into Sheyenne River had ceased. Such relations indicate that the evaporation from the surface of the combined lakes exceeeded the inflow. This greatly decreased inflow was due first to the recession of the ice sheet resulting in a diversion of the glacial drainage and a modification of the climate.

Below the B stage the water was never held at a constant level by outlet or otherwise a sufficient length of time to produce cliffs, though well-marked beaches occur in many places. All indications point to the fact that all the beaches below the B stage are very recent as compared with those of the B and A stages. With the falling of the waters below the level of the coulee at Jerusalem the lake ceased to have any outlet, and assumed a form and character similar to that of the present day. The history of the glacial Lake Minnewaukan passed to that of Devils Lake.

The B Beaches.—Undoubtedly the Jerusalem outlet was utilized and the work resumed several times in the earlier history of the lake, but the overflow checked the rise of the lake waters and produced a maximum stage beyond which they probably never rose sufficiently to flow into Sheyenne River after the close of the A stage. The gradual fall of the waters between these two levels and possible later rises is indicated by minor beaches, but not by characteristic cliffs, between those of the A stage and those of the B stage. These belong properly to the B stage and are occasionally noted as B+ beaches wherever found.

The inflow from the Harrisburg sloughs and Swan Lake into Stump Lake has been small compared with that into Devils Lake by Mauvaise Coulee, since the outlet from Devils Lake to Stump Lake was maintained long after the outlet of Stump Lake ceased. The B series of cliffs and beaches very similar to the A series and 6.5 feet lower were formed in Devils Lake during the stage in which the elevation of the water in Devils Lake was determined by the elevation of the Jerusalem outlet in Stump Lake. As one may expect, the B shore lines are well marked in Devils Lake, where they represent a temporary maximum level determined by the outlet. The shore lines of the B stage are not so well represented in Stump Lake, since their elevation is not determined by outlet but by inflow. Though well marked, they are a part of the series of beaches formed during dessication.

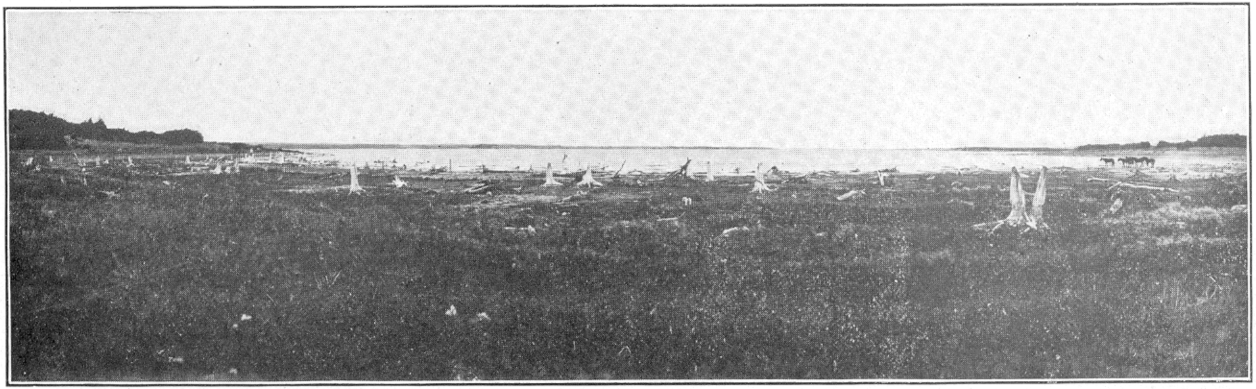
Time and Duration of B Stage.—When the waters of Lake Souris were diverted to the Pembina River the inflow into Lake Minnewaukan must have materially decreased. How long the natural drainage of this interior basin through Mauvaise Coulee and the Harrisburg sloughs was sufficient to hold the waters of the combined lakes up to the level of the outlet by way of Tolna cannot be known, but it may have been a very long time, since the appearance of the B cliffs leads us to infer that once the water had reached the B stage it never again rose to obliterate these, and we may infer that the ultimate fall was the result of climatic change and was therefore very slow. This stage was long enough to leave a record in a second line of beaches and cliffs 6.5 feet below the A line and almost as well marked. In fact, in many cases the cliff line was driven back to and even beyond that of the A stage, thus obliterating the earlier and creating very prominent cliffs as on the north side of the Main Bay along the front of Military Reserve parade ground.

The B stage was brought to a close very gradually, since it was undoubtedly due to change of climate which finally reduced the inflow into Lake Minnewaukan below the evaporation from that lake alone, or reduced the ground water level below the level of the outlet. Variations in weather for periods of years undoubtedly produced fluctuations bringing the lake level up to the outlet and obliterating all lower beaches formed.

STAGES OF DEVILS LAKE

HYDROGRAPHIC FEATURES OF DEVILS LAKE DRAINAGE BASIN

The recent history of Devils Lake began when it ceased to have outlet at Jerusalem. The Devils-Stump Lake drainage basin came into existence when the level of the two lakes fell below that of the Tolna outlet into the Sheyenne River. Since that time no part of the water that has fallen within this large basin has reached the ocean by surface drainage. Escape of the water has been by evaporation and seepage only. The study of the bed rock has indicated that there is no opportunity for any considerable underground drainage. The Pierre shale underlying all of this region is one of the most impervious of rocks known. A study



Stump Lake, looking north from south end of East Bay. Shows many old stumps. (Photo by Anderson), of the geologic relations shows also that the slight movement of water within the drift is southward throughout the interior basin and is therefore into the lakes, while seepage out from the lakes to the southward is barred by massive shale hills. Only eastward through the drift filling the preglacial valley would there be a strong tendency to seepage and from the fact that this is undoubtedly a till-filled valley it would not be considerable.

The B stage, during which time Devils Lake had outlet but Stump Lake did not, may be considered in the nature of a transition stage. From the standpoint of drainage relations it belongs to the recent or interior basin stage, but since the waters of these lakes were probably maintained at the A stage with outlet into the Sheyenne only by glacial drainage, and outlet ceased when these waters were diverted by the Pembina river, the destruction was not climatic.

So long as a lake has a constant outlet the water is fresh and sweet, but interrupted outflow gives rise to brackish conditions and long continued absence of outlet results in such concentration of salts left behind by the evaporation of a large quantity of water as to form a strong brine.

Connection between the several lakes lying in the southern portion of this interior drainage basin has been so varied and intermittent as to result in several graduations between sweet water and brackish; the extremes are probably found at the two geographic ends of the formerly connected series. These are Sweetwater Lake with its most recent important outlet, and Stump Lake, the one evidently longer without outlet.

The ephemeral character of the shallow lakes of an interior drainage system is also well illustrated in the disappearance and reappearance of some of the lesser lakes of the series, notably by Dry Lake. The most striking feature of the series as a whole is the evidence of gradual reduction to be seen about all of these lakes. This is remarkably well shown in the Sweetwater chain of lakes.

"A careful study of the shore line and the gravel and other deposits about Lake Irvine and to the southeast shows very plainly that the small lakes north of Devils Lake were also very much larger at some time in their history. There is little doubt that Lake Irvine, at no very remote period, extended from one mile to three miles farther east, and stretching toward the south, widened out irregularly three or four miles more toward the southeast. At this time Lac aux Morts, Twin Lakes, and Dry Lake were probably connected and formed one sheet of water, which may have been continuous with Cavanaugh and Sweetwater lakes, thus forming a large body of water which stretched out with irregular shore line toward the southeast, nearly parallel to the present Devils Lake, presenting an appearance similar to the Devils Lake of today."[1]

The rapid changes which take place in all of the lakes of this chain is to a large extent due to their shallowness and the flatness of their basin floors. Few places in any of the chain are over 5 or 6 feet in depth and probably none over 10 feet.

FLUCTUATIONS OF DEVILS LAKE

Interest in the recent history of Devils Lake centers in its fluctuations and recent decline. About the borders of its immediate basin are seen shore features, especially cliffs and beaches, in an almost perfect stage of preservation, readily recognized by the most casual observer as marks of ancient lake levels. Those at elevations of 1,460 and 1,453.5 feet above sea level, 35 and 28.5 feet respectively above the present lake level, have already been described, as they belong to the two distinct stages of Lake Minnewaukan. (Fig. 8.)

The remarkable development of these two upper shore lines is undoubtedly due to the fact that they mark the levels of the Tolna and Jerusalem outlets, levels at which the waters were held repeatedly and for considerable lengths of time. Below these are several shore lines well marked by beaches with but few small cliffs. They present a fairly continuous succession formed by the lake during a period of relatively rapid dessication. The highest of this more recent series falls about seven feet below the B beach, and is evidently younger than the B but is much older than those below. It is not strikingly marked and in many places it is inconspicuous. It cannot be used everywhere, therefore, as a standard of reference and has been termed the B— stage. It probably represents the maximum stage of the water for a short period at some time between the outlet stage at B and the very recent series of receding beaches commencing with the one next below and is probably both preceded and followed by other beach levels now obliterated.

The more marked of the recent succession of shore lines are designated by the letters C, D, and E, the latter being the present lake beach. These are all low sand and gravel beaches and only in very rare cases, as on the east side of Creel Bay just north of the sand pit, do they give place to a series of low cliffs. (Plate XXV, Figs. 1 and 2.) The series of beaches below the B may be but the latest of several similar series entirely reworked during successive fluctuations of lake level.

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1. E. J. Babcock, Water Resources of the Devils Lake Region, First Biennial Report, N. D. Geol. Survey, 1901-02, p. 227.

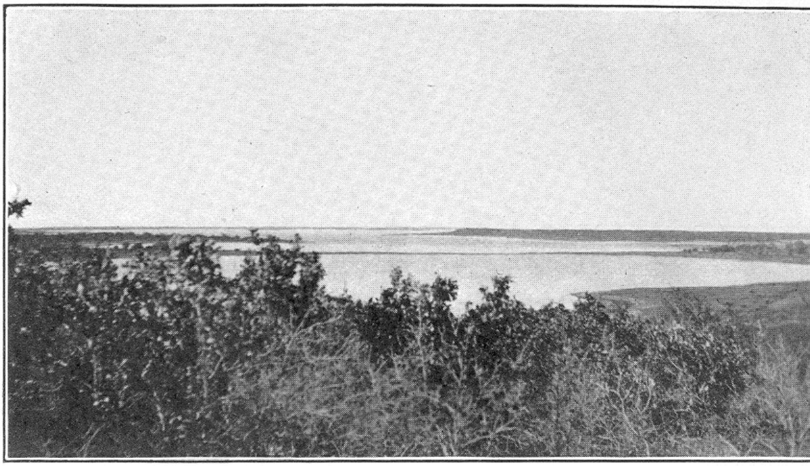

Fig. 1. Mission Lake, Mission Bay and Devils Lake showing bay head bar and "points," two stages in transition of bay and lake. (Knudson.)

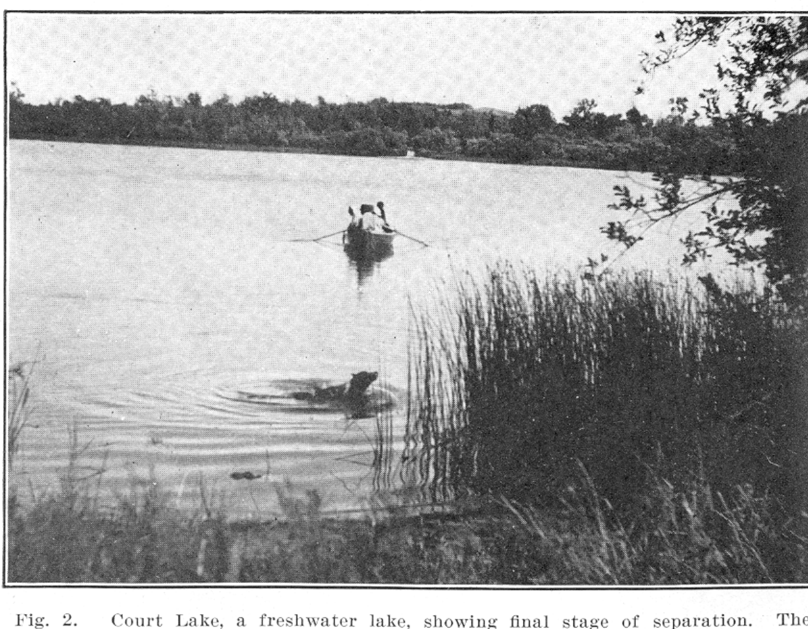

Fig. 2. Court Lake, a freshwater lake, showing final stage of separation. The timbered beach in background is same as that in foreground of Fig. 1. (Knudson.)

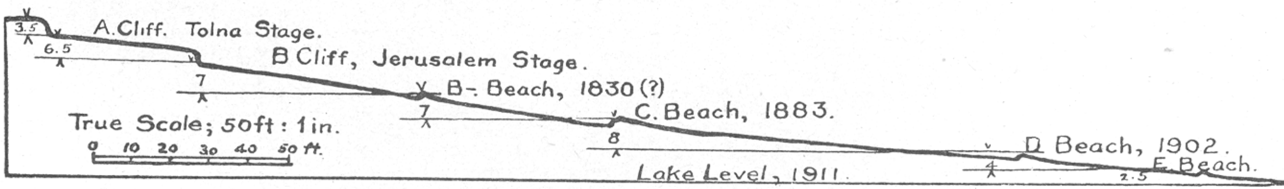

Fig. 8. Section of shore of Devils Lake midway between steamer landing and Chautauqua Point, showing characteristic cliffs and beaches.

Traditions[1] connected with the old trading post of Augustus Roche, established about 1819 on the extreme northeastern point of the timebered upland which bears his name, indicates that this was an island at that time, but that the water stood at a level not lower than 1,466, nor higher than 1,453 feet. The field evidence favors the former.

The earliest historical statement of level of Devils Lake[2] places the elevation at 1,446, about 1830. This is 21 feet above the low stage in 1911. If this is correct, it undoubtedly fixes the date of the B— beach as the highest level attained since the outlet ceased. This line is about seven feet[3] below the outlet level and limits the hard wood timber of the groves of Roche Island, only smaller scattering trees, chiefly box elder and willow, being found below that level.

Beginning in 1867, occasional well authenticated records of levels are found. That the water stood at the B— stage as late as 1867 is corroborated also by traditions which show that Roche "Island" and Grahams "Island" were still islands and that water to a depth of three or more feet was found at the ford across the narrow strait seperating Roche Island from the mainland south of Devils Lake city.

In June, 1901, a guage was established by the United States Geological Survey on the piles supporting the pier at the Chautauqua steamer landing. The gauge zero is 1,416.2 feet above sea level and is 22.90 below the bench mark established by the same survey about 130 feet in the rear in the yard of Capt. E. E. Heerman, owner of the pier. This gauge was read at intervals for several years by Capt. Heerman and is now read by the staff of the State Biological Survey, the lakeside station of which is located on the adjacent lot.

A list of observed gauge heights of the water level, together with a few of the previous records reduced to gauge readings, is tabulated below:

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1. Traditions among both the Indians and the French agree that the Sioux crossed the Narrows in buffalo skin boats and skirted the woods, approached the post from the west, killed one of the traders on the beach, and drove off the others. The beach indicated on the west must be between B and B— inclusive.

2. Warren Upham, Glacial Lake Agassiz, Mon. 25, U. S. Geol. Survey, 1894, p. 595, (Authority not cited).

3. Upham's statement (ibid) that the outlet level was reached at this stage may be explained in part by his belief that tilting had occurred between Devils Lake city and the Jerusalem outlet—a theory for which no corroborative evidence could be obtained by the author. Careful leveling to the highest shore line at Devils Lake, Chautauqua, and at the Tolna outlet reveal an elevation of 1,460 feet at each point.

GAUGE HEIGHTS IN FEET, OF DEVILS LAKE, NORTH DAKOTA

Date	Gauge Height
1867	26.75
1879	22.90
1880	18. ?
1883	22.88
1887—	
Aug. 8	15.4
1889	13.8
1890—	
August	13.0
1901—	
June 7	12.15
June 8	12.4
June 23	12.35
June 27	12.25
August 17	12.05
September 14	11.9
September 19	11.65
September 26	12.15
October 8	12.1
October 21	12.05
1902—	
April 25	13.55
April 30	13.6
May 5	13.8
May 7	13.85
May 24	13.95
June 5	14.0
June 10	13.95
June 13	14.1
June 22	14.0
June 27	13.95
July 15	13.7
August 7	13.5
August 23	13.7
September 13	13.2
September 28	13.2
October 12	13.1
October 22	13.05
November 15	13.0
1903—	
May 29	13.1
June 5	13.1
June 13	13.1
June 17	12.9
June 26	12.8
July 6	12.6
July 10	12.55
July 19	12.4
July 25	12.3
August 15	12.2
August 25	12.1
August 29	12.2
September 10	12.1
October 27	11.9
November 15	11.75
1904—	
April 24	12.7
April 30	12.8
May 1	12.7
May 5	12.75
May 11	12.8
May 17	13.2
June 8	13.4
June 26	13.4
July 5	13.4
August 23	13.0
September 6	13.0
October 3	12.8
October 10	12.75
November 29	12.65
1905—	
July 15	13.3
July 16	13.5
November 29	12.65
1906—	
April 8	12.8
May 6	12.65
June 7	13.0
June 21	12.95
July 8	13.0
August 22	12.4
September 24	12.15
October 11	11.85
November 16	11.6
1907—	
May 7	12.35
June 2	12.35
July 1	12.4
July 9	12.5
July 17	12.3
August 1	12.1
August 8	11.95
August 28	11.8
November 15	11.3
1908—	
April 21	11.7
June 27	11.35
July 12	11.3
July 17	11.2
August 3	11.1
August 12	10.9
August 20	10.8
August 29	10.7
November	10.2
1909—	
May 1	10.35
May 15	10.40
May 29	10.95
June 6	11.00
July 11	10.80

GUAGE HEIGHTS, IN FEET, OF DEVILS LAKE, NORTH DAKOTA—Continued.

Date	Gauge Height	Date	Height Gauge
Aug. 17	10.80	Sept. 1	8.60
Oct. 25	10.00	Sept. 13	8.80
Oct. 31	10.01	1911—	
1910—		April 16	8.66
June 23	9.67	July 13	8.50
July 2	9.57	Aug. 4	8.50
July 12	9.21	Aug. 10	8.70
July 20	9.02	Aug. 14	8.72
July 26	9.01	Sept. 30	8.46
Aug. 1	8.90	Oct. 17	8.60
Aug. 4	8.85	1912—	
Aug. 13	8.75	April 8	8.75
Aug. 22	8.66		

Evidences of stages of water lower than at present are not wanting in both Devils and Stump lakes. On the south shore of East Bay of Stump Lake may be seen a most remarkable group of stumps standing rooted in place in lake silts and sands. (Plate XXII.) Most of these now standing are slightly above the present lake level, but a few are still partly submerged and reports of others entirely submerged in the deeper waters offshore are given by the neighboring farmers. Not only are the stumps found in place, but many rooted logs are found thrown upon the beach by the waters and ice. In such numbers are these that they literally form log beaches, spits and bars, notwithstanding the fact that the owners of property abutting on the lake have hauled away many loads per year for years back to be used for fuel, posts, and building purposes. In fact, they have furnished the exclusive fuel supply for several farm homes. The stumps and logs are all in an incipient stage of petrification and are thoroughly impregnated with the salts found in the waters of the lake. These indicate that the waters of this lake stood for a long period of years at least several feet lower than at present, and if report of the submerged stumps is true, the bed undoubtedly free from water. Similar stumps are reported on the shores of North and South Washington Lakes and Lake Coe, T. 149, R. 65.[1]

Along the shores of Devils Lake, notably on the Chautauqua shore of Creel Bay, are found a number of rooted logs similar in all respects to those found in Stump Lake; but no well authenticated report of stumps having been found in place can be secured. However, there exists on this same shore a well defined submerged terrace at a depth of six or seven feet below the surface which appears to be a low cliff on a submerged shore line.

All of these point to a well defined stage of extremely low

1. Upham, Glacial Lake Agassiz, Mon. 25, U. S. Geol. Survey, 1895, p. 597.

water, a period of comparative if not complete dessication which seems to have marked an epoch of relative aridity in this region. Such an epoch may have coincided with the yet more arid conditions of the Great Basin, which appear to have entirely dried up Pyramid, Winnemucca and other lakes of Nevada in a period ending about 300 years ago.[1] The minimum length of this stage of dessication in this region is suggested by the fact that some of these stumps at Stump Lake measure twenty to twenty-two inches in diameter and show 120 to 130 annular rings.

Thus we see that Devils and Stump lakes are subject to periodic fluctuations in response to variations in weather, especially to rainfall and also to certain greater fluctuations which may be considered as climatic in their nature.

Studies in the climate of the earth have shown that there are rather definite changes characteristic of the several elements of climate and particularly evident in rainfall, in all portions of the earth. Theses changes occur in fairly well marked cycles of 11 and 35 years, and undoubtedly of longer periods which are not so evident. The cyclic character of rainfall has been observed both directly by measurement of rainfall and for a longer period by the effect on lakes and streams.

The most marked effects upon drainage occur in interior-basin regions, as in the case of Devils Lake, where the water rises during periods of heavier rainfall until evaporation from the increased surface balances the supply, other conditions remaining the same, and the amount of rise would depend on the increase in rainfall. The ratio would not be direct, but decreasing, however, owing to the increase of area of the lake, especially in flat basins, with increase in height of surface.

Besides these fluctuations there appears to be in the Devils-Stump Lake region a progressive change since the glacial period when a very wet climate prevailed toward a dryer climate which affects all lakes and all regions and may be said to be geologic in character. Such changes are most faithfully recorded in interior drainage basins, and it is hoped that further study in this region may throw more light on the character and duration of this change.

One other factor remains to be considered in the history of Devils Lake. The rapidity of dessication since the settlement of the region in 1883 and 1884 has been such as to seem to demand explanation other than climatic or meteorologic. The lowering of the lake level seems to be due to two causes: decrease in runoff and a lowering of the ground water level. These

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1. Russell, Geological History of Lake Lahontan, Mon. XI, U. S. Geol. Survey, pp. 223-237, 252; also G. K. Gilbert, Lake Bonneville, Mon. I, U. S. Geol. Survey, p. 258.

conditions suggest a decrease in rainfall, but extended observations of the United States Weather Bureau stations disprove this. This condition is one which has been common throughout the prairie states of the Middle West and is best accounted for by the extensive cultivation of the soil. The prairies were formerly covered by a thick, tough, almost impenetrable sod which favored runoff and prevented rapid evaporation from the soil. The conversion of this sod cover into cultivated fields, the surface of which is kept loose and porous by the plow, disc and harrow, greatly interferes with the runoff and absorption is increased. This would tend to raise the ground water level and thus equalize the loss of lake level by decrease in inflow, were it not for the fact that the cultivation of the soil, and particularly the planting of such crops as corn and wheat, causes a very great loss of soil moisture by evaporation both directly and through the plant, which moisture is replaced by capillarity from below, thus reducing the ground water table and consequently lowering the level of all permanent lakes and streams and causing many to become intermittent or temporary and some to disappear entirely. It also results in the disappearance of springs and the failure of shallow wells. These conditions have all been reported in the Devils Lake region, but are common throughout the prairie plains of the Middle West. In Iowa, for instance, the three generations of wells may frequently be found on a single farm: the shallow dug well, the deeper bored well, and the tubular well drilled into rock. Increased demand for water with increase in stock only partially accounts for the necessity of the deeper well. The final cause must be found. Subsidence of the water table and cultivation of the prairie offers the best explanation for this.

THE FUTURE OF DEVILS LAKE

The future of Devils Lake may only be read from the past. The progressive decrease in lake level since glacial times may be regarded as due to geologic causes and may be expected to continue indefinitely. Half of the morainal lakes of the United States have been converted into marshes, meadows, and rich farming lands and only the peaty and marly character of the soil remains to show where the lakes have been. This is especially true of those portions of the Middle West unaffected by the latest ice sheet. Such changes involve, however, geologic periods of time. They cannot be measured in terms of human life and are so slow in operation as to be of scientific interest only.

Fluctuations in response to variations in rainfall may be repeated in the future as in the past and those of a cyclic nature undoubtedly will be repeated. Periods of rise will follow periods of fall. It is not improbable that these may bring variations of

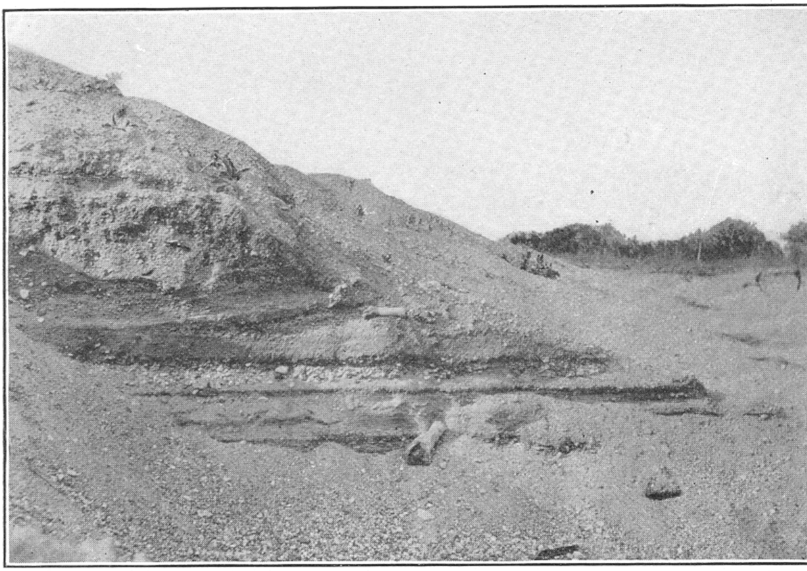

Fig. 1. Section of beach, C 1884, in gravel pit east side Creel Bay.

Fig. 2. Recent shore cliffs; D, 1902 above and E, 1911 below. East side Creel Bay near Greenwood. Timber in background borders lower B beach. Shows logs in water washed up by recent waves.

lake levels as great as those indicated by the submerged stumps on the one hand and the forest edge on the other, for these indicate stages of level reached in the comparatively recent past.

Reduction of level due to the cultivation of the soil is a permanent loss which cannot be regained. Further lowering may, in fact, be looked for as more intensive cultivation of the land is maintained, but such a decrease in level must of necessity be at a very much slower rate in the future than in the past quarter of a century and may soon approximate a state of equilibrium in so far as this factor is concerned. Decrease from this cause may not be with entire regret, since it is undoubtedly true that wheat and homes are the returns received for the disappearing lakes.

Probably too much emphasis has been placed upon the human factor—the effect of cultivation—and not sufficient upon the fluctuation of the ground water level due to variations in rainfall. The lakes appear now to be lower than at any time in the memory of man, yet we know that they have been lower. The turn of the cycle may at no distant date cause them to rise almost as rapidly. Lakes are as fickle as the weather, yet they approach climate in their constancy.

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