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To the Director of the
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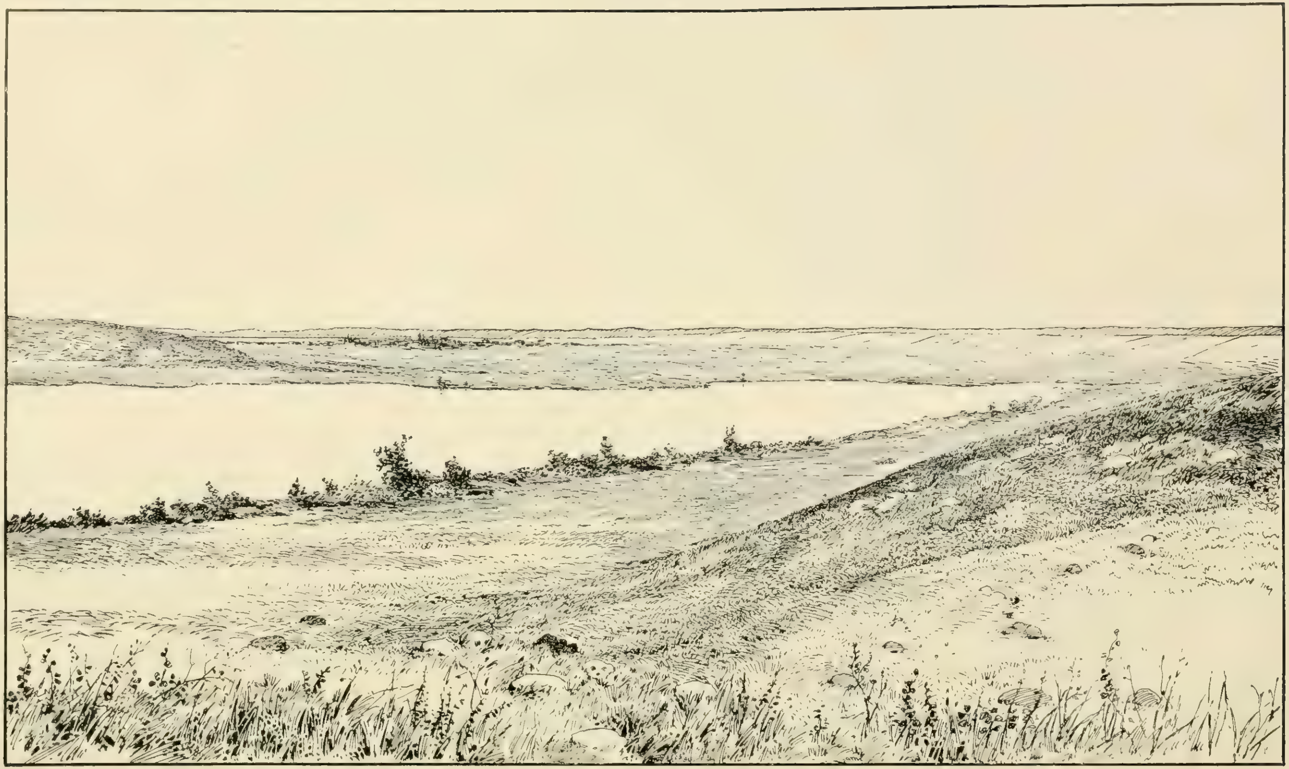
Washington, D. C., *October, 1895.*



CHANNEL OF THE RIVER WARREN, THE OUTLET OF LAKE AGASSIZ.

Looking southeast, over the south end of Lake Traverse and the town of Browns Valley, to Big Stone Lake at a distance of 6 miles

DEPARTMENT OF THE INTERIOR

MONOGRAPHS

OF THE

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VOLUME XXV

WASHINGTON
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1896

UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

THE GLACIAL LAKE AGASSIZ

BY

WARREN UPHAM

WASHINGTON
GOVERNMENT PRINTING OFFICE
1895

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ILLUSTRATIONS.

LETTER OF TRANSMITTAL.

UNIVERSITY OF CHICAGO,
Chicago, Ill., March 8, 1894.

SIR: I have the honor to transmit herewith, for publication as a monograph of the United States Geological Survey, the manuscript of a report on the Glacial Lake Agassiz, by Mr. Warren Upham. I am confident that it will be welcomed by the scientific world as a valuable contribution to the literature of North American glaciology.

Very respectfully,

T. C. CHAMBERLIN,
Geologist in Charge

To the DIRECTOR UNITED STATES GEOLOGICAL SURVEY.

PREFACE.

In my work for the Geological and Natural History Survey of Minnesota, from 1879 to 1885, under the direction of Prof. N. H. Winchell, State geologist, the highest shore-line of Lake Agassiz in that State was mapped through its prairie portion, extending about 175 miles from Lake Traverse eastward to Herman and thence northward to Maple Lake. During this survey Mr. Horace V. Winchell was my efficient assistant as rodman in leveling. The exploration showed that a very large lake occupied the Red River Valley in the closing stage of the Glacial period, when the ice-sheet was being melted away from this district. Terminal moraines of the ice-sheet, forming a series of eleven in consecutive order from south to north, were also explored and mapped in Minnesota; and it was seen that the glacial lake and moraines were intimately related as records of the recession of the ice and the transition from the Pleistocene to the Recent or present geologic period.

It became evident, however, that a satisfactory investigation of the extent and history of Lake Agassiz must comprise both sides of the Red River Valley. The United States Geological Survey therefore undertook the more extended examination of this lake area, which was assigned to me, as a member of the Glacial Division, under the direction of Prof. T. C. Chamberlin, for whose friendly counsel and constant interest in this work I have the pleasure of recording here my great indebtedness. Suggestions derived from the previous work for this Survey by Mr. G. K. Gilbert and Mr. I. C. Russell on other Pleistocene lakes also aided me much in both the field work and the study for preparing this report.

Again, when the shore-lines of Lake Agassiz had been mapped through North Dakota from Lake Traverse to the international boundary, it was found that a comprehensive monograph of this subject could not be presented while the exploration was restricted by a political limit. Hence it was generously arranged by Director J. W. Powell, of this Survey, and Director A. R. C. Selwyn, of the Geological and Natural History Survey of Canada, that my work of mapping the Lake Agassiz shores, with determination of their heights by leveling, should be continued through the prairie region of southwestern Manitoba, which was done in the summer of 1887, the termination of my survey being near the southern end of Riding Mountain. Important observations of the part of Lake Agassiz adjoining the international boundary had been previously made by Dr. George M. Dawson; and during 1887 and subsequent years Mr. J. B. Tyrrell, of the Canadian Geological Survey, has added much to the explored extent of the shores of this glacial lake, tracing them northward along the east side of the Riding and Duck mountains, and noting them in isolated localities farther north to the Saskatchewan River. My work in Manitoba being thus supplemented, this monograph is enabled to include under its descriptions and discussion a continuous extent of nearly 700 miles of the ancient lake border.

The field work on Lake Agassiz for the United States Geological Survey occupied four summers; and during three of these, in 1885 and the two following years, I had the very satisfactory assistance of Mr. Robert H. Young as rodman. The fourth summer of exploration, in 1889, included no leveling, and was chiefly devoted to tracing the course of terminal moraines adjacent to the area of Lake Agassiz. With two summers which I had spent in exploration of this lake while engaged on the Minnesota Geological Survey, the work here reported comprises the field observations of six years.

Study, writing, and preparation of maps and illustrations for this report and three preliminary official publications relating to Lake Agassiz, which are noticed in Chapter I, have required considerably more time than was used in the collection of field notes. For so full opportunity to give to this subject long-continued investigation and to present it in this volume, my grateful thanks are due and are hereby respectfully tendered to the Director and to the Geologist in Charge of the glacial investigations of this Survey.

W. U.

ABSTRACT OF VOLUME.

CHAPTER I: INTRODUCTION.—Lake Agassiz occupied the basin of the Red River of the North and of Lake Winnipeg. Its northern barrier was the retreating ice-sheet of the Glacial period. That a great lake had existed here was recognized by Keating in 1823, and later by Owen, Palliser, Hind, Dawson, Warren, and N. H. Winchell.

It was named in 1879 to commemorate Louis Agassiz, who established the theory that the drift was due to glaciation. Its southward outlet was named the River Warren in 1883. The work here reported comprises explorations performed for the geological surveys of Minnesota, the United States, and Canada. Previous reports and papers relating to Lake Agassiz and its dependence on the waning ice-sheet are noted.

CHAPTER II: TOPOGRAPHY OF THE BASIN OF LAKE AGASSIZ.—The bed of this lake is the flat Red River Valley plain. Its channel of outlet by the River Warren is now occupied by lakes Traverse and Big Stone and the Minnesota River. The shore-lines of Lake Agassiz are commonly marked by beach ridges of gravel and sand a few feet high; less frequently by an eroded escarpment from 10 to 30 feet high. Several large deltas were formed contemporaneously with the highest shore-line. East of Lake Agassiz is a somewhat higher wooded country, on which are the Giants and Mesabi ranges and the morainic Leaf Hills. On the west are the Coteau des Prairies and the Manitoba escarpment, the latter comprising the Pembina, Riding, and Duck mountains and the Porcupine and Pasquia hills. Lake Agassiz is now represented by lakes Winnipeg, Manitoba, and Winnipegosis; while Rainy Lake, the Lake of the Woods, and Red Lake lie within its southeastern boundary. Its basin is drained by the Rainy, Winnipeg, Red, Assiniboine, and Saskatchewan rivers, and others of smaller size. For some time, also, Lake Agassiz probably received streams outflowing from glacial lakes in the basins of the Peace and Athabasca rivers. The area of Lake Agassiz was approximately 110,000 square miles, and the country tributary to it was 350,000 to 500,000 square miles. The length of the lake was nearly 700 miles; its maximum width in Manitoba was probably more than 250 miles; and its maximum depth, during its earliest and highest stage, was about 700 feet above the present level of Lake Winnipeg.

CHAPTER III: GEOLOGIC FORMATIONS UNDERLYING THE DRIFT.—The bed rocks of this lacustrine area comprise, in their order from east to west, Archean, Lower and Upper Silurian, Devonian, and Cretaceous formations. Sections of the Paleozoic rocks are known by borings for artesian wells at Humboldt, Minn., Grafton, N. Dak., and Rosenfeld and Morden, Manitoba. Cretaceous strata extend from Lake Agassiz westward across the plains to the Rocky Mountains. During the Tertiary era these strata had been greatly denuded, being generally worn down to an almost flat expanse. The vertical amount of the erosion was thousands of feet at the west and hundreds of feet at the east, as shown by mountains and hills that were spared. Later erosion, during an epeirogenic uplift closing the Tertiary and beginning the Quaternary era, removed the eastern part of the Cretaceous beds, and thus formed the broad trough of the Red River Valley and of the Manitoba lake region, which was the basin of Lake Agassiz.

CHAPTER IV: THE GLACIAL PERIOD AND ITS DRIFT DEPOSITS.—The continental ice-sheet attained an area of about 4,000,000 square miles, and had a maximum thickness, in its central portion, of probably 1 to 2 miles. It extended from the Atlantic to the Pacific and from the northern United States to the Arctic Sea, probably enveloping the Rocky Mountains in the region of the Peace River and northward. The closing stage of this glaciation was the time of existence of Lake Agassiz. On the greater part of the lacustrine area the drift is from 100 to 300 feet thick, consisting chiefly of till or bowlder-clay. A series of twelve terminal moraines is found in proceeding from south to north and northeast in Minnesota and North Dakota. The last six of these, named the Dovre, Fergus Falls, Leaf Hills, Itasca, Mesabi, and Vermilion moraines, were contemporaneous with Lake Agassiz, besides probably others to be traced farther north. Birds Hill, near Winnipeg, a remarkable esker, indicates that much drift was contained in the lower part of the ice-sheet. The deltas of Lake Agassiz were formed chiefly of modified drift, brought by streams from the receding ice. Very little transportation of bowlders and other drift was effected by icebergs or floes on this lake.

CHAPTER V: HISTORY OF LAKE AGASSIZ.—The records of glacial lakes are their outlets across present lines of watershed; eroded cliffs, beach ridges, and deltas at the levels of the former outlets; and lacustrine sediments in the basin inclosed by the old shores. Lake Agassiz grew from south to north as fast as the ice-sheet receded, forming its series of moraines. The outlet by the River Warren was eroded to a depth of about 90 feet. Afterwards lower outlets were opened toward the northeast. Probably the early northeastward outflow passed along the ice border and through the upper Laurentian lakes to the Mississippi, then to the Hudson River, and later to the much enlarged Gulf of St. Lawrence. Finally the outflow was tributary to Hudson Bay when the ice had melted so far as to admit the sea to that basin. With the uncovering of the course of the Nelson River, Lake Agassiz ceased to be held by the ice barrier, and became Lake Winnipeg. Epeirogenic uplifting of the area of Lake Agassiz, increasing in vertical extent from south to north, gave to its beaches a northward ascent, and caused the several shores of its southern part to become double or multiple as they are traced northward. The molluscan fauna of Lake Agassiz, so far as it has been discovered, consists of five fresh-water species. The amount of the shore erosion of Lake Agassiz and the volume of its beaches, compared with the postglacial erosion and beach deposits of the present Great Lakes, have a ratio approximately as one to ten. The duration of postglacial time is believed to have been from seven to ten thousand years; of Lake Agassiz, probably not more than one thousand years.

CHAPTER VI: BEACHES AND DELTAS OF THE HERMAN STAGES.—These shore deposits are described in detail. The earliest and highest beach, named from Herman, Minn., has been mapped, with determination of its height by leveling, through an extent of about 175 miles in Minnesota, from Lake Traverse east to Herman, and thence north to Maple Lake. In 140 miles, from south to north, this shore-line ascends from 1,050 feet to 1,170 feet, approximately, above the sea. Near Maple Lake four lower beaches, successively about 8, 15, 30, and 45 feet below the highest, were also formed during the time of accumulation of the single Herman beach at the south; and on the west side of the lake in Manitoba the Herman series of beaches is increased to seven. In North Dakota the uppermost Herman shore has a northward ascent of about 180 feet in the distance of 224 miles from Lake Traverse to the international boundary, where its height is 1,230 feet above the sea. At the latitude of Gladstone, in Manitoba, 84 miles farther north, the altitude of 1,315 feet is attained by the second of the Herman shores, which is the highest one extending so far. Six noteworthy deltas were brought into Lake Agassiz, contemporaneously with the formation of the Herman beaches, by streams which were exceptionally supplied with much modified drift by the melting ice-sheet. These are the Buffalo River and Sand Hill River deltas in

Minnesota, the Sheyenne, Elk Valley, and Pembina deltas in North Dakota, and the very large delta of the Assiniboine in Manitoba.

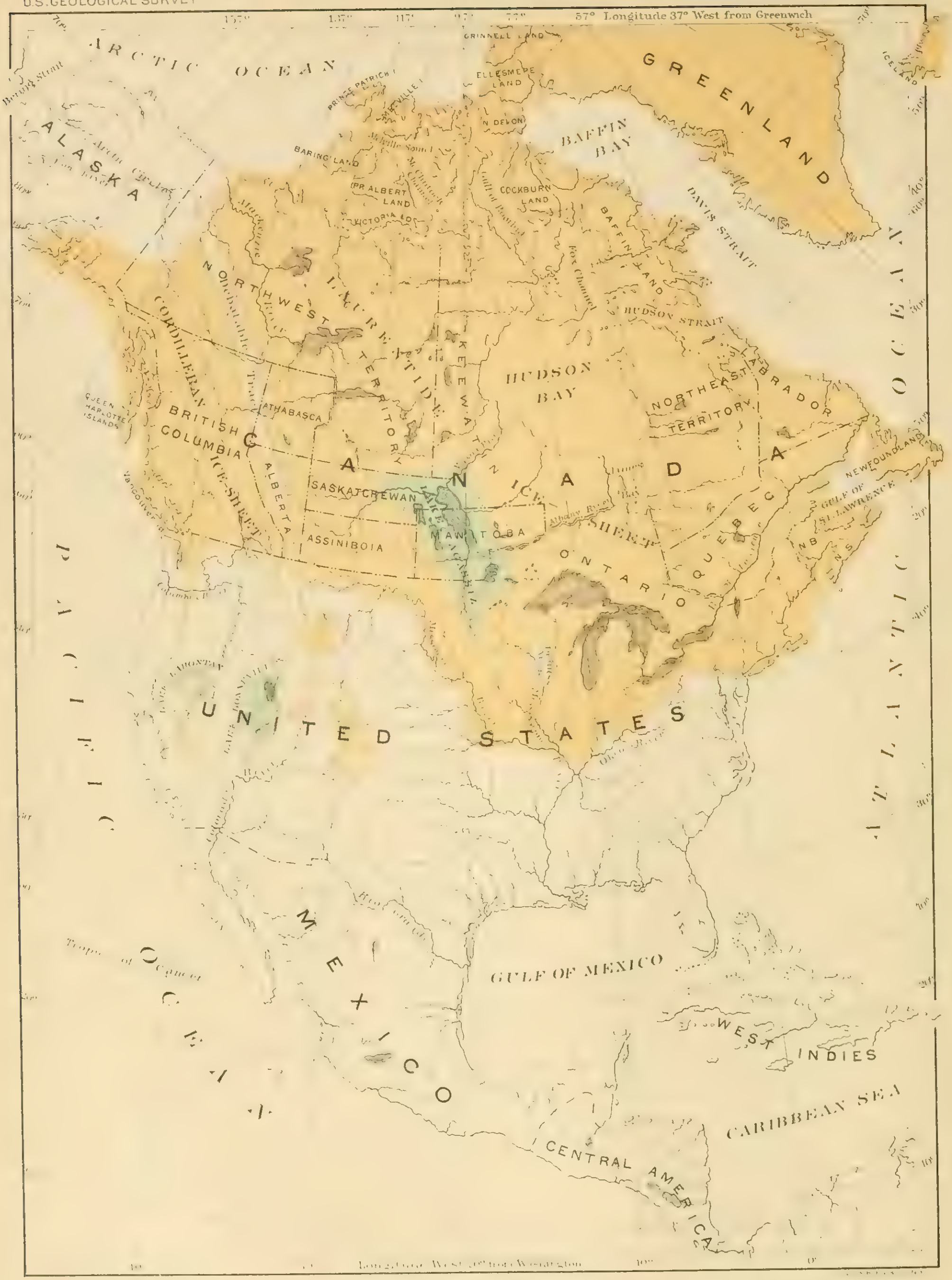
CHAPTER VII: LOWER BEACHES WITH SOUTHWARD OUTFLOW.—Below the Herman shore the southern part of Lake Agassiz has four shore-lines, which receive names from Norcross, Tintah, Campbell, and McCauleyville, in Minnesota. Portions of these shores have been traced with leveling and are here described. In the northern part of the area of my exploration the Norcross and Tintah beaches are double, and the Campbell and McCauleyville beaches are each represented by three. With the seven Herman shores recorded in Manitoba, Lake Agassiz had thus at the north seventeen stages marked by successive beaches during its time of southward discharge by the River Warren. The upper Norcross shore rises from about 1,030 feet above the sea at Lake Traverse to 1,215 feet on the latitude of Gladstone. In the same distance the upper Tintah shore rises from 1,015 to 1,150 feet; the upper Campbell shore, from 990 to 1,080 feet; and the upper and lower McCauleyville shores, respectively, from 970 to 1,035 feet, and from 960 to 1,012 feet, approximately, above the present sea-level.

CHAPTER VIII: BEACHES FORMED WHEN LAKE AGASSIZ OUTFLOWED NORTHEASTWARD.—Fourteen stages of Lake Agassiz are shown by beaches that were formed after the lake had fallen below its southern outlet. These comprise, in descending order, three successive Blanchard beaches, passing near Blanchard, N. Dak.; the Hillsboro beach, and two Emerado and two Ojata beaches, named likewise from towns in North Dakota; and the Gladstone, Burnside, Ossowa, Stonewall, and Niverville beaches, the last being double northward, named from places in Manitoba. These shore-lines are as definitely marked by beach ridges, and occasionally by low eroded escarpments, as the series belonging to the time of the River Warren. Their northward ascent is gradually diminished, until in the latest-formed Niverville beach it is only about 20 feet in the distance of more than 200 miles from near Winnipeg and the southern part of Lake Winnipeg northward to the mouth of the Saskatchewan.

CHAPTER IX: CHANGES IN THE LEVELS OF THE BEACHES.—The rate of northward ascent of the originally level highest beach, within the area of my leveling, varies from about 6 inches per mile near its southern end to about 1 foot per mile along the greater part of its extent to southern Manitoba. On the east side of the Red River Valley the old shores are higher than on its west side, the rate of ascent from west to east being about half as much as from south to north. The direction of maximum ascent of the planes of the former lake levels is therefore toward the north-northeast. Farther north several beaches of the series mapped by Tyrrell along the bases of the Riding and Duck mountains have a northward rise of 2 to 3 feet per mile. These changes of level were in progress and were nearly completed during the existence of Lake Agassiz, as is shown by the gradual diminution in the northward ascent of the successive lower beaches, until the latest and lowest differs only very slightly from perfect horizontality. Gravitation of Lake Agassiz toward the ice-sheet accounts for a small part of the present inclination of the beaches. Changes in the temperature of the earth's crust due to the Glacial period and its termination produced a still smaller effect, but this tended to give the opposite slope, or a descent toward the north. Upward epeirogenic movements, resulting from the unburdening of the land by the departure of the ice-sheet, were the chief element in the causes of the differential changes in the height of this basin. Flow of the plastic inner part of the earth's mass, restoring isostasy, uplifted first the southern half of the area of Lake Agassiz, from Lake Traverse to Gladstone; next it raised the northern half of the lake area, while the region at the south was almost at rest; and finally, during the Recent epoch, after the whole basin of Lake Agassiz was passed by this wave-like permanent uplift, it has been elevating the basin of Hudson Bay, where the movement still continues. Pleistocene oscillations of the land in many other parts of the world have been independent of glaciation, or these have been combined with movements due to the accumulation of ice-sheets and to their removal; but the uplifting of the basins of Lake Agassiz and Hudson Bay is apparently attributable wholly to the departure of the ice-sheet.

CHAPTER X: ARTESIAN AND COMMON WELLS OF THE RED RIVER VALLEY.—Hundreds of artesian wells, from 40 to 300 feet deep, have been obtained in the drift formations of the Red River Valley plain, the axial lowest part of the Lake Agassiz basin. South of Crookston and Blanchard they yield fresh water; but northward, to the border of Manitoba, their water is usually saline and alkaline. The fresh water is derived from rainfall on the higher land adjoining this valley. The saline matter is brought mostly by water flowing through the Dakota sandstone and issuing into the drift of the Red River Valley upon tracts where this sandstone is the next underlying formation. The saline and alkaline wells in the drift of this district are thus supplied, like the deeper artesian wells penetrating the Cretaceous strata at Devils Lake and in the James River Valley, from rainfall on the flanks of the Black Hills and Rocky Mountains. Analyses and experience show that the saline and alkaline water is not suitable for use in irrigation. Sections of many artesian and common wells on the area of Lake Agassiz are reported, with notes of the characters of their water supply.

CHAPTER XI: AGRICULTURAL AND MATERIAL RESOURCES OF THE AREA OF LAKE AGASSIZ.—The fertility of the soil and the climatic conditions of the prairie portion of this area make agriculture its leading industry and source of wealth. Previous to its occupation by the present farming population the rich pasturage and countless herds of buffaloes betokened the value of the land for the cultivation of grain and for stock-raising. The annual wheat product of the six counties in Minnesota and six in North Dakota lying mainly within the Red River Valley is about 46,000,000 bushels, or on an average 285 bushels for each of the 161,049 people enumerated by the census of 1890 in these counties. Other crops which receive considerable attention are oats, barley, hay, potatoes, and flax. The tendency is toward diversified farming, with stock-raising and dairying. Magnesian limestones, which outcrop near Winnipeg, are used for building and the manufacture of lime. Clay of the best quality for brickmaking is found along all the Red River Valley, and this business is carried on in many places. The brines and natural gas occasionally supplied by wells, and the lignite occurring in very thin layers in Cretaceous formations of this region, and thence sparsely distributed in fragments through the drift, are not of economic importance. Many streams within the area of Lake Agassiz, especially in the northeastern wooded country, have valuable water powers, which are beginning to be utilized for mills and manufactures.



MAP SHOWING THE RELATIONSHIP OF LAKE AGASSIZ TO THE DRIFT-BEARING AREA OF NORTH AMERICA AND TO LAKES BONNEVILLE AND LAHONTAN.

Scale, about 550 miles to an inch.

Areas covered by Land Ice during the Quaternary Era | Quaternary Lakes Bonneville and Lahontan and the Glacial Lake Agassiz

THE GLACIAL LAKE AGASSIZ.

By Warren Upham.

CHAPTER I.

INTRODUCTION.

BASIN OF THE RED RIVER OF THE NORTH AND OF LAKE WINNIPEG.

The glacial lake which is the theme of this volume extended along the Red River Valley and covered the lake country of Manitoba. Its situation in the center of the continent, and its geographic relation to the drift-covered area and to lakes Bonneville and Lahontan, are displayed in Plate II. Lake Agassiz was the largest of the many Pleistocene lakes of North America, some of which were formed by the barrier of the ice-sheet during its recession, while others were produced by increased rainfall in the great western arid region that has no drainage to the sea.

Only a comparatively small fraction—about one-fifth—of the area of Lake Agassiz lies within the United States, but this includes the greater portion of its exactly explored shore-lines. A very large part of its area in Canada, besides a considerable tract within its limits in northern Minnesota, is covered by forest, which makes it impracticable to trace there the beach ridges and deltas, low escarpments of erosion, and other evidences of this lake so continuously as has been done through the prairie region. This great expanse of prairie, upon which the shore-lines have been accurately and continuously mapped, comprises the Red River Valley and adjoining higher land, and reaches north to the southern ends of lakes Winnipeg and Manitoba and of Riding Mountain. Farther north tracts of prairie, divided by woodlands and thickets, continue interruptedly along the eastern base of Riding and Duck mountains, permitting considerable parts of the ancient shores to be traced in that district.

As this report necessarily treats of the topographic features of the basin of the Red River and Lake Winnipeg, it has seemed desirable to devote a chapter to the rock formations which underlie the glacial drift and the old lake bed, with discussion of the preglacial erosion that gave the general outlines of the Red River Valley plain and of the Manitoba escarpment bounding it on the west. Though this part is presented somewhat briefly, it is hoped that the reader will be able to obtain in it a comprehensive review of the entire geologic history of this area, and of its uplift and sculpturing to the form of a basin, previous to the Ice age and the time of Lake Agassiz.

The economic geology of this basin has received a large share of attention during the progress of the field work and in the present volume. Owing to the structure of the drift deposits and of the underlying rocks, many artesian wells have been obtained in the Red River Valley, descriptive notes of which are given, with analyses of their waters, and an explanation of the sources, in part near and probably in part hundreds of miles distant, from which the waters and their dissolved mineral matter are derived. No commercially valuable deposits of ores, coal, natural gas, or salt can be reported, but the northern part of the Red River Valley, in Manitoba, has magnesian limestone of excellent quality for building purposes and for the manufacture of lime, and the whole valley has plentiful beds of clay, unsurpassed for brickmaking. The chief resources of this extensive prairie region of Lake Agassiz, however, are found in its very fertile soil and favorable climate for agriculture, and especially for wheat raising.

THE GLACIAL LAKE AGASSIZ.

During the closing part of the latest completed division of geologic time a vast lake stretched from the southern end of the Red River Valley north to the Saskatchewan and Nelson rivers. The late date of its existence is known by the position of its shore-lines and deltas, which lie upon the glacial drift and have nearly as perfect outlines as those of the present shores of the Manitoba and Laurentian lakes or of the ocean. This ancient lake, several times larger than Superior—indeed, exceeding the aggregate area of the five great lakes tributary to the St. Lawrence—washed the east and west borders of the Red River Valley and the base of the Riding and Duck mountains. Its surface during storms was raised into waves which formed well-defined beach ridges of gravel and sand, and these are found at many successive levels, showing that the area and depth of the lake were gradually diminished. Before these deserted shores and the inclosed lacustrine area were examined in the field work for this report, their character had been observed and was generally attributed to lake action by the immigrant farmers, who in many instances selected the beach ridges as the sites of their dwellings.

Intervals of small vertical amount divide the consecutive beaches, from the highest to the lowest. Through the earlier and probably greater part of the duration of the lake it outflowed southward by the way of Lake Traverse, Browns Valley, Big Stone Lake, and the Minnesota River to the Mississippi. Seventeen shore-lines on the northern portion of the lake area were formed contemporaneously with this southern outlet. Later the lake was further reduced through stages shown by fourteen shore-lines, while it outflowed by successively lower avenues of discharge northeastward. Finally it was reduced to lakes Winnipeg, Manitoba, and Winnipegosis, which are the lineal descendants and representatives of Lake Agassiz.

RELATIONSHIP TO THE ICE-SHEET.

The conditions to which Lake Agassiz owed its existence, however, were very unlike those of the present time. It could not have been held in a landlocked basin, for there has been no subsidence of the country between this area and Hudson Bay since the Glacial period. Instead, the area of Lake Agassiz and all the region northeastward to Hudson Bay and Strait have experienced a gradual uplift during the time of the departure of the ice-sheet and subsequently. As shown by the northwardly ascending shore-lines of this lake and by fossiliferous marine beds overlying the glacial drift on the lower country adjoining Hudson Bay and along the Ottawa and St. Lawrence rivers, the vertical extent of this uplift was greatest toward the north and east. It was little at Lake Traverse, but amounted to 400 or 500 feet in Manitoba, and was approximately 500 to 600 feet on the southwest side of Hudson and James bays and upon all the interior portion of the continent thence to Ottawa and Montreal. It is evident, therefore, that no barrier of land held the lake which covered the Red River Valley and a large part of Manitoba. But a southward outlet is found through which the lake flowed to the Mississippi, and no marine fossils have been detected in or above the drift upon this area, from which reasons it is certain that these ancient shore-lines were not produced by subsidence of the land beneath the sea-level, followed by reelevation. While the beaches and deltas here described are thus known to be lacustrine, fossils have been discovered in them at only two localities, these being shells of five species of fresh-water mollusks, occurring in beaches that belong to the middle and later part of the lake's history.

From all these features of the former lake, when they are considered in their relationship to the Glacial period and its drift deposits, we are led to the conclusion that the northern barrier by which its water was held in was a waning ice-sheet. The glacial striæ, till, terminal moraines, and other drift formations prove that the northern half of our continent has been enveloped by a continuous mantle of ice stretching from the eastern shores of New England and Canada west to the Rocky Mountains and the Pacific, and from the northern part of the United States to the Arctic Sea. When this ice-sheet was melted away, its border gradually withdrew from south to north, and hydrographic basins descending northward were temporarily occupied by glacial lakes, held by the ice barrier until its continued retreat allowed free drainage of these basins in the direction of their slopes. This explanation fully accounts for the presence of Lake Agassiz in the basin of the Red River and of Lake Winnipeg during the recession of the ice-sheet, for the scantiness of its fauna, and for the northward ascent of its originally level shores, since the earth's crust had been depressed by the ice burden, and was uplifted, in the preservation of its equilibrium, when the ice-sheet departed.

The work of Gilbert, Chamberlin, Leverett, and others in the basins of the Laurentian lakes has proved that their formerly much higher levels, marked by shore-lines similar to those of Lake Agassiz, were contemporaneous with the departure of the ice-sheet and the formation of its recessional moraines. Records of many other smaller glacial lakes have been observed upon all the glaciated area of our continent from New England to British Columbia. The ice-sheet of northwestern Europe also formed such lakes during its final melting. Some of these lakes, pent up in valleys 2,000 to 3,000 feet above the sea, between the eastern side of the Scandinavian Mountains and the remnant of the ice still covering eastern Sweden, attained lengths of about 100 miles and depths of about 1,000 feet.[1] In Scotland, likewise, the famous Parallel Roads of Glen Roy are shown to be the shores of successive stages of a lake held by the barrier of the waning Scottish ice-sheet.[2] The positions of the European glacial lakes, as of those in North America, were determined by the areas of greatest thickness of the ice and the manner of its recession.

When the Glacial period in North America was ending, as soon as the border of the ice had receded beyond the watershed dividing the basins of the Minnesota and Red rivers, it is evident that a lake, fed by the glacial melting, stood at the foot of the ice fields and extended northward as they withdrew along the Red River Valley to Lake Winnipeg, filling this valley to the height of the lowest point over which an outlet could be found. Until the ice barrier was so far melted upon the area between Lake Winnipeg and Hudson Bay that this glacial lake began to be discharged northeastward, its outlet was along the present course of the Minnesota River. Because of its relation to the retreating continental ice-sheet, this lake has been named in memory of Prof. Louis Agassiz, the first prominent advocate of the theory that the drift was produced by land ice.[3] Within the past fifteen years the truth of this explanation of the drift has been demonstrated by the recognition and detailed study of the morainic deposits that were accumulated along the boundary of the ice-sheet from

[1] A. H. Hansen, in Nature, Vol. XXXIII, 1886, pp. 268, 269, 365.

[2] T. F. Jamieson, in Quart. Jour. Geol. Soc., Vol. XLVIII, 1892, pp. 5–28.

[3] Geol. and Nat. Hist. Survey of Minnesota, Eighth Annual Report, for the year 1879, pp. 84, 85. (Jean Louis Rodolphe Agassiz was born in Motier, Switzerland, May 28, 1807, and died in Cambridge, Mass., December 14, 1873. His observations of the Swiss glaciers and his principal writings concerning them and the glacial origin of the drift were during the years 1836 to 1846. In the autumn of 1846 Agassiz came to the United States, and the remainder of his life was mostly spent here in zoological researches and in teaching in Harvard College, where he founded the Museum of Comparative Zoology. The interests of science in this country were inestimably advanced by his great influence as a teacher and by his extensive writings in zoology, in which and the care of the museum his work has been ably continued by his son, Alexander Agassiz. See the biography, Louis Agassiz: His Life and Correspondence, edited by Elizabeth Cary Agassiz. 2 vols. 1885.)

southern New England and Long Island to North Dakota and Assiniboia. The characters of other drift deposits point with equal certainty to a vast sheet of land ice as their cause; and the explanation accounts for this lake in the Red River Valley, for similar lakes that were tributary to it from the basins of the Souris and South Saskatchewan rivers, and for the contemporaneous higher levels of the great lakes now discharged by the River St. Lawrence.

EARLY OBSERVATIONS OF LAKE AGASSIZ.

The evidences of the former existence of a great lake in the Red River Valley were observed in 1823 by Keating, the geologist of the first scientific expedition to this district,[1] in 1848 by Owen,[2] in 1857 by Palliser,[3] in 1858 by Hind,[4] and in 1873 by Dr. G. M. Dawson.[5] Each of these geologists explored considerable tracts of the lacustrine area, recognizing its limits in a few places; and Hind especially described and mapped portions of the lower beach ridges. Dr. Dawson's work was in connection with the British North American Boundary Commission, and includes detailed notes of the part of this area lying between the Lake of the Woods and the Pembina Mountain. Several references to these authors and quotations from their reports are presented in later pages of this volume.

The excavation of the valley occupied by Lakes Traverse and Big Stone and the Minnesota River was first explained in 1868 by Gen. G. K. Warren, who attributed it to the outflow from this ancient lake. He made a careful survey of this valley, and his maps and descriptions, with the accompanying discussion of geologic questions, are most valuable contributions to science.[6] After his death, in commemoration of this work,

[1] Narrative of an Expedition to the Source of St. Peters River, Lake Winnepeek, Lake of the Woods, etc., performed in the year 1823, * * * under the command of Stephen H. Long, U. S. Topographical Engineer. London, 1825. Vol. II, p. 3.

[2] Report of a Geological Survey of Wisconsin, Iowa, and Minnesota. Philadelphia, 1852. P. 178.

[3] Journals, detailed reports, etc., presented to Parliament, 19th May, 1863, p. 41.

[4] Report of the Assiniboine and Saskatchewan Exploring Expedition. Toronto, 1859. Pp. 39, 40, 167, 168.

[5] Report on the Geology and Resources of the Region in the Vicinity of the Forty-ninth Parallel, from the Lake of the Woods to the Rocky Mountains. Montreal, 1875. P. 248.

[6] "On certain physical features of the Upper Mississippi River," American Naturalist, Vol. II, pp. 497–502, November, 1868. Annual Report of the Chief of Engineers, United States Army, for 1868, pp. 307–314. "An essay concerning important physical features exhibited in the valley of the Minnesota River, and upon their signification," with maps; Report of Chief of Engineers, 1875. "Valley of the Minnesota River and of the Mississippi River to the junction of the Ohio; its origin consid-

the glacial river that was the outlet of Lake Agassiz was named River Warren.[1]

That this lake existed because of the barrier of the receding ice-sheet was first pointed out in 1872 by Prof. N. H. Winchell.[2]

WORK REPORTED IN THIS MONOGRAPH.

The part of the area of Lake Agassiz which lies in Minnesota, so far as it is prairie, was explored by the writer in 1879 and 1881, under the direction of Prof. N. H. Winchell, State geologist; and in the latter year the highest or Herman beaches in that State, and small parts of lower shore-lines, were carefully surveyed and mapped, their heights being determined by leveling, with the assistance of Horace V. Winchell as rodman. This work has been reported in publications of the Minnesota Geological Survey.[3] It is also used in this monograph, which comprises in addition, for the part of the lake area in Minnesota, a large amount of later observations made during my field work for the United States Geological Survey, pertaining chiefly to the lower beaches, artesian wells in the Red River Valley, and terminal moraines upon the region eastward to Red Lake, Itasca and Leech lakes, and Brainerd.

Exploration of the Lake Agassiz shore-lines, deltas, and associated glacial and lacustrine formations was again entered upon by the writer, for the United States Geological Survey, in 1885, as a part of the work of the Glacial Division, under the direction of Prof. T. C. Chamberlin. During the years 1885 to 1887, inclusive, the upper or Herman beaches in North Dakota, and extensive portions of the lower shores both in North Dakota and Minnesota, were mapped and their altitudes ascertained continuously by leveling, in which I was assisted by Robert H. Young. We traveled mostly afoot for this surveying, our daily advance varying from 3 to 10

ered; depth of the bed rock," with maps; Report of Chief of Engineers, 1878, and Am. Jour. Sci. (3), Vol. XVI, pp. 417–431, December, 1878. (General Warren died August 8, 1882.)

[1]Proc. A. A. A. S., Vol. XXXII, for 1883, pp. 213–231; also in Am. Jour. Sci. (3), Vol. XXVII, Jan. and Feb., 1884; and Geology of Minnesota, Vol. I, p. 622.

[2]Geol. and Nat. Hist. Survey of Minnesota, First Annual Report, for 1872, p. 63; and Sixth Annual Report, for 1877, p. 31. Professor Winchell also explained in like manner the formerly higher levels of the Laurentian lakes, Popular Science Monthly, June and July, 1873; and the same view is stated by Prof. J. S. Newberry in the Report of the Geological Survey of Ohio, Vol. II, 1874, pp. 6, 8, and 51.

[3]Geol. and Nat. Hist. Survey of Minnesota, Eighth Annual Report, for 1879, pp. 84–87; Eleventh Annual Report, for 1882, pp. 137–153, with map; and Final Report, Vols. I and II.

miles. A preliminary report of part of these observations was published in 1887.[1]

By cooperation of the geological surveys of the United States and Canada, a portion of my field work in 1887 was devoted to the examination of the northward extension of the beaches of Lake Agassiz in Manitoba. Traveling with horse and wagon, and assisted by Mr. Young, a somewhat detailed exploration of this lacustrine area was continued about a hundred miles north from the international boundary, the most northern points reached being Shoal Lake, between Lakes Winnipeg and Manitoba, and Orange Ridge post-office, near the southeast end of Riding Mountain. The mainly wooded character of the country farther north makes continuous leveling and tracing the beaches of this lake impracticable; and the same condition limited my examination on the east to a narrow belt adjoining the Red River. The western border of this portion of Lake Agassiz is formed by the Pembina Mountain, the Tiger Hills, the Brandon Hills, and Riding Mountain; and the mouth of the Assiniboine was at Brandon during the highest stage of the lake. In this direction my observations were extended west of the shore-line of Lake Agassiz to include the vicinity of the Assiniboine and the Canadian Pacific Railway to Griswold, the course of the Souris River below Plum Creek, Langs Valley, a glacial water-course extending from the elbow of the Souris southeast to Pelican Lake and the Pembina River, and the lower course of that river, by which a large delta was deposited in the west margin of Lake Agassiz a few miles south of the international boundary. The breadth of the country thus traversed from east to west is about 150 miles. A report of this work has been published by the Canadian Geological Survey.[2]

For all these surveys in the United States and Manitoba profiles of the numerous railway lines crossing this district supplied reliable elevations above the sea-level at their stations; and in many instances they also show distinctly their intersections of the beaches of this lake. These elevations were taken as the data and reference points of my leveling, which was

[1] U. S. Geol. Survey Bulletin, No. 39. The Upper Beaches and Deltas of the Glacial Lake Agassiz. Pp. 84, with map

[2] Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. IV, for 1888–89, Part E, Report of Exploration of the Glacial Lake Agassiz in Manitoba, pp. 156, with two maps and a plate of sections.

proved throughout its entire extent to be accurate within close approximation by its agreement with the railway surveys, the comparisons being made at intervals varying from 20 to 40 or 50 miles. A very large number of railway profiles, extending beyond the limits of Lake Agassiz to Lakes Superior and Michigan and to the Pacific Ocean, were examined during this work, and the altitudes of their stations, summits of grade, bridges, and low and high water of the streams crossed, were tabulated for convenient reference and comparison, being uniformly referred to the sea-level at mean tide. This auxiliary part of the investigations relating to Lake Agassiz has been separately published.[1] In the present volume the altitudes of the railway stations are noted on Pls. XXIII to XXXIII, which give the detailed surveys of the lake beaches and deltas. For the whole area of this glacial lake, so far as it has been explored with leveling and is traversed by these railway surveys, their altitudes are noted on Pl. X.

Exact or close agreements of several independent surveys from the sea to this district, and of the profiles of the many intersecting lines of railway in Minnesota, South and North Dakota, and Manitoba, give complete assurance that these heights, and those determined therefrom by leveling along a thousand miles or more of the shore-lines of Lake Agassiz, are not only consistent together but also absolutely true within limits of error probably nowhere exceeding 5 feet. Such exact determinations of the elevations of the beaches seem very important, because these deposits which were formed along the level shores of the lake in its successive stages are found at the present time to have a gradual ascent from south to north, amounting, within the portion of the lake area surveyed by me, to about a foot per mile in the highest and oldest beach, and gradually diminishing to a quarter or even an eighth part of this amount in the lowest and latest of the beaches. Some interesting problems are thus presented as to the relationship of these progressive changes of level, when they were produced, and their causes.

During the year of my exploration in Manitoba, and since that time, important observations of the beaches of Lake Agassiz farther northward along the Manitoba escarpment and near the mouth of the Saskatchewan

[1] U. S. Geol. Survey, Bulletin No. 72. Altitudes between Lake Superior and the Rocky Mountains. 1891. Pp. 229.

have been made during work for the Geological Survey of Canada by Mr. J. B. Tyrrell.[1] Notes of these additions to our knowledge of the glacial lake are included in this monograph, and contribute much to the history of the differential uplift of the lake area. Mr. Tyrrell finds that in northwestern Manitoba the lower beaches formed during the time of southward outflow of Lake Agassiz have been changed in height, so that they now ascend 2 to 3 feet per mile northward. Their changes of level are thus twice as great as those of the higher and earlier beaches within the area of my leveling, and they took place after the uplifting of the more southern part of the lake area had nearly ceased.

The close relationship of Lake Agassiz and the uplift of its area with the recession of the ice-sheet showed that this work would not be complete without a special examination of the terminal moraines which form conspicuous belts of hilly drift upon the country both east and west of the lacustrine area, and whose courses in the Red River Valley are commonly marked only by a somewhat uneven or almost flat surface of till, with frequent or often plentiful bowlders. Accordingly, in 1889 several months were given to field work in tracing these moraines. The region explored in North Dakota extended from the head of the Coteau des Prairies, west of Lake Traverse, northward and northwestward to Devils Lake, Turtle Mountain, the Souris River, and the Coteau du Missouri, in the northwestern part of this State. On the other side of Lake Agassiz my field work in 1889 extended east to Lake Itasca and the upper part of the Mississippi. With the account of these observations given in Chapter IV, brief notes are also supplied from my earlier reports relating to the terminal moraines in Minnesota.[2]

While my xplorations and studies of Lake Agassiz have been in progress for the Minnesota, United States, and Canadian Geological Surveys, I have presented portions of their results in various reports and papers, as

[1] Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. III, for 1887-88, Part E, Notes to accompany a preliminary map of the Riding and Duck mountains in northwestern Manitoba, 16 pages, with map. Other papers by Mr. Tyrrell, including descriptions of portions of the Lake Agassiz beaches, are "Post-Tertiary Deposits of Manitoba and the adjoining territories of northwestern Canada," Bulletin, G. S. A., Vol. I, 1890, pp. 395-410, and "Pleistocene of the Winnipeg Basin," Am. Geologist, Vol. VIII, pp. 19-28, July, 1891.

[2] Geol. and Nat. Hist. Survey of Minn., Eighth and Ninth Annual Reports, for the years 1879 and 1880; and Final Report, Geology of Minnesota, Vol. I, 1884, and Vol. II, 1888.

MAP SHOWING THE AREAS OF LAKE AGASSIZ AND OF THE UPPER LAURENTIAN LAKES.

Scale, about 165 miles to an inch.

Lake Agassiz and associated Glacial Lakes — Glacial Striæ — Terminal Moraines

enumerated below in their chronologic order.[1] These preliminary reports and discussions bearing more or less directly on this subject have been drawn from in many places during the preparation of the present work.

The map given in Pl. III shows the whole extent of Lake Agassiz, and, for comparison with it, the upper great lakes that outflow by the St. Lawrence. The courses of glacial striæ and terminal moraines are also shown, so far as they have been mapped; but doubtless numerous moraines in Canada remain to be filled in by future exploration. It should be remarked, however, that the northern and northeastern boundaries of this glacial lake probably can never be exactly determined, and must be laid down in any attempt of this kind by estimation, for they were formed by the receding ice-sheet instead of a land surface on which beaches would be discoverable.

6	5	4	3	2	
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

United States.

31	32	33	34	35	36
30	29	28	27	26	25
19	20	21	22	23	24
18	17	16	15	14	13
7	8	9	10	11	12
6	5	4	3	2	

Manitoba.

FIG. 1.—Order of sections in townships.

Detailed descriptions of the beaches and deltas occupy three chapters and are illustrated by a series of ten map plates (XXIII to XXXII), hav-

[1] "Preliminary report on the geology of central and western Minnesota," Geol. and Nat. Hist. Survey of Minn., Eighth An. Rep., for 1879, pp. 70–125.

"Lake Agassiz: a chapter in glacial geology," Bulletin of the Minnesota Academy of Natural Sciences, Vol. II, pp. 290–314, Jan., 1882; also in Geol. and Nat. Hist. Survey of Minn., Eleventh An. Rep., for 1882, pp. 137–153, with map.

"The Minnesota Valley in the Ice age," Proc. A. A. A. S., 1883, Vol. XXXII, pp. 213–231; also in Am. Jour. Sci. (3), Vol. XXVII, pp. 34–42 and 104–111, Jan. and Feb., 1884.

Geology of Minnesota, Final Report, Vol. I, 1884, pp. 408, 442, 461, 484, 581, 622.

"The upper beaches and deltas of the glacial Lake Agassiz," Bulletin No. 39, U. S. Geol. Survey, 1887, pp. 84, with map.

"The recession of the ice-sheet in Minnesota in its relation to the gravel deposits overlying the quartz implements found by Miss Babbitt at Little Falls, Minn.," Proc. Boston Soc. of Nat. Hist., Vol. XXIII, pp. 436–447, Dec., 1887.

Geology of Minnesota, Final Report, Vol. II, 1888, pp. 134, 500, 504, 517–527, 551, 656, 662, 664–7.

"Glaciation of mountains in New England and New York," Appalachia, Vol. V, 1889, pp. 291–312; also in Am. Geologist, Vol. IV, Sept. and Oct., 1889.

"Probable causes of glaciation," appendix in Prof. G. F. Wright's Ice Age in North America, 1889, pp. 573–595.

"Report of exploration of the Glacial Lake Agassiz in Manitoba," Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. IV, for 1888–89, Part E, 1890, pp. 156, with two maps and ing the scale of 6 miles to an inch. Section lines are drawn on these maps, which will enable the reader to refer readily to the localities designated in the text by the numbers of the section, township, and range. For the convenience of those who may not be acquainted with the unlike systems employed in the United States and in Manitoba for numbering the sections of each township, fig. 1 is here inserted. Occasional reference to this figure, with attention given to the township and range numbers noted on the maps, will soon fix in one's memory the significance of these terms of the land surveys.

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a plate of sections. (The division of this report forming its pages 42–56, entitled "History of Lake Agassiz," was reprinted in the Am. Geologist, Vol. VII, March and April, 1891.)

"Artesian wells in North and South Dakota," Am. Geologist, Vol. VI, pp. 211–221, Oct., 1890.

"On the cause of the Glacial period," Am. Geologist, Vol. VI, pp. 327–339 and 396, Dec., 1890.

"A review of the Quaternary era, with special reference to the deposits of flooded rivers," Am. Jour. Sci. (3), Vol. XLI, pp. 33–52, Jan., 1891.

"Glacial lakes in Canada," Bulletin, G. S. A., Vol. II, 1891, pp. 243–276.

"Altitudes between Lake Superior and the Rocky Mountains," Bulletin No. 72, U. S. Geol. Survey, 1891, pp. 229.

"The ice-sheet of Greenland," Am. Geologist, Vol. VIII, pp. 145–152, Sept., 1891.

"Criteria of englacial and subglacial drift," Am. Geologist, Vol. VIII, pp. 376–385, Dec., 1891.

"Inequality of distribution of the englacial drift," Bulletin, G. S. A., Vol. III, 1892, pp. 134–148.

"Relationship of the glacial lakes Warren, Algonquin, Iroquois, and Hudson-Champlain," Bulletin, G. S. A., Vol. III, 1892, pp. 484–487.

"The Champlain submergence," Bulletin, G. S. A., Vol. III, pp. 508–511.

"Conditions of accumulation of drumlins," Am. Geologist, Vol. X, pp. 339–362, Dec., 1892.

"Estimates of geologic time," Am. Jour. Sci. (3), Vol. XLV, pp. 209–220, March, 1893.

"Comparison of Pleistocene and Present ice-sheets," Bulletin, G. S. A., Vol. IV, 1893, pp. 191–204.

"Beltrami Island of Lake Agassiz," Am. Geologist, Vol. XI, pp. 423–425, June, 1893.

"Englacial drift," Am. Geologist, Vol. XII, pp. 36–43, July, 1893.

"Epeirogenic movements associated with glaciation," Am. Jour. Sci. (3), Vol. XLVI, pp. 114–121, Aug., 1893.

"Evidences of the derivation of the kames, eskers, and moraines of the North American ice-sheet chiefly from its englacial drift," Bulletin, G. S. A., Vol. V, 1894, pp. 71–86.

"The succession of Pleistocene formations in the Mississippi and Nelson River basins," Bulletin, G. S. A., Vol. V, 1894, pp. 87–100.

"Wave-like progress of an epeirogenic uplift," Journal of Geology, Vol. II, pp. 383–395, May–June, 1894.

"Causes and conditions of glaciation," Am. Geologist, Vol. XIV, pp. 12–20, July, 1894.

"Tertiary and early Quaternary baseleveling in Minnesota, Manitoba, and northwestward," Am. Geologist, Vol. XIV, pp. 235–246, Oct., 1894. (Abstract in Bulletin, G. S. A., Vol. VI, pp. 17–20, Nov., 1894.)

"Departure of the ice-sheet from the Laurentian lakes," Bulletin, G. S. A., Vol. VI, pp. 21–27, Nov., 1894.

"Quaternary time divisible in three periods, the Lafayette, Glacial, and Recent," Am. Naturalist, Vol. XXVII, pp. 979–988, Dec., 1894.

"Preliminary report of field work during 1893 in northeastern Minnesota, chiefly relating to the glacial drift," in the Twenty-second Annual Report of the Geol. Survey of Minnesota for 1893 (pub. 1894), pp. 18–66, with map and sections.

"Late Glacial or Champlain subsidence and reelevation of the St. Lawrence River basin," Am. Jour. Sci. (3), Vol. XLIX, pp. 1–18, with map, Jan., 1895.

Many changes will be brought by coming years upon the areas thus mapped, in the springing up of new villages, the organization and naming of townships, and the construction of new lines and branches of railways. It is to be hoped, also, that local observers, as teachers in the common schools and in the colleges and universities of Fargo, Grand Forks, Winnipeg, and other cities, will supplement the work herein described and mapped by adding such portions of the lower shore-lines of Lake Agassiz as have not yet been definitely traced. The sections of new artesian wells should likewise be recorded and studied in comparison with the notes of wells here reported.

CHAPTER II.

TOPOGRAPHY OF THE BASIN OF LAKE AGASSIZ.

The area that was covered by Lake Agassiz occupies the geographic center of the North American continent. Its extent is approximately from 45° 30′ to 55° of north latitude, and from 92° 30′, on the international boundary, to 106°, on the Saskatchewan River, of west longitude.

If we consider the contour of the entire continent, it is seen to include on the east and west two mountainous regions and between them a comparatively flat expanse, at the middle of which Lake Agassiz lay. The eastern mountainous tract stretches from Labrador southwestward to Alabama, culminating in the Laurentide highlands north of the River St. Lawrence, the White Mountains and the Adirondacks, the Green Mountains and the Catskills, and the parallel Appalachian ranges farther southwest. The summits of this mountain belt vary in elevation from a half mile to one mile and slightly more above the sea-level. On the west, a longer and wider region of mountains, including generally three or four lofty parallel ranges, extends from the northern and southern coasts of Alaska southeasterly and southerly through the Canadian Northwest Territory, British Columbia, the western third of the United States, Mexico, and Central America, to the Isthmus of Panama; and beyond this it continues south in the great Andes range along the entire western coast of South America to Cape Horn. In the United States this Cordilleran mountain belt includes the Rocky Mountains and the Sierra Nevada and Coast ranges, and its highest summits are nearly 3 miles above the sea.

Lake Agassiz, situated on the central expanse between these mountainous regions, was a fifth of a mile above the present sea-level. Where the slow northward ascent from the Gulf of Mexico ceases at a distance of 1,100 miles from the Gulf and an elevation of about 1,100 feet, and is succeeded farther north by a descending slope toward Hudson Bay, the barrier of the receding ice-sheet caused this glacial lake to fill the Red River Valley and to reach northward, as the ice front retreated, over the region of Lakes Winnipeg, Manitoba, and Winnipegosis, until the continued melting of the ice at last permitted it to be drained by the natural slope of the land to the northeast, excepting its remnants, which form these lakes of Manitoba.

OUTLET, BED, AND SHORES OF LAKE AGASSIZ.

RIVER WARREN.

The lowest point of the watershed dividing the great areas that are drained respectively to Hudson Bay and the Gulf of Mexico is between Lakes Traverse and Big Stone, on the boundary line of Minnesota and South Dakota. Its elevation above the ocean is 975 feet. Here an ancient watercourse, called Browns Valley (see the frontispiece and Pl. IV), which was occupied by the River Warren, outflowing from Lake Agassiz, is eroded in the thick sheet of glacial drift to a depth of 100 to 125 feet, with a width of about 1½ miles. The tops of its inclosing bluffs and the general level of the adjoining country of undulating or moderately rolling till are about 1,100 feet above the sea. Portions of this channel contain the long and narrow Lakes Traverse and Big Stone, the former outflowing by the Bois des Sioux River and the Red River of the North to Lake Winnipeg and Hudson Bay, and the latter by the Minnesota River to the Mississippi. But this channel shows that subsequent to the deposition of the drift a great river has flowed here across what is now one of the principal watersheds of the continent.

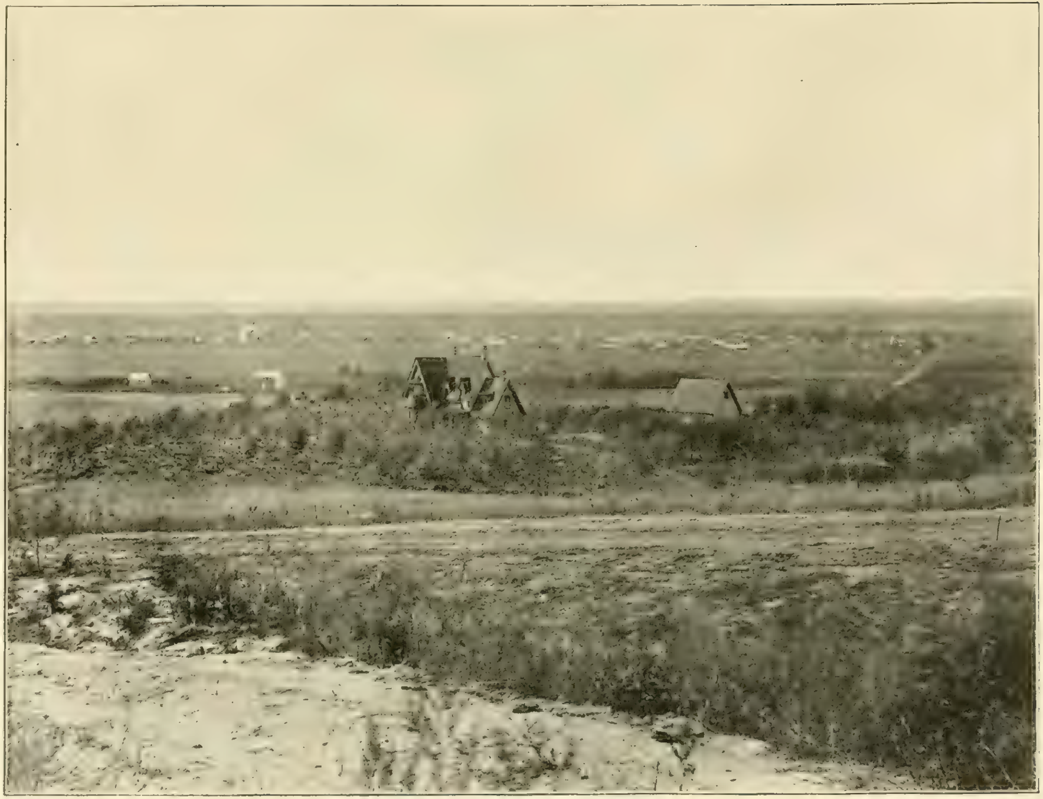
The head stream of the Minnesota[1] River, from which the State of Minnesota receives its name, after flowing eastward about 20 miles from its sources on the Coteau des Prairies, turns southerly at Browns Valley and enters the northwest end of Big Stone Lake. Here, and in its whole extent thence to its mouth, the Minnesota River occupies the channel of the glacial River Warren. This valley or channel begins at the northern

[1]The aboriginal Dakota name, meaning "water nearly clear, but slightly clouded," or, poetically translated, "sky-tinted water." (A. W. Williamson, in Thirteenth Annual Report, Geol. and Nat. Hist. Survey of Minn., for 1884, p. 109. E. D. Neill, History of Minnesota, 1858, p. xlvii. Nicollet's Report, 1843, p. 69.)

part of Lake Traverse, and first extends southwest to the head of this lake, thence southeast to Mankato, and next north and northeast to the Mississippi at Fort Snelling, its length being about 250 miles. Its width varies from 1 to 4 miles, and its depth is from 100 to 225 feet. The country through which it lies, as far as Carver, about 25 miles above its junction with the Mississippi, is a nearly level expanse of till, only moderately undulating, with no prominent hills or notable depressions, excepting this deep channel and those formed by its tributary streams. Below Carver it intersects a belt of terminal moraine, composed of hilly till. Its entire course is through a region of unmodified drift, which has no exposures of solid rock upon its surface.

Bluffs in slopes from 20 to 40 degrees, and rising 100 to 200 feet to the general level of the country, form the sides of this trough-like valley. They have been produced by the washing away of their base, leaving the upper portion to fall down and thus take its steep slopes. The river in deepening its channel has been constantly changing its course, so that its current has been turned alternately against the opposite sides of its valley, at some time undermining every portion of them. In a few places this process is still going forward, but mainly the course of the Minnesota River is in the bottom-land. Comparatively little excavation has been done by the present river. As we approach its source it dwindles to a small stream flowing through long lakes, and we finally pass to Lake Traverse, which empties northward; yet along the upper Minnesota and at the divide between this and the Red River this valley or channel and its inclosing bluffs are as remarkable as along the lower part of the Minnesota River. It is thus clearly shown to have been the channel of outflow from a lake formerly extending northward from Lake Traverse.

The Minnesota Valley in many places cuts through the sheet of drift and reaches the underlying rocks, which have frequent exposures along its entire course below Big Stone Lake. This excavation shows that the thickness of the general drift sheet upon this part of Minnesota averages about 150 feet. The contour of the old rocks thus brought into view is much more uneven than that of the drift. In the hundred miles from Big Stone Lake to Fort Ridgely the strata are Archean gneisses and granites,



TOWN OF BROWNS VALLEY, MINNESOTA.

Looking west, over the channel of the river Warren, to the Coteau des Prairies, at a distance of 20 to 25 miles.

which often fill the entire valley, 1 to 2 miles wide, rising in a profusion of knolls and hills 50 to 100 feet above the river. The depth eroded has been limited here by the presence of these rocks, among which the river flows in a winding course, crossing them at many places in rapids or falls.

From New Ulm to its mouth the river is at many places bordered by Cretaceous and Lower Silurian and Cambrian rocks, which are nearly level in stratification. These vary in height from a few feet to 50 or rarely 75 or 100 feet above the river. From Mankato to Ottawa the river occupies a valley cut in Shakopee limestone underlain by Jordan sandstone, which form frequent bluffs upon both sides, 50 to 75 feet high. After excavating the overlying 125 to 150 feet of till, the river here found a former valley eroded by preglacial streams. Its bordering walls of rock, varying from one-fourth of a mile to at least 2 miles apart, are in many portions of this distance concealed by drift, which alone forms one or both sides of the valley. The next point at which the river is seen to be inclosed by rock walls is in its last 2 miles, where it flows between bluffs of Trenton limestone underlain by St. Peter sandstone, 100 feet high and about a mile apart. This also is a preglacial channel, its further continuation being occupied by the Mississippi River. The only erosion effected here by the Minnesota River has been to clear away a part of the drift with which the valley was filled. Its depth at some earlier time was much greater than now, as shown by the salt well on the bottom-land of the Minnesota at Belle Plaine, where 202 feet of stratified gravel, sand, and clay were penetrated before reaching the rock.[1] The bottom of the preglacial channel there is thus at least 165 feet lower than the mouth of the Minnesota River.

The height of Lake Traverse,[2] in the range between its lowest and highest stages, is 970 to 976 feet above the sea; the lowest point in Browns Valley between this and Big Stone Lake is only 3 feet above the ordinary stage of Lake Traverse; Big Stone Lake[3] ranges from 962 to 967 feet

[1] Geology of Min., Vol. II, p. 151.

[2] A translation of the Dakota name (Williamson, l. c., p. 108). "The lake has received its present appellation from the circumstance that it is in a direction nearly transverse to that of the Big Stone and Qui Parle lakes." Keating's Narrative, Vol. II, p. 2.

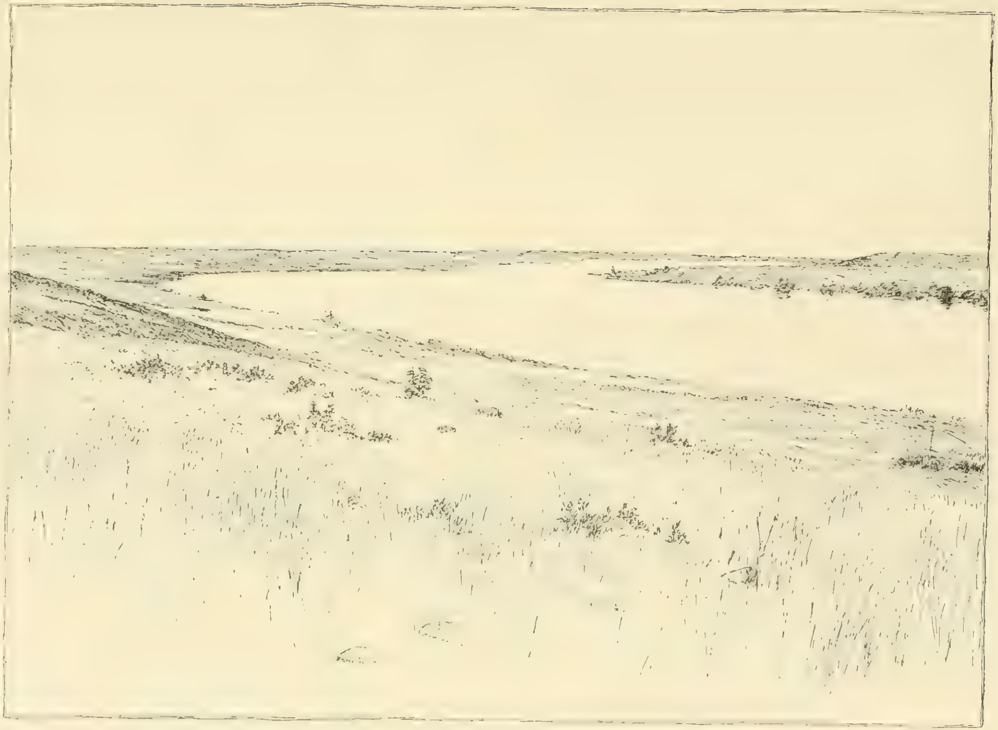
[3] Translated from the Dakota (Williamson, l. c., p. 105). The name probably alludes to the conspicuous outcrops of granite found in the Minnesota Valley 1 to 3 miles below the foot of the lake.

above the sea, its ordinary stage being about 8 feet below that of Lake Traverse; and the mouth of the Minnesota River at extreme low water is 688 feet above the sea, the descent from Big Stone Lake to the mouth of the river being 274 feet.

Lakes Traverse and Big Stone are from 1 to 1½ miles wide, mainly occupying the entire area between the bases of the bluffs, which rise about 125 feet above them. Lake Traverse (Pl. V) is 15 miles long; it is mostly less than 10 feet deep, and its greatest depth probably does not reach 20 feet. Big Stone Lake is 26 miles long, and its greatest depth is reported to be from 15 to 30 feet. The portion of the channel between these lakes is widely known as Browns Valley. As we stand upon the bluffs here, looking down on these long and narrow lakes in their trough-like valley, which extends across the 5 miles between them, where the basins of Hudson Bay and the Gulf of Mexico are now divided, we have nearly the scene which was presented when the melting ice-sheet of British America was pouring its floods along this hollow. Then the entire extent of the valley was doubtless filled every summer by a river which covered all the present areas of flood plain, in many places occupying as great width as these lakes.

General Warren observed that Lake Traverse is due to partial silting up of the channel since the outflow from the Red River basin ceased, the Minnesota River at the south having brought in sufficient alluvium to form a dam; while Big Stone Lake is similarly referred to the sediment brought into the valley just below it by the Whetstone River. Fifteen miles below Big Stone Lake the Minnesota River flows through a marshy lake 4 miles long and about a mile wide. This may be due to the accumulation of alluvium brought into the valley by the Pomme de Terre River, which has its mouth about 2 miles below. Twenty-five miles from Big Stone Lake the river enters Lac qui Parle,[1] which extends 8 miles, with a width varying from one-fourth to three-fourths of a mile and a maximum depth of 12 feet. This lake, as General Warren suggested, has been formed by a barrier of stratified sand and silt which the Lac qui Parle River has

[1] The French translation of the Dakota name, which is of uncertain origin (Williamson, l. c., p. 106).



LAKE TRAVERSE.

Looking northeast from the top of its western bluff about 2 miles northwest of Browns Valley.

thrown across the valley. He also showed that Lake Pepin, on the Mississippi, is dammed in the same way by the sediment of the Chippewa River; and that Lake St. Croix and the last 30 miles of the Minnesota River are similarly held as level backwater by the recent deposits of the Mississippi.

The valleys of the Pomme de Terre and Chippewa rivers, 75 to 100 feet deep along most of their course and one-fourth of a mile to 1 mile in width, were probably avenues of drainage from the melting ice fields in their northward retreat. Between these rivers, in the 22 miles from Appleton to Montevideo, the glacial floods at first flowed in several channels, which are excavated 40 to 80 feet below the general level of the drift sheet, and vary from an eighth to a half of a mile in width. One of these, starting from the bend of the Pomme de Terre River, 1½ miles east of Appleton, extends 15 miles southeast to the Chippewa River, near the center of Tunsburg. This old channel is joined at Milan station by another, which branches off from the Minnesota Valley, running 4 miles east-southeast; it is also joined at the northwest corner of Tunsburg by a very notable channel which extends eastward from the middle of Lac qui Parle. The latter channel, and its continuation in the old Pomme de Terre Valley to the Chippewa River, are excavated nearly as deep as the channel occupied by the Minnesota River. Its west portion holds a marsh generally known as the "Big Slough." Lac qui Parle would have to be raised only a few feet to turn it through this deserted valley. The only other localities where we have proof that the floods of the River Warren at first ran in several channels are 7 and 10 miles below Big Stone Lake, where isolated remnants of the general sheet of till occur south of Odessa station and again 3 miles southeast. Each of these former islands is about a mile long, and rises 75 feet above the surrounding lowland, or nearly as high as the bluffs inclosing the valley, which here measures 4 miles across, having a greater width than at any other point.

THE RED RIVER VALLEY.

Proceeding northward to the area of Lake Agassiz, whose outflow formed this channel, the observer finds that the broad watercourse, with its bluffs and the adjoining highland on each side, ends a few miles north of Lake Traverse. There the country sinks gradually to a level not much above the small Bois des Sioux River, which is the outlet of Lake Traverse, flowing north 35 miles and emptying into the Red River of the North at Breckenridge and Wahpeton. The Red River, here turning abruptly from its western course, flows thence north to Lake Winnipeg, 285 miles. These streams occupy the axial depression of a vast plain of glacial drift and lacustrine and fluvial deposits, 40 to 50 miles wide and more than 300 miles long, stretching from Lake Traverse to Lake Winnipeg. This expanse, widely famed for the large harvests and superior quality of its wheat, is commonly called the Red River Valley. It has a very uniform continuous descent northward, averaging a little less than 1 foot per mile. So slight an inclination is imperceptible to the eye, as is also the more considerable ascent, usually 2 or 3 feet per mile, for the first 10 or 15 miles to the east and west from the Red River. This river flows along the lowest portion of the plain, somewhat east of its central line, in a quite direct general course from south to north, but meanders almost everywhere with minor bends, which carry it alternately a half mile to 1 mile or more to each side of its main course. Thus its length from Breckenridge and Wahpeton to St. Vincent and Pembina, forming the boundary between Minnesota and North Dakota, is 397 miles, according to the surveys of the United States Engineer Corps, while the distance in a direct line is only 186 miles; yet the river nowhere deviates more than 5 or 6 miles from this straight line.

The Red River has cut a channel 20 to 50 feet deep. It is bordered by only few and narrow areas of bottom-land, instead of which its banks usually rise steeply on one side and by moderate slopes on the other to the lacustrine plain, which thence reaches nearly level 10 to 30 miles from the river. Its tributaries cross the plain in similar channels, which, as also the Red River, have occasional gullies connected with them, dry through the most of the year, varying from a few hundred feet to a mile or more in length. Between the drainage lines areas often 5 to 15 miles wide remain unmarked by any water courses. The highest portions of these tracts are commonly from 2 to 5 feet above the lowest. The material of the lower part of this valley plain, shown in the banks of the Red River and reaching several miles from it (excepting a morainic belt of till crossing the river at Goose Rapids), is fine clayey silt, horizontally stratified; but the south end and large areas of each side of the plain are mainly unstratified bowlder-clay, which differs from the rolling or undulating till of the adjoining region chiefly in having its surface nearly flat. Both these formations are almost impervious to water, which therefore in the rainy season fills their shallow depressions; but these are very rarely so deep as to form permanent lakes. Even sloughs that continue marshy through the summer are infrequent, but, where they do occur, cover large tracts, usually several miles in extent.

In crossing the vast plain of the Red River Valley on clear days the higher land at its sides and the groves along its rivers are first seen in the distance as if their upper edges were raised a little above the horizon, with a very narrow strip of sky below. The first appearance of the tree tops thus somewhat resembles that of dense flocks of birds flying very low several miles away. By rising a few feet, as from the ground to a wagon, or by nearer approach, the outlines become clearly defined as a grove, with a mere line of sky beneath it. This mirage is more or less observable on the valley plain nearly every sunshiny day of the spring, summer, and autumn months, especially during the forenoon, when the lowest stratum of the air, touching the surface of the ground, becomes heated sooner than the strata above it.

A more complex and astonishing effect of mirage is often seen from the somewhat higher land that forms the slopes on either side of the plain. There, in looking across the flat valley a half hour to two hours after sunrise of a hot day following a cool night, the groves and houses, villages and grain elevators, loom up to twice or thrice their true height, and places ordinarily hidden from sight by the earth's curvature are brought into view. Occasionally, too, these objects, as trees and houses, are seen double, being repeated in an inverted position close above their real places, from which they are separated by a very narrow, fog-like belt. In its most perfect development the mirage shows the upper and topsy-turvy portion of the view quite as distinctly as the lower and true portion; and the two are separated, when seen from land about a hundred feet above the plain, by an apparent vertical distance of 75 or 100 feet for objects at a distance of 6 or 8 miles, and 300 to 500 feet if the view is 15 to 20 miles away. Immediately above the inverted images there runs a level false horizon, which rises slightly as the view grows less distinct, until, as it fades and vanishes, the inverted groves, lone trees, church spires, elevators, and houses at last resemble rags and tatters hung along a taut line.

The traveler in the Red River Valley is reminded, in the same manner as at sea, that the earth is round. The surface of the plain is seen only for a distance of 3 or 4 miles; houses and grain stacks have their tops visible first, after which, in approaching, they gradually come into full view; and the highlands, 10 or 15 miles away, forming the side of the valley, apparently lie beyond a wide depression, like a distant high coast.

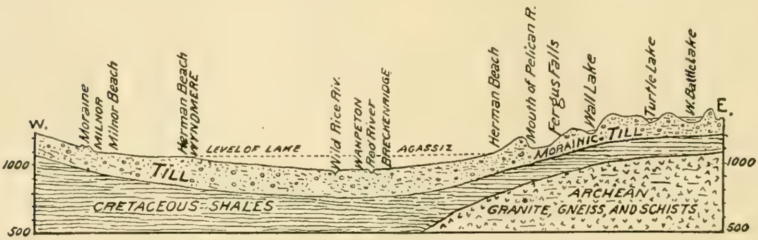


FIG. 2.—Section across the Red River Valley on the latitude of Breckenridge and Wahpeton. Horizontal scale, 20 miles to an inch; vertical scale, 1,000 feet to an inch.

At Breckenridge and Wahpeton, 35 miles north of Lake Traverse, the surface of this plain is 960 feet above the sea (fig. 2). In 17 miles east it ascends to 1,080 feet at the highest beach of Lake Agassiz; and on the west it rises in 28 miles to 1,065 feet at the corresponding beach near Wyndmere, beyond which for 8 miles farther west it maintains a level 2 to 5 feet below the crest of that beach.

At Moorhead and Fargo, 75 miles north of Lake Traverse, the surface adjoining the Red River is 900 to 905 feet above the sea (fig. 3). In the first 15 miles east it ascends about 60 feet. The highest beach of Lake Agassiz here lies at Muskoda, 17 miles east of the Red River, on the slope of a highland of till, which rises in a distance of 6 or 8 miles to an elevation of 250 feet above the flat Red River Valley, having thus an average ascent of 30 or 40 feet per mile. On the west the plain ascends only 50 feet in the first 25 miles, beyond which it ascends within 7 miles to 1,099 feet above the sea-level at the highest beach line, 4½ miles west of Wheatland, and a similar slope continues to a height of 1,200 feet at a distance of 4 or 5 miles farther west.

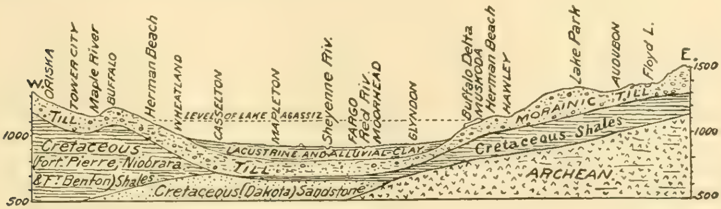


Fig. 3.—Section across the Red River Valley on the latitude of Moorhead and Fargo. Horizontal scale, 20 miles to an inch; vertical scale, 1,000 feet to an inch.

At Grand Forks, where the Red Lake River joins the Red River, 150 miles north of Lake Traverse, the surface of the plain is 830 feet above the sea (fig. 4). In the first 20 miles east the ascent is about 75 feet. Thence in 25 miles southeast there is a gradual rise of nearly 300 feet to the

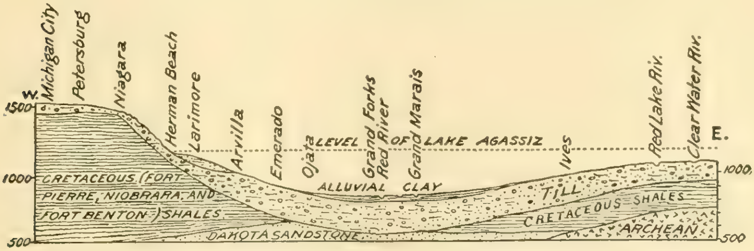


Fig. 4.—Section across the Red River Valley from Larimore and Grand Forks to Maple Lake. Horizontal scale, 20 miles to an inch; vertical scale, 1,000 feet to an inch.

highest beach of Lake Agassiz, close west and north of Maple Lake; but in a line passing due east the surface ascends only about 200 feet in an equal distance, and continues at a lower elevation than this beach to the east side of Red Lake, 100 miles from Grand Forks. On the west the surface rises only 35 feet in the first 14 miles, beyond which it rises about

300 feet in the next 19 miles to 1,162 feet above sea-level at the highest beach of Lake Agassiz, 4½ miles west of Larimore. The westward ascent continues to 1,525 feet above the sea 12 miles west of this beach.

At St. Vincent and Pembina, near the international boundary, which is 224 miles north of Lake Traverse, the surface of the plain is 785 to 790 feet above the sea (fig. 5). Eastward on the boundary it is nearly level, rising only a few feet in the first 10 miles. Thence an ascent of about 50 feet is made in 2 miles to the crest of a slight ridge. Farther east the country is wooded, and many extensive tracts are tamarack swamps. The Lake of the Woods, about 85 miles east from the Red River, is 1,060 feet above the sea; and the highest land near the international boundary west of this lake is approximately 1,090 feet. Continuing eastward along the

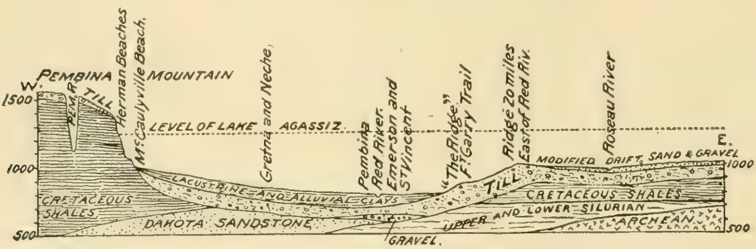


FIG. 5.—Section across the Red River Valley on the international boundary. Horizontal scale, 20 miles to an inch; vertical scale, 1,000 feet to an inch.

boundary, which here is formed by the Rainy River and Rainy Lake, the elevation of the highest beach of Lake Agassiz is reached a short distance east from the east end of Rainy Lake, more than 200 miles from the Red River. Westward the surface rises about 40 feet in 15 miles from Pembina to Neche, and 187 feet in the next 21 miles along the international boundary to the base of the great Cretaceous escarpment called Pembina Mountain, which, within 2 miles farther west, ascends nearly 400 feet to an elevation approximately 1,400 feet above the sea.

These sections give a good idea of the average width and elevation of the flat plain to which the name Red River Valley seems to be properly limited, both by topographic features and by the common usage of this term. At a distance of 35 miles north of Lake Traverse its width is about

45 miles, and its limits on each side are a slightly higher area of more rolling contour. On the latitude of Moorhead and Fargo its width is about 40 miles, and it is bordered by prominent highlands which rise 200 to 300 feet above this broad valley. On the latitude of Grand Forks its width is nearly 50 miles, and it is bordered on the east by land that rises slowly 200 to 300 feet above the plain, while on the west the surface rises by moderate slopes to a height of 600 to 700 feet. Where it is crossed by the international boundary the width of this plain is 48 miles, its limit on the east being a slightly higher and more undulating wooded region, while on the west it is a conspicuous terrace-like ascent of several hundred feet. On the average, for its extent within the United States, about one-third of the width of the Red River Valley is in Minnesota and two-thirds in North Dakota.

The northward slope of the lowest part of the Red River Valley, along the course of the Bois des Sioux and Red rivers, from Lake Traverse, 970 feet, to Lake Winnipeg, 710 feet above the sea, may thus be said to be 260 feet in a distance of 320 miles, averaging about 10 inches per mile. The valley proper, however, does not take on its distinctive character in the first 10 or 15 miles of the course of the Bois des Sioux River, but 10 miles farther east in Minnesota the same topographic features that mark the Red River Valley continue south nearly to the latitude of the southwest end of Lake Traverse. The elevation of this southern extremity of the area of Lake Agassiz is 1,050 feet above the sea, being 90 feet above the surface at Breckenridge and Wahpeton, 43 miles distant to the north, so that this part of the valley plain has a northward descent of 2 feet per mile. Thence to Moorhead and Fargo the descent is $1\frac{1}{2}$ feet per mile; next, for 75 miles to Grand Forks, it averages almost exactly 1 foot per mile; and in the 74 miles from Grand Forks to the international boundary this axial lowest portion of the valley falls about 40 feet, or a little more than 6 inches per mile. In the 60 miles thence to Winnipeg the descent is about 35 feet, or 7 inches per mile, the surface there being 45 feet above Lake Winnipeg, about 35 miles distant.

SHORE-LINES.

Considered in relation to the general topography, the shore-lines of Lake Agassiz are inconspicuous, though they are very distinctly traceable. They are usually marked by a beach deposit of gravel and sand, forming a continuous, smoothly rounded ridge, such as is found along the shores of the ocean or of our great Laurentian lakes wherever the land sinks in a gently descending slope beneath the water level. The beach ridges of Lake Agassiz (fig. 6) commonly rise 3 to 10 feet above the adjoining land

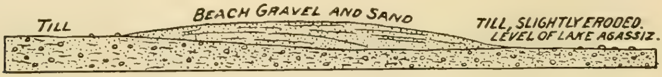


FIG. 6.—Typical section across a beach ridge of Lake Agassiz. Scale, 100 feet to an inch.

on the side that was away from the lake, and 10 to 20 feet above the adjoining land on the side where the lake lay. In breadth these ridges vary from 10 to 25 or 30 rods. In some places they have been cut through and carried away by streams, and occasionally they are interrupted for a quarter or a half mile, or even 2 or 3 miles, where the outline of the lake shore and the direction of the shore currents prevented such accumulation. Throughout almost the whole extent of Lake Agassiz examined within the United States the regular outlines of the surface, its gentle slope toward this lake, and its material, which nearly everywhere is till, were very favorable for the formation of beach deposits. Many beach ridges, record-

FIG. 7.—Eroded terrace marking the shore of Lake Agassiz. Scale, 100 feet to an inch.

ing the successive reductions in the elevation and area of this lake, have been traced in continuous, approximately parallel courses along each side of the Red River Valley. Pl. VI shows an exceptionally massive beach ridge marking the highest shore-line of Lake Agassiz close northwest of Maple Lake, about 20 miles east-southeast from Crookston, Minn.

Another type of shore-lines is presented where the lake has formed a terrace in the till (fig. 7), with no definite beach deposit, the work of the waves having been to erode and carry away rather than to accumulate. The

UPPER HERMAN BEACH OF LAKE AGASSIZ.

Looking northeastward from the south line of the SE ¼ of sec. 35, Tilden, Minn., near Maple Lake

height of these steep, wave-cut slopes varies from 10 to 30 feet, which is indeed a very slight elevation in comparison with the cliffs of similar origin on some portions of the shores of Lake Michigan and others of the Laurentian lakes. No portions of the beach ridges, nor of these low, eroded escarpments marking the margin of Lake Agassiz, are noteworthy objects in the view from points so far away as 2 or 3 miles, but nearer at hand they appear sufficiently impressive when the mind reverts to the receding ice-sheet and this great glacial lake by which they were made.

DELTAS.

Sand and gravel deltas, so extensive as to be important features in the topography, were formed in the edge of Lake Agassiz during its earliest and highest stage by several of its tributary streams. Such deltas were brought into the east side of the lake by the Buffalo and Sand Hill rivers, and into the west side by the Sheyenne, Pembina, and Assiniboine rivers. They all consist for the greater part of modified drift, derived directly from the ice-sheet in which it had been held; and another delta of this lake, extending south from the Elk Valley, in North Dakota, was deposited by a large glacial river, flowing where no river exists now.

The delta of the Buffalo River is well seen from the Northern Pacific Railroad, on which the traveler going westward enters the delta area at Muskoda and passes through it in the next 2½ miles. Its eastern border bears a massive beach ridge, 15 feet thick, of coarse gravel and sand, which marks the highest level of the lake; but the chief mass of the delta, attaining a thickness of 25 to 75 feet, is stratified sand, with occasional layers of fine gravel, as exhibited in the railroad cuts.

The Pembina River intersects the highest part of its delta, which rises 200 to 250 feet above the stream. Its eroded eastern border, carved in a steep escarpment by the waves of Lake Agassiz while this lake fell to successive lower stages, forms the "First Pembina Mountain," passing from south to north and northwest by Walhalla as a very conspicuous wooded bluff 100 to 175 feet above the flat prairie of the Red River Valley at its base, with its crest 1,100 feet to nearly 1,200 feet above the sea.

DUNES.

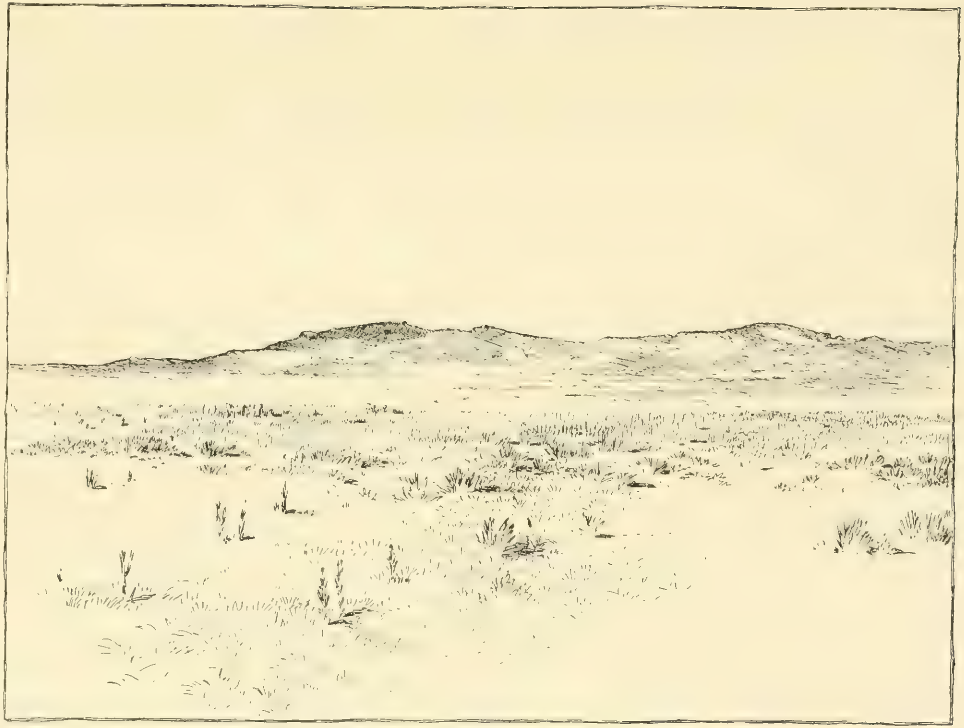
Large tracts of the deltas formed by the Sand Hill, Sheyenne, and Assiniboine rivers have been heaped up by the wind in dunes or drifting sand hills, which vary in height from 25 to 100 feet. Their extremely uneven contour, and their singular aspect, being partly covered by small trees and bushes, but in many places wholly destitute of vegetation where they are now gullied and drifted by the wind, make these hills a unique element in the topography of the Red River basin. The worthlessness of the dunes for agriculture is also in marked contrast with the great fertility of the surrounding prairie, but they frequently include patches of good pasturage in the intervening hollows.

On the delta of the Sand Hill River, dunes 25 to 75 feet high have been formed in irregular groups and series, scattered over a tract about a mile wide and extending 3 or 4 miles south from the Sand Hill River, besides a single isolated group on its north side. Their highest points are 1,180 to 1,200 feet above the sea.

Portions of the originally flat sand and gravel beds brought into Lake Agassiz by the Sheyenne have been blown into dunes, which vary from a few feet to more than a hundred feet in height, and cover areas 5 to 15 miles long and 1 to 3 miles wide. Their summits are 1,100 to 1,150 feet above the sea. The most southeastern of these large areas of conspicuous sand hills of the Sheyenne delta lies close south of the Wild Rice River, and is continued southeastward several miles by a lower belt of such hillocks to a high isolated cluster of them called the "Lightning's Nest" (Pl. VII).

In Manitoba, wind-blown sand hills border the Assiniboine River in many places along a distance of 60 miles, from near Brandon to near Portage la Prairie, lying on the very extensive Assiniboine delta.

The time of formation of the dunes on all these deltas was probably soon after the withdrawal of Lake Agassiz, before vegetation had spread over the surface. The winds could then erode more rapidly than now, and heaped up these hills of sand in nearly their present size and height; but it is evident also that their forms have been constantly undergoing slight changes since that time.



"THE LIGHTNINGS NEST" (DUNES OF THE SHEYENNE DELTA).

Looking east from a distance of about a half mile

WOODED REGION OF NORTHERN MINNESOTA AND OF MANITOBA AND KEEWATIN, PARTLY COVERED BY THIS LAKE.

East from the flat prairie of the Red River Valley is the undulating and in part rolling and hilly wooded region of northern Minnesota and eastern Manitoba. This is a difficult district for exploration, as the greater part of it has neither settlement nor roads, excepting those of the scanty population of Ojibway Indians, who maintain themselves chiefly by hunting and fishing and live in nearly the same manner as when Beltrami crossed this country from the Red River Valley to the Upper Mississippi River seventy years ago. Their abodes are usually on the shores of lakes and streams, which they navigate in birch-bark canoes; and this is the only practicable means of travel for geologic exploration. Considerable tracts, especially west of the Lake of the Woods and south to Red Lake, are tamarack swamps, morasses, and quaking bogs, called "muskegs," which extend many miles and can be crossed only when they are frozen in winter. Northwest of Red Lake a large area, described and named Beltrami Island in Chapter VI, rises to a maximum height of about 100 feet above the highest level of Lake Agassiz. Eastward from Beltrami Island a large tract between Red Lake and the Rainy River, reaching to the Big and Little Forks, lies 50 to 150 feet below the highest stage of Lake Agassiz; but the northeastern part of this area may have been still covered by the waning ice-sheet when the lake stood at that height. On account of the impracticability of tracing the shores of Lake Agassiz through this wooded and uninhabited region, the northeastern limits of this glacial lake, where the shore in its successive stages passed from the land surface to the barrier of the receding ice-sheet, remain undetermined.

The part of Keewatin north and northeast of Lake Winnipeg presents no considerable elevations, but is mainly a broad, nearly flat expanse, similar to the Red River Valley and the lake district of Manitoba, slowly declining to the sea-level. Dr. Robert Bell writes of it as follows:

> The region through which the upper two-thirds of the Nelson River flows may be described as a tolerably even Laurentian plain, sloping toward the sea at the rate of about 2 feet in the mile. The river, for the first hundred miles from Great Playgreen Lake, does not flow in a valley, but spreads itself by many channels over a consider-

able breadth of country. This tendency to give off "stray" channels is characteristic of numerous rivers throughout the northern and comparatively level Laurentian regions, but it is perhaps more strongly marked in the Nelson than in any other. In the above section of this stream the straggling channels are of all sizes, from mere brooks up to large rivers. * * * The general aspect of the country * * * is even or slightly undulating, the highest points seldom rising more than 30 or 40 feet above the general level.

The country adjoining the lower part of this river, according to the same explorer, has a similar contour, only moderately uneven; but the channel of the river, excepting in the 10 miles next to its mouth, is deeply eroded. Its inclosing bluffs vary in height from 100 to 200 feet between Broad Rapid, where the river is approximately 125 feet above the sea, and Gillams or Lower Seal Island, which is at the head of the tide, about 20 miles from Hudson Bay.[1]

COUNTRY BORDERING LAKE AGASSIZ ON THE EAST.

Northern Minnesota, from Maple, Red, and Rainy lakes east to the high northwestern shore of Lake Superior and south to Mille Lacs and the Leaf Hills, varies in its average height from the highest level of Lake Agassiz to 600 feet above it, or from 1,200 to 1,800 feet above the sea. It is mostly a moderately rolling or hilly country, abounding with little lakes which fill its depressions. The watershed dividing the basin of Lake Agassiz from the basins of Lake Superior and the Mississippi culminates northeastward in the Giants Range and the Mesabi Range, and southwestward in the Leaf Hills. These ranges of hills rise several hundred feet above the average height of the district. Excepting its western border from near Maple Lake southward, where it is in large part prairie like the adjacent Red River Valley, this district is covered with an almost unbroken forest. Toward the east it forms a plateau, in part hilly and mountainous and in part only moderately undulating or nearly flat, everywhere well wooded and dotted with frequent small lakes, bordering the entire northern shore of Lake Superior, above which it rises 600 to 1,000 feet; and thence a downward slope, characterized by the same general features, stretches west

[1] Geol. Survey of Canada, Reports of Progress for 1877 to 1879.

and north with gradually declining surface to Lake Winnipeg and Hudson Bay. The highest point of this plateau on the line of the Canadian Pacific Railway is 1,584 feet above the sea, or 982 and 874 feet, respectively, above Lakes Superior and Winnipeg.

Giants Range.—The Giants Range extends in a west-southwest course from north of Gunflint Lake, on the international boundary, to the lakes on the Embarras River, about 15 miles south of Vermilion Lake, and its mostly lower continuation, forming the northern border of the Mesabi iron-bearing belt, appears to reach to the falls of Prairie River and Pokegama Falls, on the Mississippi. Southeast and south of Vermilion Lake, where it has been called the Mesabi Range, Prof. N. H. Winchell describes it as "a distinct, narrow ridge, rising about 200 feet above the average level on either side. It is intersected at several places by streams." Its elevation there is mainly about 1,800 feet above the sea, but eastward it rises to nearly 2,200 feet.

Mesabi Range.—Professor Winchell restricts the title "Mesabi Range" to a more prominent and persistent belt of highland 5 to 15 miles south of the foregoing, with which it is approximately parallel. The eastern and highest part of its extent is commonly known by this name. "It is, however, broad as well as high, and holds on its summit some of the largest lakes of this part of the State, Brulé Lake being one. It is characterized by bare rock, alternating with peat bogs and muskegs, with scattered and stunted spruces. * * * Its width is sometimes 15 miles, but generally from 4 to 6; and in most places, especially north from Grand Marais and south from Ogishkie Muncie Lake, its rounded low crest is distinct and narrowed to less than a mile."[1] The summits of the Mesabi Range and of outlying hills near are 1,800 to 2,230 feet above the sea, including the highest points of land in Minnesota. The latter elevation is that of hills adjoining the south side of Winchell Lake, as determined by leveling for the Minnesota Geological Survey. Near the international boundary the Mesabi Range extends from south of Gunflint Lake eastward to South and North lakes and the south side of Mountain Lake.

[1] Geol. and Nat. Hist. Survey of Minnesota, Thirteenth Annual Report, for 1884, p. 22.

These ranges of hills cross the international boundary respectively about 90 and 120 miles east of Rainy Lake, which, as before stated, was the extreme eastern arm of the glacial Lake Agassiz at its highest stage, unless that area was still ice-covered; and their western portions are respectively 65 and 75 miles south-southeast of the east end of Rainy Lake. They coincide nearly with the line of watershed dividing the basin of Rainy Lake and River from that of Lake Superior; but this watershed takes a less direct course, winding its way circuitously over this generally uneven and hilly region. On the international boundary the belt between the Giants and Mesabi ranges is drained partly through the former to Rainy Lake and partly through the latter to Lake Superior; and the Embarras River, which sends its waters to the St. Louis River and Lake Superior, has its source north of the northern range.

About Vermilion Lake and the upper Embarras River the average height of the country is 1,500 to 1,600 feet. Thence the surface falls slowly westward to the vicinity of Pokegama Falls, Lake Winnebagoshish, and Leech and Cass lakes, where the mean elevation is from 1,300 to 1,400 feet. Still farther west it rises to 1,500 and 1,600 feet about Lake Itasca and the White Earth Agency. The hills of these areas consist of morainic accumulations of glacial drift, and are not so high and massive as the Giants and Mesabi ranges, which, near the international boundary and west to the Embarras River, are mostly projecting knobs and ridges of the bed-rock.

Mesabi and Itasca moraines.—Drift hills and short ridges, having heights from 50 to 200 feet or more, extend in an approximately east to west belt, to which I have applied the name Mesabi moraine, from the lakes of the Embarras River to Deer and Bowstring lakes and the northeast side of Lake Winnebagoshish. Its continuation northwestward probably passes to the prominent terminal moraine, 100 to 200 feet high, between the north and south portions of Red Lake, east of the Narrows. Eastward from the Embarras River, this morainic belt coincides in part with the Giants and Mesabi ranges for a considerable distance, so that the elevations of rock forming those heights are overspread and sometimes concealed by morainic drift deposits; but it appears to pass finally south of those ranges and to reach the north shore of Lake Superior in the vicinity of Grand Portage.

An approximately parallel morainic belt, 12 to 25 miles distant to the south and west, lies on the south side of Pokegama and Leech lakes and reaches west to Itasca Lake, where it bends to a northerly course. Its very irregular hills and ridges rise 50 to 250 feet above the adjoining lakes and streams. This belt, especially prominent at the head of the Mississippi River, I have called the Itasca moraine.[1]

Leaf Hills.—From Itasca Lake and the White Earth Agency the surface gradually falls southward to Detroit, 1,364 feet above the sea. Thence a mean elevation of 1,350 to 1,400 feet extends south through Ottertail and Douglas counties along the low plateau that forms the height of land between the Red and Mississippi rivers, east of the south part of Lake Agassiz. Upon this area, in southern Ottertail County, are the Leaf Hills, whose highest portions rise 100 to 350 feet above the general level, or 1,500 to 1,750 feet above the sea, being the most prominent morainic accumulations found within the State of Minnesota. They reach in a semicircle from Fergus Falls southeast to the south line of the county, and thence east and northeast to East Leaf Lake, a total distance of 50 miles. In the first 20 miles, or from Fergus Falls to the north side of Lake Christina, at the northwest corner of Douglas County, these morainic deposits are divided into two or three belts of roughly hilly land, with intervening areas of smoother contour. For the next 20 miles to the east and northeast they form a range 5 to 3 miles wide, composed of very irregular, roughly outlined hills, 100 to more than 300 feet high, widely known by the name Leaf Mountains. Northeast of East Leaf Lake, where this moraine is crossed by the road from Wadena to Ottertail Lake, its elevations rise only about 100 feet and are named Leaf Hills, which seems a more appropriate title and should include the highest part of the range. The common name has currency because they are the only hills in this part of Minnesota that are conspicuously seen at any great distance.

[1] Detailed descriptions of these and other moraines crossing the basin of Lake Agassiz are given in Chapter IV.

The Leaf Hills are crossed northwest of Parkers Prairie by a road that winds 3 or 4 miles among their knolls, hills, and short ridges, rising about 100 feet above the land on each side. Again, the road from Alexandria to Clitherall crosses this range in the township of Leaf Mountain, the summit of the road being near the south line of this township, about 1,525 feet above the sea. The top of a hill a quarter of a mile east of the road here, and about 125 feet higher, affords a fine view of these "mountains" (Pl. VIII), which westward and northeastward rise in most tumultuous confusion 150 to 250 feet or more above the intervening depressions. They are massive, though very irregular in contour, with steep slopes. No prevailing trend is noticeable. Between them are inclosed frequent lakes, which vary from a few rods to a mile in length, and one of the largest lies at the northeast foot of this hill. The material is chiefly unmodified drift, nearly like that which forms very extensive, gently undulating tracts elsewhere. The principal difference is that rock fragments, large and small, are generally much more numerous upon these hills, and occasionally they occur in great abundance.

South of the Leaf Hills the country adjoining Lake Agassiz is an expanse of smoothly undulating or rolling till, 1,200 to 1,075 feet above the sea. So slight are its elevations and depressions, usually differing from each other by 10 to 25 feet, that in an extensive prospect these inequalities are lost sight of, and the land seems bounded by a level line at the horizon. This contour extends south through Grant and Stevens counties, and thence more than 100 miles southeast, descending on the average about a foot per mile along the wide, slightly undulating basin of the Minnesota River, which seems to be a continuation of the same topographic belt that forms the Red River Valley.

COUNTRY WEST OF LAKE AGASSIZ.

Along the west side of the basins of the Minnesota River, of the Red River Valley, and of Lakes Manitoba and Winnipegosis, the surface rises from 200 or 300 to 1,000 feet above their slightly undulating or quite flat belt of lowland. No other feature in the contour of the northwestern States and adjoining British territory is more noteworthy, extended, and

THE LEAF HILLS.

View looking northeast from a hill in the east part of section 33 Leaf Mountain township

prominent than this, excepting perhaps the ascent along the similar and parallel Coteau du Missouri. The latter, however, lacks the accompaniment of such a continuous broad depression beside it. This wide valley, occupied by Lakes Winnipeg, Manitoba, and others, and by the Red and Minnesota rivers, varying in elevation from 710 to 1,100 feet above the sea, is the base of the slowly ascending expanse of the great plains which rise thence westward to a height somewhat exceeding 4,000 feet above the sea-level at the foot of the Rocky Mountains, on the international boundary. Most of this elevation is attained by a gradual slope, averaging 4 or 5 feet per mile throughout the distance of 730 miles from the Red River to the mountains; but at two lines, extending from south to north or northwest, first on the west side of this valley and again in the Coteau du Missouri, 100 to 200 miles farther west, the surface rises more rapidly several hundred feet within a few miles by a terrace-like ascent. The first was the western shore of Lake Agassiz, and continuing south and southeast held the same relation to an earlier glacial lake which occupied the basin of the Minnesota and Blue Earth rivers.

The southern portion of this line of elevation is the massive and high Coteau des Prairies. Its lower continuation from the head of the Coteau des Prairies, west of Lake Traverse, for the next 175 miles northward, bears no name, and is scarcely more conspicuous, or in some parts even less so, than the moderate ascent that forms the opposite border of the Red River Valley in Minnesota. Farther north this line of higher land rises abruptly 300 to 500 feet in Pembina Mountain, and from 500 to 1,000 feet or more in Riding and Duck mountains and the Porcupine and Pasquia hills. All of these are successive parts of a very remarkable terrace-like escarpment, called by Mr. J. B. Tyrrell the Manitoba escarpment,[1] stretching from North Dakota by the west side of Lakes Manitoba and Winnipegosis to the Saskatchewan River. Its portions thus differently named are divided by deep and broad valleys eroded by intersecting streams.

This whole belt of highland, reaching in a nearly direct north-northwest course about 800 miles, may thus be considered in three parts. At the south a quarter of its length is the great plateau-like ridge of the

[1] Am. Geologist, Vol. VIII, pp. 19-28, July, 1891.

Coteau des Prairies. Next, a nearly equal extent, is the less elevated highland that gradually rises west of the Red River Valley, between it and the Sheyenne River and Devils Lake. The northern half is a somewhat interrupted, mountain-like escarpment, lying mainly in Manitoba, whose top, like the highland just mentioned, is the verge of plains that extend thence westward, generally with a nearly level but slowly ascending surface, excepting where they are channeled and irregularly sculptured by stream erosion. Occasional groups of hills also rise above the average height of these plains, as Turtle Mountain and others farther northwest. Beneath their thin covering of drift these hilly tracts contain remnants of older formations, of which the portions formerly continuous between these elevations and on each side have been eroded and carried away.

The accompanying maps, which form Pls. IX and X, giving altitudes as determined chiefly by railway surveys upon the area of Lake Agassiz and the adjoining country, show the extent and height of the Manitoba escarpment, of portions of the Coteau des Prairies and the Coteau du Missouri, and of the region extending eastward from Lake Agassiz to Hudson and James bays and the great Laurentian lakes.

THE COTEAU DES PRAIRIES.

A large area extending from south-southeast to north-northwest in southwestern Minnesota and the northeast part of South Dakota, and terminating on the west side of the south end of Lake Agassiz, has an elevation from 500 to 1,000 feet above the Minnesota River, and from 1,300 to 2,000 feet above the sea. Upon this highland district are the sources of the Lac qui Parle, Yellow Medicine, Redwood, and Cottonwood rivers, tributary to the Minnesota; of the Des Moines River; and of the Little Sioux and Big Sioux rivers, tributary to the Missouri. The outermost of the series of terminal moraines of the waning ice-sheet, denominated the Altamont moraine, generally lies on the highest portion of this area, which extends in Minnesota from southeastern Nobles County in a nearly north-northwest course, passing west of Worthington, through southwestern Murray County, the northeastern township of Pipestone County, and southwestern Lincoln County, by the west ends of Lakes Benton, Shaokatan, and Hen-

MAP WITH ALTITUDES OF LAKE AGASSIZ AND ADJOINING COUNTRY.

Scale, about 165 miles to an inch.

Lake Agassiz and associated Glacial Lakes

Altitudes in feet above the sea

dricks into South Dakota, where it continues in the same course through Deuel and Grant counties and the Sisseton and Wahpeton Indian Reservation. It thus reaches past the sources of the Big Sioux River, and farther northward becomes the divide between the head streams of the Minnesota and Wild Rice rivers on the east and the James River on the west. This elevated tract, extending 200 miles, was called by the earliest French explorers the Coteau des Prairies, meaning the Highland of the Prairies. This name, according to Nicollet, alludes to its conspicuous appearance, "looming as it were a distant shore," when viewed from the valleys of the Minnesota and James rivers, as is very noticeable from the vicinity of Lakes Traverse and Big Stone and from the highest points near the Minnesota River for perhaps 20 miles below Big Stone Lake. Farther southeast this title was applied to the first prominent ascent above the broad, gently undulating expanse that reaches everywhere 20 or 30 miles from the Minnesota River.

In crossing the Coteau des Prairies from northeast to southwest there is generally a very gradual, smooth slope, rising 100 to 300 feet in 5 to 15 miles. Then comes a steeper ascent, which amounts to 300 feet or more within a width of 2 or 3 miles, coinciding through the greater part of its extent with the tract of knolly and hilly drift that forms the second or Gary moraine. The average height beyond, sometimes after a slight descent, continues to rise, but only slowly, amounting to 100 or 150 feet in crossing the smoother, undulating or rolling area, 5 to 15 miles wide, between this and the outer morainic range, which next rises 100 to 200 or 300 feet within 2 or 3 miles and forms the crest of the highland along nearly its whole extent. West of this moraine in Minnesota the surface soon drops 50 to 100 feet, this descent being greatest at the south and diminishing northward, and thence a smooth slope of till falls southwesterly some 200 feet within 10 miles. Farther to the north, from Lake Hendricks nearly to Goodwin, S. Dak., a gently undulating expanse of till, slightly lower than this western belt of drift hills, extends from them westward, approximately level, for a width of several miles, beyond which a similar slope falls to the southwest.

On the Minnesota division of the Chicago and Northwestern Railway the traveler going west enters the inner moraine belt of the Coteau at the west edge of Minnesota, a little east of Gary, about 1,450 feet above the sea (fig. 8). The line crosses this belt obliquely, occupying about 4 miles, and ascending some 200 feet. Then 6 miles are moderately rolling, mainly in smooth swells; and the next 6 miles, lying partly on each side of Altamont, are among the knolls and small hills of the outer moraine, 1,750 to 1,950 feet above the sea; succeeded by a smooth, slightly undulating area of till, which rises to the summit of this line near Goodwin, 2,000 feet above the sea, extends thence nearly level to Kranzburg, and then descends 250 feet by a very gradual slope to Watertown.

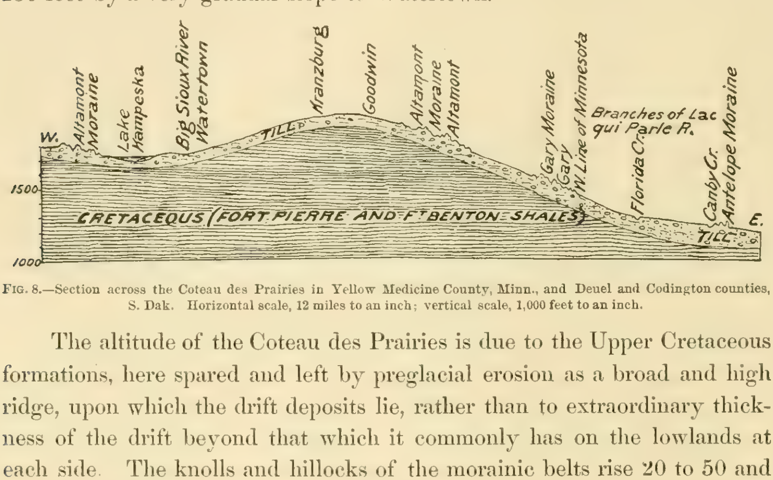


FIG. 8.—Section across the Coteau des Prairies in Yellow Medicine County, Minn., and Deuel and Codington counties, S. Dak. Horizontal scale, 12 miles to an inch; vertical scale, 1,000 feet to an inch.

The altitude of the Coteau des Prairies is due to the Upper Cretaceous formations, here spared and left by preglacial erosion as a broad and high ridge, upon which the drift deposits lie, rather than to extraordinary thickness of the drift beyond that which it commonly has on the lowlands at each side. The knolls and hillocks of the morainic belts rise 20 to 50 and rarely 75 or 100 feet above the intervening hollows, and the thickness which they add to the drift sheet of the Coteau des Prairies appears to be from 50 to 150 feet. That the prominence of this highland is not due to these morainic accumulations is shown in South Dakota at Goodwin and farther north by the greater elevation that is reached within a distance of 2 to 5 miles by the smooth sheet of till at their west side, which there forms the watershed and beyond descends to the Big Sioux River.

Nearly a constant elevation, varying between 1,950 and 2,050 feet above the sea, is maintained along the entire northern half of the Coteau des Prairies, lying in South Dakota. The north end of this highland, called the Head of the Coteau des Prairies, is about 35 miles west-northwest of Lake Traverse and the south end of Lake Agassiz. Within 5 or 6 miles farther north there is a descent of nearly 800 feet to a level only about 1,200 feet above the sea. Along the continuation of this line northward, instead of such a prominent massive ridge, bordered by much lower land on each side, there is a more gradual ascent, attaining a third or half as great elevation above the valley on the east, with only slight descent or none thence westward to the Sheyenne and James rivers.

ASCENT FROM THE RED RIVER VALLEY IN NORTH DAKOTA.

From the Head of the Coteau des Prairies for 140 miles north to the latitude of Larimore and Devils Lake the highland bordering the west side of the Red River Valley rises by such gentle slopes that it is not generally seen conspicuously from the flat plain of this valley. Standing on the upper beach of Lake Agassiz, the observer sees a smoothed surface descending very slowly eastward within the area of this lake, and a moderately undulating or rolling surface rising slowly toward the west. Along most of this distance, however, the slope both to the east and west is so slight that the view in each direction reaches only a few miles.

On the line of the Fargo and Southwestern Railroad the highest land crossed between the west shore of Lake Agassiz and the Sheyenne River is 1,190 feet above the sea; and between the Sheyenne and James rivers it is about 1,400 feet above sea-level, or 500 feet above the central part of the Red River Valley at Fargo.

The Northern Pacific Railroad attains a height of 1,440 feet between the area of Lake Agassiz and the Sheyenne River, and the highest land between that stream and the James River is approximately 1,500 feet, being thus 600 feet above Fargo. By each of these lines the descent to the James River is only about 100 feet.

Between Larimore and Devils Lake, at the northern end of this extent, where the highland west of the Red River Valley rises less prominently than in the Coteau des Prairies on the south or in Pembina Mountain on the north, there is a slightly greater ascent than on the two preceding railroads which cross its southern half. At Larimore, near the highest western shore of Lake Agassiz, the elevation of the Great Northern Railway is 1,134 feet, or about 300 feet above the plain of the Red River Valley at Grand Forks. Thence the surface in the next 17 miles westward rises to 1,525 feet, and this elevation is maintained somewhat uniformly, nowhere exceeding 1,535 feet nor falling below 1,450 feet, to the city of Devils Lake, 1,464 feet above the sea, 60 miles west of Larimore.

THE MANITOBA ESCARPMENT.

A very remarkable series of highlands, forming the eastern limit of the elevated plains of the northern part of North Dakota and of western Manitoba and the Saskatchewan region, extends in a north-northwest course 400 miles, from the Pembina Mountain to the Pasquia Hills. Along much of this distance a steep, mountain-like escarpment, which was the west shore of Lake Agassiz, rises 500 to 1,000 feet above the bed of that lake, now the low plain bordering the Red River and the great lakes of Manitoba. Topographically, this line of conspicuous highlands is allied with the Coteau des Prairies by their together forming the western ascent from the broad, continuous valley plain, which in its southeast part passes from the Red River Valley to the lowland of the basin of the Minnesota River. Both the Coteau des Prairies and the Manitoba escarpment consist, beneath their drift covering, of nearly horizontal Cretaceous shales, whose continuation has been removed by erosion on both sides of the Coteau, but only east of the escarpment.

Pembina Mountain.—The southern end of the Pembina Mountain, where it is reduced to rounded hills, about 100 feet above the lowland at their east base and 1,300 feet above the sea, is in section 30, township 158 north, range 56 west, between the south and middle branches of Park River. Thence for the next 5 miles northward this ascent is merely a slope that rises 50 or 60 feet, or in some portions only 30 or 40 feet, within a quarter or half mile from east to west, succeeded beyond by a moderately rolling surface with slower ascent westward. Along the west line of townships 159 and 160 of range 56 this highland rises gradually in its course from south to north, attaining an elevation about 1,500 feet above the sea; and it holds this height quite uniformly northward to the Pembina River, in the south part of township 163, range 57, about 5 miles south of

MAP WITH ALTITUDES OF THE SOUTHERN PORTION OF LAKE AGASSIZ EXPLORED WITH LEVELLING IN MINNESOTA, NORTH DAKOTA, AND MANITOBA.

Scale, about 42 miles to an inch.

Area of Lake Agassiz Altitudes in feet above the sea 1060

the international boundary. It is a prominent wooded bluff, some 300 feet high, extending in a very direct course from south to north or a few degrees west of north. From its southern end to the Pembina River the base of this escarpment is 1,200 to 1,225 feet above the sea. The width occupied by its slope varies from a half mile to 2 or 3 miles, and from its crest a treeless plateau, having a moderately rolling surface, stretches with slow ascent westward. North of the Pembina River its crest sinks to about 1,400 feet, and its base to about 1,025 feet, at the international boundary.

Where the Pembina River cuts through this escarpment, entering the area of Lake Agassiz, the eroded eastern front of its delta deposit forms another conspicuous bluff, about 200 feet high, falling in a steep, wooded slope from 1,175 to 975 feet, approximately, above the sea-level. The delta bluff, called the "First Pembina Mountain," is composed of sand and gravel, and lies about 5 miles east of this more prolonged line of highland, which is denominated in that vicinity the "Second Pembina Mountain." The latter, throughout its entire extent both in North Dakota and Manitoba, is caused by the outcrop of a continuous belt of almost level Cretaceous strata, mostly overspread by glacial drift.

The ascent of this highland on the international boundary, where it occupies a width of about 1½ miles, is described by Dr. G. M. Dawson as follows:

> The eastern front of Pembina escarpment is very distinctly terraced, and the summit of the plateau, even at its eastern edge, thickly covered with drift. The first or lowest terrace, which is about one-third from the prairie level toward the top of the escarpment, does not seem to preserve exactly the same altitude. On the boundary line its height above the general prairie level was found to be about 90 feet, a second terrace 260 feet, and that of the third level, or summit of the plateau, about 360 feet. The surface of the first terrace, which is here wide, is strewn with bowlders, as is also that of the second terrace and plateau above. These are chiefly of Laurentian gneiss and granite, but a few smaller ones of limestone occur. The banks of ravines cutting the top of the plateau and draining westward into the Pembina River show in some places a great thickness of light-colored, yellowish, marly drift, with few bowlders embedded in it.[1]

[1] Report on the Geology and Resources of the Forty-ninth Parallel, from the Lake of the Woods to the Rocky Mountains, 1875, p. 219.

In Manitoba this escarpment extends with a north-northwest course by Mountain City and Thornhill to 6 miles east-southeast of Treherne, a distance of about 50 miles With its extent in North Dakota, the whole length of Pembina Mountain is approximately 80 miles. Its crest north of the international boundary averages about 400 feet above its base, or 1,400 feet above the sea; but within a few miles farther west the rolling surface of the highland rises 100 to 200 feet higher.

Northwestward from Treherne the plateau of which Pembina Mountain forms the eastern edge is interrupted across a distance of 65 miles to Riding Mountain. This broad depression is occupied by the Assiniboine River and its tributaries, and by small streams on the northeast which send their waters to Lake Manitoba. The plateau, indeed, loses its regularity of surface upon the country farther north and west, because it has been eroded to the depth of several hundred feet on the greater part of the Assiniboine basin.

Tiger Hills.—The border of the plateau south of the Assiniboine, reaching from close south of Treherne westerly 50 miles to the elbow of the Souris River, is called the Tiger Hills.[1] It is irregularly sculptured in steep, rounded, massive hills, and is overspread by drift deposits, consisting partly of morainic accumulations. For a distance of 40 miles west from the Pembina Mountain this belt occupies a width of 5 to 8 miles, upon which the surface falls from south to north 300 to 400 feet. The country on the south has an average elevation nearly the same as the summits of the hills, which yet rise very prominently as seen from the lower region on the north. The western part of the Tiger Hills, extending 10 or 12 miles east and an equal distance west from the gorge that is cut through the range by the Souris, rises considerably above the adjoining nearly flat surface on each side. The foot of the belt of hills there is 100 to 150 feet lower on the north than on the south, and the Souris flows through it in a gorge 350 feet deep. From this vicinity Hind applied the name Blue Hills of the Souris to this belt, but that name is not used by the people of the district.

Riding and Duck mountains.—North of the Assiniboine River the eastern outline of the continuation of this plateau is preserved in the prominent

[1] From the aboriginal name, which doubtless refers to the cougar or American panther (*Felis concolor* L.).

elevations of Riding and Duck mountains, two remarkable wooded highlands, much alike in their general features and extent. The steep eastern escarpment of each is about 50 miles long, that of Riding Mountain trending from southeast to northwest and that of Duck Mountain having a course a few degrees west of north. These elevations rise above the country adjoining the Assiniboine by a somewhat gradual slope, but they are abruptly cut off on their northeast side by a precipitous descent. This takes place on a line approximately parallel with Lakes Manitoba and Winnipegosis, the former of these lakes being about 40 miles east of Riding Mountain, while the south end of the latter is 25 miles east of Duck Mountain. The crests of these highlands, according to Mr. J. B. Tyrrell's measurements, are respectively about 2,000 and 2,300 to 2,700 feet above the sea, the latter being the highest land in Manitoba; and the bases of their escarpments are about 1,200 to 1,500 feet above the sea, being 400 to 700 feet above the lakes on the east, whose height slightly exceeds 800 feet.

The reader is referred to Mr. Tyrrell's map and descriptions of the district of Riding and Duck mountains for details of its topography and geology, and of the shore-lines of Lake Agassiz north of the limit of my exploration.[1]

Porcupine and Pasquia hills.—Beyond Duck Mountain, after an interruption of about 30 miles across the basins of Swan and Woody rivers, this line of highlands is continued in the Porcupine Mountain or hills, which reach about 25 miles from south to north. These form a somewhat broken plateau, similar with the preceding in its general features of steep acclivity on the east and gentle descent westward. On their north side another gap, about 20 miles wide, is occupied by the Red Deer and Overflowing rivers.

Next are the Pasquia Hills, whose eastern end is in line with Pembina, Riding, and Duck mountains and the Porcupine Hills; being about 100 miles west from the mouth of the Saskatchewan. The Pasquia Hills extend thence 150 miles westward, where they formed the southern shore of the northwestern arm of Lake Agassiz, lying about 25 miles south of the

[1] Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. III, for 1887–88, pp. 1–16 E, with a preliminary contour map. Bulletin, G. S. A., Vol. I, 1890, pp. 395–410. Am. Geologist, Vol. VIII, pp. 19–28, July, 1891.

Saskatchewan River and parallel with it to the Birch Hills and the South Saskatchewan. They are the northern escarpment limiting the irregularly eroded country, which is here considered as an extension of the great plateau of North Dakota and southern Manitoba and Assiniboia, thus holding the same relation to the valley of the Saskatchewan that the Tiger Hills sustain to the Assiniboine Valley.

Great Bear Hills.—On the north side of the Saskatchewan the Great Bear Sand Hills, extending in a north-northwest course to the east end of Lac la Rouge and to the Churchill River, are geographically a continuation of the line of highlands thus described from the Coteau des Prairies and Pembina Mountain to the Pasquia Hills, and they will probably be found also to belong to the same geologic age. If this be true, they differ from this great Cretaceous escarpment south of the Saskatchewan by being outlying remnants, separated from the broad Cretaceous area on the west by a belt of Devonian limestones where these overlying beds have been eroded. The amount of erosion west of the middle portion of this escarpment, through North Dakota and in southern Manitoba, since the cycle of base-leveling which spared the Turtle Mountain area, has been inconsiderable, so that in general the surface is a great plain with a gradual ascent westward. On the south the Cretaceous strata are deeply eroded west of the Coteau des Prairies, exposing the underlying red quartzite, probably of Keweenawan age, at the celebrated Pipestone quarry in southwestern Minnesota and at many localities thence westerly to the James River. Again, in western Manitoba and northwestward, between the Assiniboine and Saskatchewan rivers, the Cretaceous strata are much denuded, though not worn through, west of the highlands that form their eastern escarpment. Still farther north, between the Saskatchewan and Churchill rivers, the denudation appears to have cut through the Cretaceous beds and to have left remnants of their eastern portion.

FOREST AND PRAIRIE.

The area of Lake Agassiz is crossed by the southwestern boundary of the forest that overspreads the greater part of British America and nearly all of the eastern half of the United States. This boundary between forest and prairie (see Pl. XXXVIII, Chapter XI), having an almost wholly timbered region on its northeast side, and a region on its southwest side that is chiefly grass land, without trees or shrubs, excepting in narrow belts along the streams and occasional groves beside lakes, runs as follows: From near the junction of the South and North Saskatchewan rivers it passes southeasterly by the sources of the Red Deer and Assiniboine rivers and over the southwestern slopes of Duck and Riding mountains to the south end of Lakes Manitoba and Winnipeg. Thence it turns southward and holds this course along the east side of the Red River and approximately parallel with it, at a distance increasing from 15 to 50 miles from the river for about 300 miles to the upper part of this stream, where it flows from east to west. It enters the United States about 15 miles east of Emerson and St. Vincent and extends south-southeastward to the mouth of Thief River, the sources of Poplar and Sand Hill rivers, and the White Earth Agency, being at the last-named locality some 50 miles distant from the Red River. Its course continues to the south by Detroit and Pelican Rapids to Fergus Falls, where it crosses the Red River, and thence it runs south east and east through the central part of the south half of Minnesota.

Groves border the greater part of Lakes Big Stone and Traverse, and cover the islands of Big Stone Lake. But considerable portions of the shores and bluffs of these lakes and the islands of Lake Traverse are destitute of timber, or bear only bushes and small trees. The Bois des Sioux River has no timber along the upper two-thirds of its course, but below is fringed here and there by woods, from which it derives its name. The Mustinka River, flowing into the north end of Lake Traverse; Rabbit River, tributary to the Bois des Sioux; and the upper part of Wild Rice River, in North Dakota, and of Elm River, tributaries of the Red River, are also unwooded.

The Red River has no timber, or very little, for 20 miles east from its bend at Breckenridge and Wahpeton. In the next 10 miles downstream it has scattered groves of bur oak, ash, box elder, elm, and basswood, occupying perhaps one-fourth of this distance, while small poplars and willows occasionally appear in the spaces between the groves. Thence to the north this river is continuously fringed with timber, and its larger tributaries have their course marked in the same way. The growth of wood is here confined chiefly to the banks of the streams, which have cut hollows 20 to 40 feet deep in the broad lacustrine plain.

About a sixth part of the area of Lake Agassiz, and a larger proportion (nearly the whole) of the adjoining country on the south and west, are prairie, this term being commonly used to embrace all tracts destitute of trees and shrubs, but well covered with grass. Groves of a few acres, or sometimes a hundred acres or more, occur here and there upon this prairie region beside lakes, and a narrow line of timber usually borders streams, as just described along the Red River; but many lakes and creeks, and even portions of the course of large streams, have neither bush nor tree in sight, and occasionally none is visible in a view which ranges from 5 to 10 miles in all directions. The contour of the prairie is as varied as that of the wooded region. Within the area of Lake Agassiz the surface is almost absolutely level, but the adjoining prairie country is undulating, rolling, and hilly, having in some tracts a very rough surface of knolls, hills, and ridges of morainic drift that rise steeply 25 to 100 feet or more above the intervening hollows. The material of the greater part of all these areas, whether forest or prairie, is closely alike, being till or unmodified glacial drift, showing no important differences such as might cause the growth of forest in one region and of only grass and herbage in another. Chapter XI will include a discussion of the climatic conditions, as abundance or lack of rainfall, and auxiliary causes, as prairie fires, by which the limits of these diverse phases of vegetation have been determined.

EXISTING LAKES WITHIN THE AREA OF LAKE AGASSIZ.

The glacial Lake Agassiz was gradually reduced in size, first by the lowering of its southward outlet, and afterwards by finding successively lower outlets to the northeast, until, with the complete departure of the ice-sheet, it shrank to its present representatives, the great lakes of Manitoba. These are three in number, Lakes Winnipeg, Manitoba, and Winnipegosis. With them are associated several others, comparatively small, as Cedar Lake, through which the Saskatchewan flows near its mouth; Lake

Dauphin, south of Lake Winnipegosis and tributary to it; and Lake St. Martin, on the Fairford or Little Saskatchewan River, the outlet of Lakes Manitoba and Winnipegosis.

Many other lakes of still smaller size, but ranging up to several miles in extent, are scattered here and there on all this northern part of the bed of Lake Agassiz. Such small lakes are also frequent on its southeastern part, in northern Minnesota, eastward from Roseau, Thief, Mud, and Maple lakes, besides the three large lakes of that district, Rainy Lake, the Lake of the Woods, and Red Lake.

Lake Winnipeg.—The length of Lake Winnipeg is about 250 miles, trending from south-southeast to north-northwest, while the maximum width of its southern part is about 25 miles, and of its northern part 60 miles. Its area is approximately 8,500 square miles, being intermediate in extent between Lakes Ontario and Erie. Eighty-five miles from its south end, Lake Winnipeg is reduced to a strait 2 to 4 miles wide, which extends northwesterly 12 miles, terminating at the cape called Dog Head. The narrowest part of the strait, scarcely exceeding a mile in width, is at this cape. Here the strait opens into the northern and main portion of the lake, which includes five-sixths of its area.

The elevation of Lake Winnipeg, determined by the survey for the Canadian Pacific Railway, is 710 feet above the sea. Its depth, according to Mr. J. Hoyes Panton, nowhere exceeds 65 feet. "The shallowness of this comparatively large body of water," as Mr. Panton writes, "accounts for its treacherous nature, and explains how on many occasions it has proved a disastrous waterway to the freighting boats of bygone days. As you sit upon the deck of the steamer, threading its way among the islands, you are surprised at the tortuous course made, when water seems on every side and no shore near. So shallow is the lake that many places miles from land are not covered with more than 6 or 7 feet of water. It is only safe to experienced captains, thoroughly acquainted with the concealed channels that afford a safe course at a distance from the shore."[1] On account of this slight depth, the water of most parts of the lake is com-

[1] "Notes on the geology of some islands in Lake Winnipeg." Transactions of the Historical and Scientific Society of Manitoba, January 28, 1886.

monly turbid with mud, stirred up by the waves from its shores and bed.[1] Low land borders this lake along nearly its whole extent, and the highest points on the shore or visible from it rarely attain an elevation of 50 feet.

Lakes Manitoba and Winnipegosis.—Lake Manitoba[2] lies about 40 miles west of the south half of Lake Winnipeg; and Lake Winnipegosis,[3] separated only about 2 miles from the north end of Lake Manitoba, lies mostly 40 to 50 miles west of the north half of Lake Winnipeg, but its most northeast part is only 20 miles southwest from that lake. The length of each of these lakes, measured in a straight line, is about 120 miles, trending in parallelism with Lake Winnipeg, from south-southeast to north-northwest; and each of them covers an area of nearly 2,000 square miles. Both are shallow in proportion to their size, and are surrounded by low shores.

The maximum width of Lake Manitoba, about 28 miles, is at its south end. Near its middle it is narrowed to a strait about a half mile wide and 2 miles long. Its northern part is of quite irregular form, and is nearly intersected from the north by a long peninsula. This lake, according to leveling by Mr. H. S. Treherne, is 809 feet above the sea, being thus almost exactly 100 feet higher than Lake Winnipeg, to which it is tributary by the Little Saskatchewan. The country between these lakes and from Lake Manitoba west to Lake Dauphin and to Riding and Duck mountains is low and approximately level, but has a general westward ascent, averaging a few feet per mile.

The width of Lake Winnipegosis varies from 5 to 15 miles. Its northern portion is bent to the west and south, terminating in Dawson Bay, so that its length, following this course, is nearly 150 miles. Its outlines, moreover, are very irregular, presenting a constantly varying

[1] "Lake Winnipeek receives its name from the muddy or sallow appearance of its waters; *We* signifies muddy, and *Nepe* water, in Chippewa."—Keating's Narrative of Long's Expedition, Vol. II, p. 77.

[2] Meaning the "Narrows or Strait of the Manitou or Great Spirit," as I am informed by letters from Prof. George Bryce and Mr. J. B. Tyrrell. This name was originally pronounced by white inhabitants nearly as by the Indians, with accents on the initial and final syllables; but during the past ten years or more its almost universal pronunciation in English has been with only one accent, which is laid on the next to the last syllable.

[3] Meaning "Little Winnipeg."—Hind's Narrative of the Canadian Exploring Expeditions, Vol. II, p. 42.

MAP OF RAINY LAKE AND THE LAKE OF THE WOODS.

Scale, about 14 miles to an inch.

succession of bays, capes, and islands. This lake outflows by Water Hen Lake and River to Lake Manitoba, and has an elevation of 19 feet above the latter, as determined by surveys for the Canadian Pacific Railway, or 828 feet above the sea.

Rainy Lake.—Two bodies of water of considerable size, namely, Rainy Lake and the Lake of the Woods (Pl. XI), lie on the northern boundary of Minnesota, within the eastern part of the area of Lake Agassiz. The length of Rainy Lake is slightly more than 50 miles, trending from east-southeast to west-northwest, and its average width is about 5 miles, giving it an area of 250 square miles, approximately. It is extremely diversified by projecting points, numerous bays and narrow arms, and plentiful islands. Its height above the sea is about 1,117 feet, and its maximum depth, according to soundings by Dr. A. C. Lawson, is 110 feet.

Lake of the Woods.—The Lake of the Woods has a very irregular form, nearly surrounding a large peninsula in its northern part, and including many bays on the north and east, some of them connected with the main lake only by narrow channels. A multitude of islands, large and small, dot its surface, excepting in its southwest part, called Sand Hill Lake, where it adjoins Minnesota. Measured from north to south or from east to west, its maximum extent in either direction is 60 miles approximately, and its area is about 1,500 square miles. Its elevation, determined by the Canadian Pacific Railway survey, is 1,060 feet above the sea, and the maximum depth of its northern part, called Clear Water Lake, is stated by Dr. G. M. Dawson to be 84 feet.

Red Lake.—The largest lake lying wholly in Minnesota is Red Lake (Pl. XII), situated in the southeast edge of the area of Lake Agassiz, at a distance of about 50 miles south from the Lake of the Woods. Its elevation, as determined by the Duluth and Winnipeg Railroad survey, is 1,172 feet above the sea, being about 40 feet below the adjacent portion of the highest shore-line of the glacial lake. A strait about three-fourths of a mile wide divides Red Lake into two nearly equal parts, which trend from east to west. The length of each part is somewhat more than 20 miles, and of both together about 30 miles, while the maximum width of each is about 10 miles. Its area is approximately 440 square miles. This lake differs remarkably from all the preceding in its regular outlines, broken by no capes nor bays, and in the complete absence of islands. The map plate shows the various drift deposits adjoining Red Lake, as observed in a canoe trip along its entire shore-line in September, 1885.

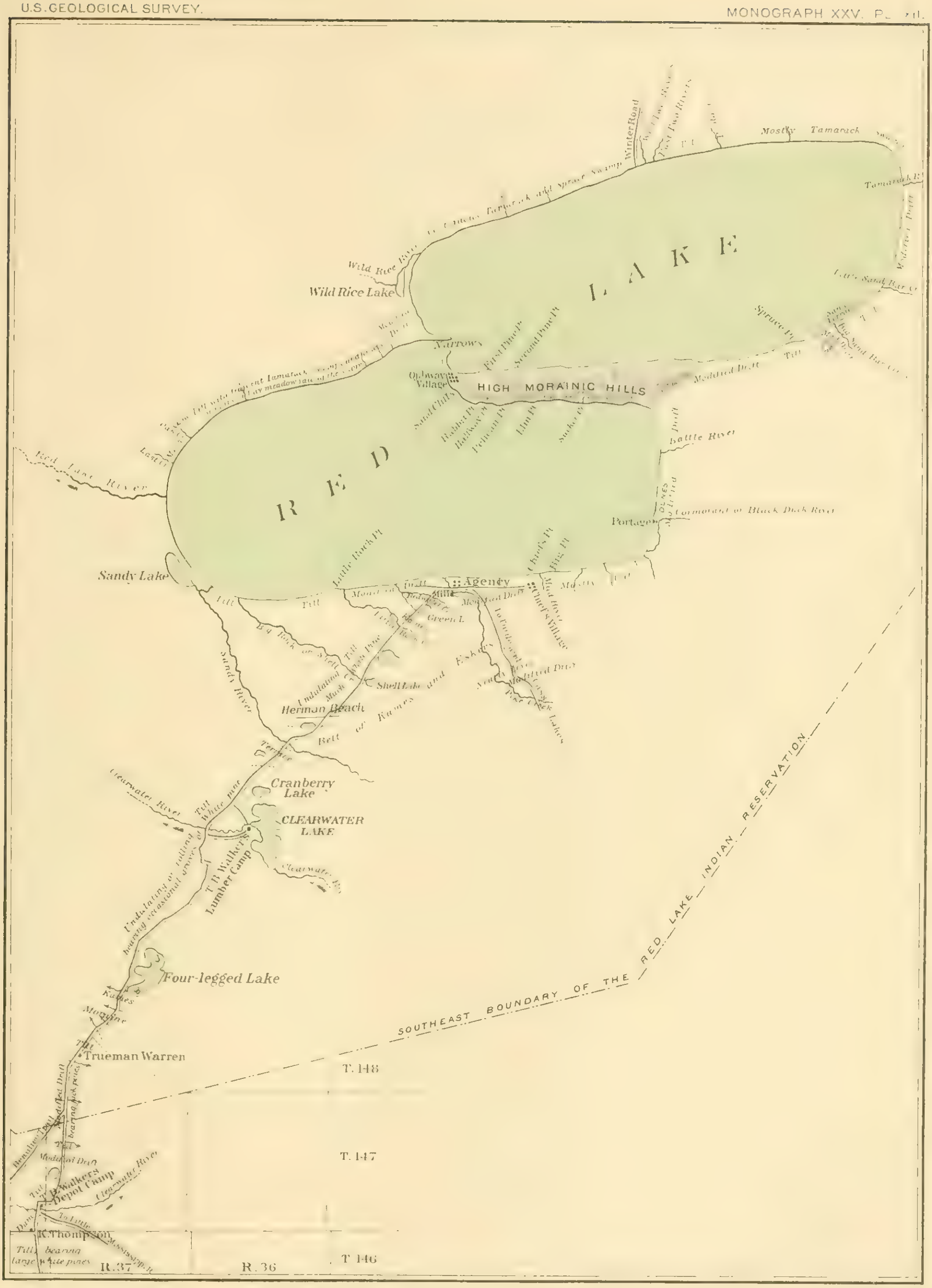
RIVERS TRIBUTARY TO LAKE AGASSIZ AND DRAINING ITS AREA.

The area of Lake Agassiz is drained to Lake Winnipeg chiefly by the Winnipeg, Red, and Little Saskatchewan (or Fairford) rivers. On the northwest this glacial lake also included the region crossed by the lower part of the Saskatchewan. Flowing out from Lake Winnipeg, the united waters of all these river systems are carried by the Nelson to Hudson Bay. Pl. XIII is colored to show the several drainage areas of the Lake Agassiz basin and adjoining country.

Rainy and Winnipeg rivers.—It seems probable that the recession of the ice-sheet uncovered the entire course of the Rainy and Winnipeg rivers before Lake Agassiz had fallen below the level of Rainy Lake. These are upper and lower portions of the main trunk of the same river system. East of Rainy Lake a large tract tributary to it reaches nearly a hundred miles on the international boundary, including almost countless lakes and small streams.

Rainy River, about 80 miles long, connecting Rainy Lake and the Lake of the Woods, is a broad and majestic, deep stream, with an average width of a sixth of a mile, flowing in general in a somewhat direct west-northwest course. At the mouth of Rainy Lake it has rapids that fall about 3 feet. Its principal falls are between Koochiching and Fort Frances, situated opposite to each other on the south and north banks of the river, a little more than 2 miles from Rainy Lake, where it descends 23 feet in about a tenth of a mile. Manitou Rapids, about 35 miles from Rainy Lake, are a short descent of about 2 feet, with outcropping rock in the channel and banks. Six miles below these is the Long Sault, a mile in length, estimated by Major Long to have "an aggregate descent of about 10 feet;"[1] but subsequent leveling by S. J. Dawson shows that it probably

[1] Keating's Narrative of Long's Expedition, Vol. II, p. 230.



MAP OF RED LAKE AND ITS VICINITY.

Scale, 6 miles to an inch.

does not exceed two-thirds this amount. Excepting these rapids, Rainy River has an average descent of only about 3 inches per mile, giving to the ordinary low stage of water a very gentle current. It is navigable for large steamboats from the Lake of the Woods to the foot of the Long Sault, and thence to Rainy Lake it is navigated by a tug or propeller, towing Mackinaw boats. The banks of the river are only 10 to 20 feet high, and are fertile and heavily wooded, having commonly a clayey soil. The most important tributaries of Rainy River are on its south side, and include the Little Fork and the Big Fork or Bowstring River (whose mouths are respectively about 15 and 21 miles from Rainy Lake), Black River (4 miles below the Big Fork), and the Rapids or Winter Road River (about 12 miles from the Lake of the Woods).

Winnipeg River, the outlet of the Lake of the Woods, has a length of about 160 miles, flowing in a winding course to the northwest. Its total descent is 350 feet, four-fifths of this being in the many falls and rapids which occur along nearly its entire extent. These falls are divided by portions with only a strong or gentle current, or by lake-like expansions of the river where no current is perceptible. At Rat Portage the Winnipeg flows out from the Lake of the Woods by two channels, which are divided by Tunnel Island. Each channel descends about 16 feet, the eastern one being called Hebes Falls, and the western one the Witches Caldron, which opens into Winnipeg or Darlington Bay. After flowing about 8 miles through this and other bays or lakes, the river enters the Dalles, passing with a very swift current between perpendicular walls of granite. Beyond the Dalles its banks and abundant islands along a distance of about 15 miles, as described by Keating, are clay slate, occasionally varying to mica-schist. "The river expands considerably, being in some places several miles wide. * * * Its current is swift, especially near the islands, but it is free from ripples; we observed none of the foaming rapids which characterize the lower part of the stream. The islands, which in some places are countless, are generally small and of a form nearly square; from the vertical stratification of the rock their banks are perpendicular; they generally rise from 10 to 20 feet above the level of the water." Below this belt of slate the river flows through a very picturesque region of granite, gneiss, and schists, over many falls, cascades, and rapids, and through numerous lakes. In descending order these include Jacks Falls, the Upper Falls, "which for beauty are second only to the Lower Falls;" Slave Falls, "computed at 20 feet;" Lac du Bonnet, "about 15 miles long and from 600 yards to 4 miles in breadth," and the Lower Falls.[1]

On each side the country rises to a moderate elevation in low hills and ridges, with frequent outcrops of the bed-rocks. The highest land crossed by the Canadian Pacific Railway south of the Winnipeg River, from 18 to 28 miles west of Rat Portage, is about 200 feet above the Lake of the Woods and about 550 feet above Lake Winnipeg, rising thus nearly to the highest level of Lake Agassiz. English River, which flows through Lac Seul, or Lonely Lake, is a large tributary of the Winnipeg from the east. The only important affluent from the south is the Whitemouth River, draining a considerable area west of the Lake of the Woods. The water of Winnipeg River is very clear, and is strongly contrasted with the muddy water of Lake Winnipeg, with which it mingles at its mouth.

Red Lake River.—Originally the name Red River was applied by the Indians to the outlet of Red Lake, flowing westerly to Grand Forks and thence northerly to Lake Winnipeg, and the stream now called Red River was known to them as the Ottertail River from Ottertail Lake to its junction with the Red Lake River. Beltrami affirms, with poetic license, that the aboriginal names of Red Lake and of its outflowing river, the latter translated by him Bloody River, refer to the "blood of the slain" in the wars between the Ojibways and Dakotas.[2] This stream is the largest trib-

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[1] Keating's Narrative of Long's Expedition, Vol. II, pp. 82–102.

[2] A Pilgrimage in Europe and America, leading to the discovery of the sources of the Mississippi and Bloody River, Vol. II, pp. 335–340. Also see Keating's Narrative of Long's Expedition, Vol. II, p. 34.

Rev. J. A. Gilfillan, however, states that the Ojibway name of Red Lake perhaps alludes to "reddish, fine gravel or sand along the shore in places, which in storms gets wrought into the water near the edges," or to the reddish color of streams flowing into the lake from bogs on its north side. (Fifteenth Annual Report, Geol. and Nat. Hist. Survey of Minnesota, for 1886, p. 460.)

D. D. Owen, in the description of his canoe journey down the Red River, writes of its junction with the Red Lake River at Grand Forks: "The Red Fork of Red River, which flows from Red Lake, * * * is the stream to which the name of Red River properly belongs. The stream which we navigated is known to the Indians by the name of Ottertail River. The color of the waters of Red River proper also shows the origin of the name. They are of a reddish brown cast, and contrast strongly with the whitish, milky appearance of the stream coming from Ottertail Lake, and which henceforth assumes a darker hue."—Report of a Geological Survey of Wisconsin, Iowa, and Minnesota, 1852, pp. 176, 177.

MAP OF DRAINAGE SYSTEMS ON THE AREA OF LAKE AGASSIZ AND ADJOINING COUNTRY.

Scale, about 165 miles to an inch.

Nelson | Churchill | Other Tributaries of Hudson and James Bays | Mackenzie | Missouri | Upper Mississippi | St. Lawrence

The chief divisions of the Nelson drainage area are designated by red lines.

utary of the Red River from its east side. From Red Lake to the mouth of Thief River it flows west-northwest about 40 miles, measured in a direct line; next it flows south 16 miles to a point about 3 miles east of Red Lake Falls; thence west-southwest 21 miles to Crookston, and finally west and northwest 23 miles to Grand Forks. Its entire length, not measuring minor bends, is thus approximately 100 miles, but if the course of the river were followed in all its meanderings this distance would be nearly doubled. Its width varies mostly from 6 to 10 rods. At its mouth it has only about half as great width as the Red River above their junction, but probably carries an equal volume of water, as it flows with a much stronger current, estimated between 2 and 3 miles per hour at the stage of ordinary low water.

The Grand Marais, extending 22 miles from the Red Lake River near Fisher to a point on the Red River 12 miles below Grand Forks, is a former channel of the Red Lake River, now occupied by marshes, pools, and lakelets. The width of this deserted channel or valley, measured between the crests of its bluffs, varies commonly from 15 to 30 rods, rarely expanding to a quarter or third of a mile, and its depth below the general level of the valley plain is mostly about 20 feet. It is only half as deep, and averages probably not more than a fifth as wide, as the present river valley. During times of abundant rains, and especially when the snow melts in the spring a stream occupies the Grand Marais, but through the greater part of the year it has no running water. In a similar manner the Wild Rice River of Minnesota, along its lower portion, at first flowed in the present channel or valley of the Marsh River, from which it has turned away about 2 miles southeast of Ada to a more southerly course. Doubtless in each case a smaller stream had previously begun the erosion of the channel into which the river was diverted.

The fall of Red Lake River between Red Lake and Thief River is 73 feet, from 1,172 to 1,099 feet above the sea. Thence to its mouth it descends 315 feet, averaging more than 5 feet per mile in its direct course. Its banks and bed consist of glacial drift, excepting where this formation is covered by alluvial deposits, and consequently the stream has acquired a somewhat regular slope, broken, indeed, by frequent rapids where it runs over cobbles and bowlders, but having no abrupt falls. The height of the banks and of the adjoining country, which has a flat or slightly undulating contour, is generally 30 to 40 feet above the river; but in the vicinity of Red Lake Falls this stream and the Clear Water River, an important tributary to it from the southeast, have eroded their channels to the depth of nearly 100 feet. The range of these rivers from low to high water at Red Lake Falls is only 5 feet, and the descent of each is about 40 feet within 2 miles.

Red River.—The Red River of the North, so named to distinguish it from the Red River of Louisiana, has its source in a small lake about 1,550 feet above the sea, 13 miles west of Lake Itasca. It first flows south about 60 miles, measured in a direct line, passing in succession through Elbow, Many Point, Round, Height of Land, Little Pine, Pine, and Rush lakes to Ottertail Lake, this portion being commonly called Ottertail River. In this distance it descends to 1,315 feet above the sea. The contour of the adjoining country is rolling or hilly northward and undulating or flat southward.

Below Ottertail Lake this stream is called the Red River by this report, following the example of Owen and the prevailing popular usage; but it is still occasionally spoken of as Ottertail River to its junction with the Bois des Sioux River at Breckenridge and Wahpeton, 42 miles west of Ottertail Lake.[1] The descent in this distance is 372 feet, or about 5 feet per mile, following the course of the stream. It is most rapid in the vicinity of Fergus Falls, amounting to 80 feet in 3 miles, from 1,210 to 1,130 feet above the sea. Because of the numerous large lakes on the upper part of the stream, its volume along this descent to Breckenridge is not greatly affected by either heavy rains and snow melting or dry seasons. At Fergus Falls the range from its lowest to its highest stage is only 2 or 3 feet. Its banks and bed are the hard, stony clay of the glacial drift, affording a good foundation for dams and canals. From Ottertail Lake to the border of Lake Agassiz, 9 miles southwest from Fergus Falls, the

[1] The Ojibways, according to Rev. J. A. Gilfillan (l. c., p. 163), thus apply the name Ottertail River as far as to the Bois des Sioux; and the Red River thence northward is called by them Kitchi-zibi (Great River).

country is rolling and hilly, rising 50 to 100 feet above the river. Farther west the flat or slightly undulating surface of the lacustrine area soon sinks, so that the average height varies from 5 to 15 feet above the river in its ordinary low stage, yet its banks are seldom or never overflowed. The only noteworthy tributary to the Red River between Ottertail Lake and Breckenridge is the Pelican River, which joins it from the north 3 miles west of Fergus Falls. This stream, nearly 50 miles long in a straight line, flows through a rolling and hilly region, receiving the waters of many lakes, of which the largest are Detroit, Cormorant, Pelican, Lizzie, and Lida.

From its bend at Breckenridge and Wahpeton the Red River flows north 285 miles, measured in a direct line, to Lake Winnipeg. Its course through this distance has been already described in an earlier portion of this chapter, treating of the Red River Valley. The entire length of the Red River, measured thus in straight lines successively to the south, west, and north, is about 390 miles; but in its meanderings, nowhere diverging far from these lines, it flows nearly 700 miles. Its descent below Breckenridge is 233 feet, and in total from its source to its mouth approximately 840 feet. All the way below McCauleyville and Fort Abercrombie, 15 miles north of Breckenridge, it is navigated by steamboats, barges, and flatboats, but along the Goose Rapids, extending about 12 miles next below the mouth of Goose River as measured in the meandering course of the stream, the channel is obstructed by bowlders which forbid navigation during low stages of water. A broad belt of till, formed by the united Fergus Falls and Leaf Hills moraines, as described in Chapter IV, causes these rapids. The width of this river in the United States varies from 6 to 20 rods, being in some places less than the length of the steamboats; but north of the international boundary it is commonly 20 rods wide.

The range between the lowest and highest stages of the Red River increases rapidly north of Breckenridge, becoming 32 feet at Moorhead and Fargo, and attaining its maximum of 50 feet at Belmont. It continues nearly at 40 feet from Grand Forks to the international boundary and to Winnipeg. At Lower Fort Garry, 16 miles north of Winnipeg and about 20 miles from the mouth of the river, it is 35 feet; but beyond that point it rapidly diminishes in approaching Lake Winnipeg. Floods rising nearly or quite to the high-water line thus noted have been rare, occurring in 1826, 1852, 1860, 1861, and 1882. They are caused in the spring by the melting of unusual supplies of snow and by accompanying heavy rains, and often are increased by gorges of ice, which is usually broken up along the southern upper portion of the river earlier than along its lower course. These floods attain a height only a few feet below the level of the adjoining prairie where that is highest, and along the greater part of the distance between Grand Forks and Lower Fort Garry the banks are overflowed and the flat land on each side of the river to a distance of 2 to 4 or 5 miles from it is covered with water 1 to 5 feet or more in depth.

The noteworthy tributaries of the Red River on its east side, in their order from south to north, are the Buffalo, Wild Rice, Marsh, Sand Hill, Red Lake, Snake, and Tamarack rivers, the stream named Two Rivers for its two branches which unite 3 miles above its mouth, and Joe, Roseau, and Rat rivers; and on the west, the Bois des Sioux, Wild Rice, Sheyenne, Elm, Goose, Turtle, Forest, Park, Pembina, Marais, Scratching or Boyne, La Salle, and Assiniboine rivers. Excepting the Red Lake River, already described, and the Sheyenne, Pembina, and Assiniboine rivers, all these are small, the farthest portions of their areas of drainage being 40 to 75 miles from the Red River. In summer droughts several of them, including the Bois des Sioux, are dried up along the greater part of their course, containing only here and there pools in the deeper hollows of the channel.

Sheyenne River.—The Sheyenne, having its sources near the great southeastern bend of the Souris or Mouse River, in North Dakota, first flows to the east nearly 100 miles, passing 10 miles south of Devils Lake; next it flows south about 100 miles, to where it enters the area of Lake Agassiz; and thence its course is eastward and northward, uniting with the Red River 10 miles north of Fargo and Moorhead. Where it is crossed by the Jamestown and Northern Railroad, south of the west end of Devils Lake, its elevation is 1,410 feet above the sea. Thence it falls to 1,064 feet at Lisbon, and 857 feet at its mouth. Along its eastward and southward course it flows through an undulating or rolling and occasionally hilly region, in which its valley is eroded 100 to 200 feet deep. Within the area of Lake Agassiz it has cut 50 to 75 feet into its delta, and beyond occupies a channel 20 to 30 feet below the flat lacustrine plain. This lower portion of the river is mostly from 50 to 75 feet wide and 1 to 3 feet deep. The Maple River, flowing south and then northeast, parallel with the Sheyenne, joins this river about 8 miles from its mouth. The large valley of the upper part of the Sheyenne River, and its extensive delta deposited in Lake Agassiz, are attributable to a stream which was doubtless much larger than the present Sheyenne, formed by drainage from the ice-sheet when it terminated near Devils Lake. At that time, also, a glacial lake in the basin of the Souris outflowed southeastward to the Sheyenne and James rivers.

Langs Valley.—During a later stage in the recession of the ice-sheet the glacial Lake Souris was extended west and north of Turtle Mountain and finally found a lower outlet in southern Manitoba. Its outflowing river ran southeasterly from the elbow of the Souris, 18 miles southwest of its mouth, to the Pembina River. Pelican Lake, 11 miles long from northwest to southeast and about a mile wide, occupies a part of the channel of this stream; and a distinct water course of similar width, called Langs Valley,[1] eroded 110 to 150 feet below the general level, extends 11 miles between this lake and the Souris. The highest portion of Langs Valley is 1,364 feet above the sea, and about 100 feet above the Souris at its elbow, and is inclosed by bluffs 110 feet high. It is a channel similar to that of Lakes Traverse and Big Stone and Browns Valley, eroded by the River Warren, outflowing from Lake Agassiz.

Pembina River.—The Pembina River[2] flows from the northern part of Turtle Mountain in a rather crooked easterly course through southern Manitoba and the edge of North Dakota about 130 miles, measured in a direct line, to its mouth at Pembina and St. Vincent. From its junction with the outlet of Pelican Lake to Walhalla, at the base of the First Pembina Mountain, its valley varies from 175 to 450 feet in depth. Rock Lake and Swan Lake, on this part of the river, each several miles long and from a half mile to 1 mile wide, are due to deposits brought into this valley by tributaries after it ceased to be the avenue of drainage from the Souris

[1] Named for James Lang, who was the first immigrant here, coming in 1880.

[2] This name is stated by Keating to be from the Ojibway word "anepeminan, which name has been shortened and corrupted into Pembina," meaning the fruit of the bush cranberry (*Viburnum opulus*, L.).—Narrative of Long's Expedition, Vol. II, p. 38.

basin. In crossing the Red River Valley the Pembina runs in a channel only 20 to 40 feet deep. Its descent from the northern base of Turtle Mountain to Walhalla is about 700 feet, and thence to its mouth 186 feet, its junction with the Red River being 748 feet above the sea. Long or White Mud River, Clear Water or Cypress River, and Tongue River are its chief tributaries, all from the south side.

Assiniboine River.—The largest tributary of the Red River is the Assiniboine, which drains a basin in Assiniboia, Manitoba, and North Dakota, 300 miles wide from south to north and 400 miles long from west to east. From its source in the south edge of Saskatchewan, 50 miles southwest of the Porcupine Hills, the Assiniboine flows south-southeasterly 200 miles, to a point about 50 miles below the mouth of the Qu'Appelle and 40 miles west of Brandon; thence it flows easterly about 150 miles to its mouth. Its height above sea-level at the mouth of the Qu'Appelle is 1,264 feet; at the bridge of the Canadian Pacific Railway near Brandon, 1,161 feet; at the mouth of the Souris, about 1,075 feet; at Portage la Prairie, 842 feet, and at its junction with the Red River in Winnipeg, 724 feet. During its high stages of water the Assiniboine has been navigated by steamboats to Fort Pelly, about 90 miles above the mouth of the Qu'Appelle. Along this portion it varies from 10 to 25 rods in width.

The highest floods of the Assiniboine at Portage la Prairie and along a considerable distance eastward rise only 12 to 15 feet above its lowest stage, but they then attain a height only a few feet below the highest portions of the adjoining country, much of which is submerged. At this extreme height, which the river reached and maintained from the 3d to the 15th of May, 1882, the only time of such high water since 1860 or 1861, it overflowed near the former site of the fort of the Hudson's Bay Company, 2 miles southwest of Portage la Prairie, and a portion of its flood passed north in shallow, winding watercourses to Lake Manitoba, making a descent of about 40 feet in the distance of 15 miles between the river and the lake. Near the same time Lake Manitoba also reached its highest stage, about 8 feet above its lowest level, rising until it overflowed southward across the east part of township 13, range 6, and thence eastward through the southern row of sections in township 13, range 5, falling

10 feet in 15 miles to Long Lake, through which old channel of the Assiniboine its waters were discharged into this river 20 miles east of Portage la Prairie.[1]

The excavation of the Assiniboine basin, before mentioned in connection with the description of Pembina, Riding, and Duck mountains, depressing much of its area hundreds of feet below the great plains farther south, was effected by preglacial rivers. Over the irregular surface thus sculptured a thick covering of glacial drift is spread somewhat uniformly, so that the preglacial contour is preserved in the broader outlines of the country; but the smaller inequalities of the surface and the present watercourses have been formed during Glacial and Recent time.

While Lake Agassiz held nearly its highest level, the Assiniboine brought into its west side a vast delta of gravel and sand, which extends from Brandon 75 miles east to Portage la Prairie, and from Treherne, Glenboro, and Milford 40 miles north to Gladstone and Neepawa. Its area is fully 2,000 square miles, and its depth probably averages 50 feet, with a maximum of about 200 feet.

Qu'Appelle and Souris rivers.—The Qu'Appelle or Calling River and the Souris or Mouse River are the largest tributaries of the Assiniboine. Each of these streams has an interesting glacial history, which is recorded in the topographic features of their valleys and areas of drainage. The Qu'Appelle Valley was eroded by the outlet of a glacial lake in the basin of the South Saskatchewan River. The description, map, and sections given by Hind[2] show that this valley is quite uniformly about 1 mile wide, and is eroded from 110 to 350 feet below the general level of the region through which it lies, this height being reached by steep bluffs on each side. Its length from the elbow of the South Saskatchewan to its junction with the Assiniboine is about 270 miles, the general course being a little to the south of east. Of this extent the west end of the valley for about 12 miles is occupied by the River that Turns, and the remainder by the Qu'Appelle, the summit or height of land in this channel at the divide

[1] Compare H. S. Treherne's description of this vicinity, "An ancient outlet of Lake Manitoba," Ninth Annual Report of the Geol. and Nat. Hist. Survey of Minnesota, for 1880, pp. 388–392.

[2] Report of the Assiniboine and Saskatchewan Exploring Expedition, 1859, by Henry Youle Hind.

between these rivers being 85 feet above the South Saskatchewan, 440 feet above the mouth of the Qu'Appelle, and 1,700 feet above the sea. The inclosing bluffs are composed mainly of glacial drift, with only a few exposures of the underlying Cretaceous rocks. The alluvial bottom land of the Qu'Appelle is generally from a half mile to 1 mile wide, and through it the river flows in a winding course, here and there passing through long lakes. Like the similar lakes of the Pembina and Minnesota rivers, these owe their existence to the recent deposits of tributaries, and show that the bed of the glacial river was considerably lower than that of the present stream. The outflow of the Saskatchewan glacial lake, fed by the melting ice fields of an immense area reaching west to the Rocky Mountains, took its course east by this trough-like channel or valley, entering the Assiniboine at Fort Ellice and reaching the border of Lake Agassiz at Brandon.

Long or Last Mountain Lake, about 50 miles long from south to north and 1 to 2 miles wide, lying north of the upper part of the Qu'Appelle and tributary to it, occupies a similar glacial watercourse. The elevation of Long Lake is 1,598 feet, being about 100 feet lower than the divide in the channel from the elbow of the South Saskatchewan to the Qu'Appelle. It seems probable that when the ice-sheet had receded so far north as to allow the Saskatchewan Lake to extend to the district northwest and north of Long Lake, it there obtained some lower point of discharge and outflowed along the course of this lake, forsaking its former outlet.[1] Owing to the changes in relative elevation which have taken place in the region of Lake Agassiz since that time, this new outlet, or the earliest and highest one of several successive outlets, across the watershed between the Saskatchewan basin and Long Lake, may now be found 50 or perhaps even 100 feet higher than the old channel to the head of the Qu'Appelle—that is, 1,750 or 1,800 feet above the sea, the possible difference being probably as much as a foot to each mile of the distance between the old and new outlets.

Souris River, flowing circuitously southwestward from Assiniboia into North Dakota and thence northeastward into Manitoba, became tributary to the Assiniboine after the waters of the glacial lake in its own basin, at

[1] Report of the Assiniboine and Saskatchewan Exploring Expedition, 1859, pp. 28, 35, 118.

first flowing to the James and Sheyenne, had been wholly drained away by its outlet through Langs Valley and the Pembina River. The length of the Souris is nearly 400 miles, but it is only 5 to 10 rods wide along its lower portion. In North Dakota its descent is approximately from 1,650 to 1,400 feet above the sea, and thence to its mouth it falls about 325 feet.

Little Saskatchewan or Fairford River.—An area that extends more than 200 miles west from Lake Winnipeg and includes an equal distance in latitude, from the most northern part of Lake Winnipegosis to the south end of Lake Manitoba, is drained by the Little Saskatchewan or Fairford River.[1] Several small streams flow into the south end of Lake Manitoba, and the Water Hen River, the outlet of Lake Winnipegosis, flows into its north end. Four considerable streams are tributary to Lake Winnipegosis, namely; Mossy River, the outlet of Lake Dauphin, flowing into its south end, and the Swan, Red Deer, and Overflowing rivers at its northwest end. Riding and Duck mountains form the southwestern boundary of this basin, but the Porcupine Hills are entirely inclosed between the Swan and Red Deer rivers, and the latter drains much of the plateau bordered by the Pasquia Hills.

Saskatchewan River.—The lower part of the basin of the Saskatchewan, next to its mouth, was latest occupied by the ice-sheet; but that area was evidently relinquished by it, allowing this great river to take its present course, before Lake Agassiz began to be drained northeastward. From the most western sources of the Saskatchewan in the Rocky Mountains to its mouth is a distance of more than 700 miles, and the maximum width of its basin is about 350 miles. Its two branches, of nearly equal size, the North and South Saskatchewan rivers, unite 230 miles west of Lake Winnipeg. The elevation of the South Saskatchewan at Medicine Hat, where it is crossed by the Canadian Pacific Railway, is 2,137 feet; at its elbow, 1,619 feet, approximately, and at its junction with the North Saskatchewan, about 1,200 feet. Cedar and Cross lakes, through which the Saskatchewan flows

[1] The portion of this river extending 10 miles, with a descent of about 15 feet, from Lake Manitoba to Lake St. Martin, is commonly called the Fairford River, and the lower portion, extending 31 miles and falling 85 feet to Lake Winnipeg, is known as the Little Saskatchewan.—J. B. Tyrrell, Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. IV, for 1888-89, pp. 19-21A.

near its mouth, are approximately 114 and 108 feet above Lake Winnipeg, or 824 and 818 feet above the sea. Hind informs us that the name Saskatchewan means "the river that runs swiftly;" and he states that in the Grand Rapids, between Cross Lake and its mouth, it falls 43 feet in 2½ miles.[1] Its average descent per mile from Medicine Hat eastward is about 2 feet. The Saskatchewan and both its north and south branches for several hundred miles above their junction vary commonly from a sixth to a third of a mile in width, and during favorable stages of water are navigated by steamboats from Cedar Lake to Edmonton, on the North Saskatchewan, about 2,000 feet above the sea, and beyond the confluence of the Bow and Belly rivers, which form the South Saskatchewan, 50 miles west of Medicine Hat, at an elevation exceeding 2,200 feet. The chief hindrances to their navigation in low stages are shifting sand bars, over which they expand in some places to widths of a half mile to 1 mile, being very shallow and divided by low sandy islands. The adjoining country rises within a few miles from these rivers, or at the farthest 10 or 20 miles, to an elevation 300 to 600 feet or more above them, excepting along the last hundred miles of the Saskatchewan, where it flows through a broad lowland region. There the highest parts of the country are only 50 to 100 feet above the river, and its shores are generally low and in many portions swampy.

The smaller tributaries of Lake Winnipeg.—Besides the great affluents of Lake Winnipeg, namely, the Winnipeg, Red, Little Saskatchewan, and Saskatchewan rivers, about a dozen streams, varying in length from 10 to 40 miles, enter its west side, and twenty or more of similar or somewhat greater length enter its east side. Of the latter the largest are Berens and Poplar rivers, each about 100 miles long. The recession of the ice-sheet from southwest to northeast uncovered the entire region west of Lake Winnipeg, and probably the whole of the country traversed by these streams on the east, before its melting finally permitted the waters of the Glacial Lake Agassiz to be drained to the level of this lake.

Nelson River.—The outlet of Lake Winnipeg, as before noted, is bordered by no areas of highland along its course of about 400 miles to

[1] Report of the Assiniboine and Saskatchewan Exploring Expedition, 1859.

Hudson Bay. The upper half of the Nelson flows in a general direction only a few degrees east of north, passing through Great and Little Playgreen, Pipestone, Cross, and Sipi-wesk lakes, to Split Lake; thence it turns to the east for about 100 miles, passing through Gull Lake, and finally takes a northeastward course along its lower 100 miles. According to Dr. Bell's observation, Sipi-wesk Lake is approximately 570 feet above the sea, or 140 feet below Lake Winnipeg; Split and Gull lakes are respectively about 440 and 420 feet above the sea; and the descent in the next 48 miles, to the foot of Broad Rapid, is nearly 300 feet. The Nelson is navigable from the sea about 90 miles to the First Limestone Rapid, where the elevation is probably about 50 feet above the sea-level.

About four-fifths of the region drained by the Nelson, including the basins of the Red River of the North, the Little Saskatchewan, and the Saskatchewan, and the greater part or possibly all of the basin of the Rainy and Winnipeg river system, were uncovered from the ice-sheet and were tributary to Lake Agassiz as early as the middle portion of the time while it had its southward outlet. The waters of a large part of British America were thus carried along the course of the Minnesota and the Mississippi to the Gulf of Mexico. The basin of Lake Agassiz then included approximately 350,000 square miles, of which nearly a third was covered by the lake itself.

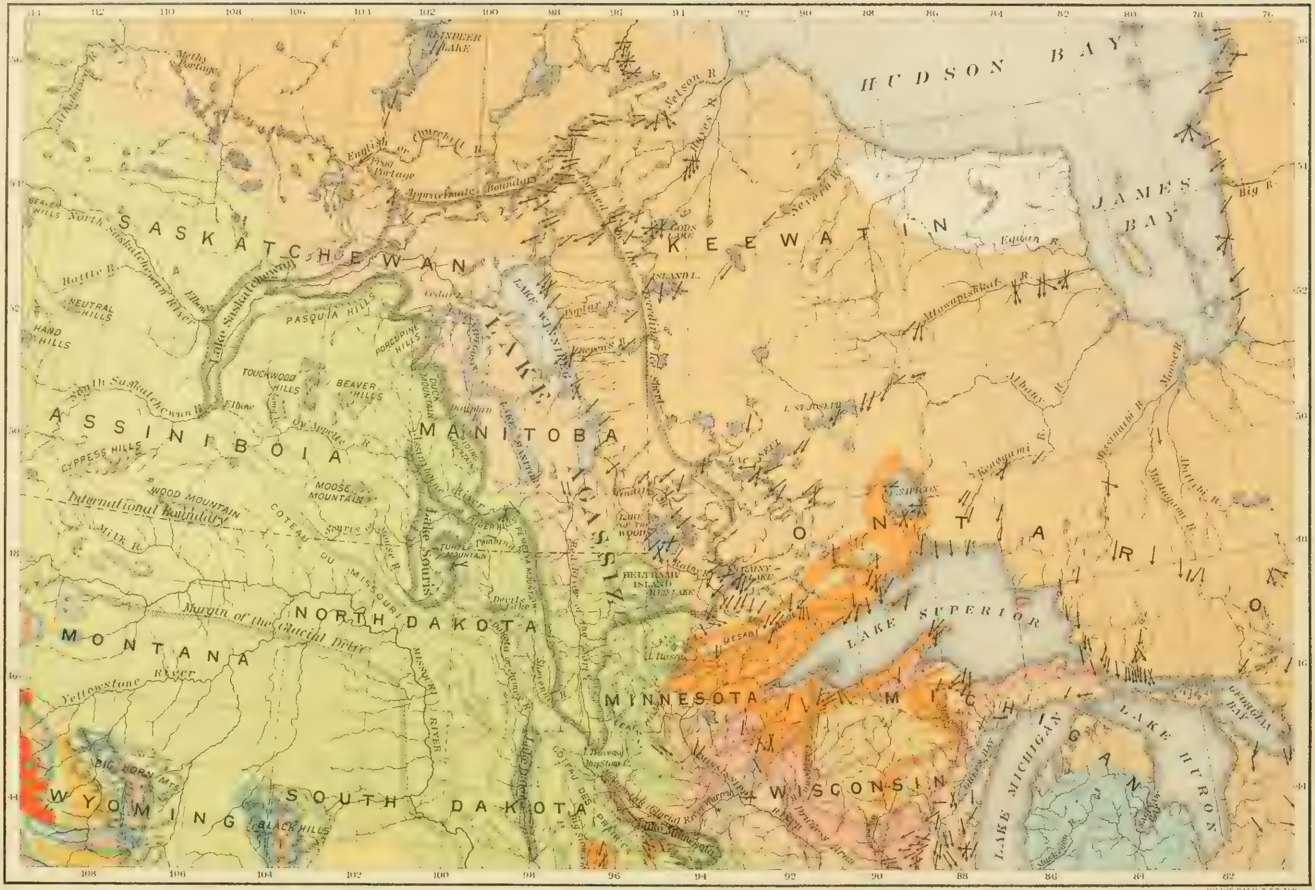
EXTENSION OF THE BASIN OF LAKE AGASSIZ BY GLACIAL LAKES OUTFLOWING TO IT FROM THE REGION OF THE PEACE AND ATHABASCA RIVERS.

Furthermore, within the time after the ice-sheet had retreated beyond the valley of the lower Saskatchewan, and before its melting upon Hudson Bay and the adjoining country permitted Lake Agassiz to gain an outlet to the northeast, it seems certain that the ice must have been melted upon a large region north of the Saskatchewan basin, where drainage now passes east by the Churchill and north by the Mackenzie, but was then pent up in lakes by the ice barrier and caused to flow to the south. Lake Agassiz thus received the waters of the upper Churchill, and of the basins of the Athabasca and Peace rivers, the great head streams of the Mackenzie;

and the Churchill, and probably also the upper Mackenzie basin, continued to be tributary to this lake through all its lower stages of outflow to Hudson Bay. With this addition, the area of the glacial lake basin was not less than 500,000 square miles.

Extensive areas bordering the Peace River are described by Dr. G. M. Dawson as "covered superficially by fine, silty deposits, resembling those of the Red River Valley, and doubtless indicating a former great lake or extension of the sea in the time immediately succeeding the Glacial period." The exploration of ancient shore-lines is very difficult in that generally forest-covered region, and it must be many years before the boundaries and outlets of former bodies of water in the basins of the Peace and Athabasca rivers can be mapped; but it may be predicted with reasonable confidence that these basins, now drained to the Mackenzie and the Arctic Ocean, will some time be found to have contained glacial lakes outflowing southeastward to Lake Agassiz. Probably the earliest outlet from the glacial lake of the Peace River was across the watersheds to Lesser Slave Lake and to the North Saskatchewan at its eastward bend, about 50 miles below Edmonton; and the latest outflow from the Athabasca glacial lake appears to have formed a channel across the Mackenzie and Churchill divide near the famous Methy Portage.

[1] Descriptive Sketch of the Physical Geography and Geology of the Dominion of Canada, 1884, p. 32.



MAP OF THE ROCK FORMATIONS UNDERLYING THE DRIFT ON THE AREA OF LAKE AGASSIZ AND ADJOINING COUNTRY.

Scale, about 165 miles to an inch.

Archean — Algonkian — Cambrian — Silurian and Devonian — Carboniferous — Triassic and Jurassic — Cretaceous — Eocene — Neocene — Volcanic — Unexplored

Chiefly from maps by Prof. C. H. Hitchcock and of the Geological Surveys of the United States and of Canada.

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CHAPTER III.

GEOLOGIC FORMATIONS UNDERLYING THE DRIFT.

Archean, Lower and Upper Silurian, Devonian, and Cretaceous formations succeed each other from east to west as the bed-rocks of the area of Lake Agassiz (Pl. XIV). They will be briefly described here in this order, which is that of their age and superposition, beginning with the oldest and lowest. Throughout large portions of this region, including the whole district drained by the Red River in Minnesota, the underlying rocks are covered by the glacial drift, and afford no outcrops; but their character and approximate boundaries on these tracts are inferred with much probability from the nearest outcrops, from topographic features, from the bowlders and other material of the drift, and from sections shown by deep wells which pass through the drift to the rocks beneath.

Intervening in stratigraphic order between the Archean and Silurian systems are large areas of the Algonkian and Cambrian systems, as mapped on Pl. XIV for the country about the west part of Lake Superior; but the Algonkian and Cambrian rocks probably have no outcrops on the Lake Agassiz area.

ARCHEAN FORMATIONS.

On the east side of the south part of Lake Agassiz a belt of Archean rocks extends from the Minnesota River northeast and north, partly covered west of Lake Superior by the Algonkian formations, through central and northern Minnesota, where it widens into the main area of these rocks in North America. This great Archean area stretches from Labrador and the lower St. Lawrence southwest to Georgian Bay of Lake Huron, west to Lakes Superior and Winnipeg, and thence northwest and north to the Arctic Sea. Its western border was covered by Lake Agassiz from the Lake of the Woods to the north end of Lake Winnipeg.

THE ARCHEAN AREA IN MINNESOTA.

The most southwestern outcrops of Archean formations in Minnesota are 10 to 20 miles southwest of the Minnesota River in Redwood and Yellow Medicine counties, where small isolated exposures of granite, gneiss, and schists occur. The deeply eroded valley of the Minnesota River, channeled by the River Warren, outflowing from Lake Agassiz, cuts through the drift sheet to the bed-rocks, which from Big Stone Lake to Little Rock Creek, 4 miles below Fort Ridgely, are Archean gneisses, varying from a granitoid to a schistose structure. In the next 13 miles no rocks older than the Cretaceous are found. Then comes the last Archean outcrop, a coarse granite, opposite to the southeast part of New Ulm, succeeded eastward by Algonkian conglomerate and quartzite. Observations of the strike and dip of the Archean rocks exposed in this valley show that the axial lines of their folds run mainly from southwest to northeast.

Central Minnesota has frequent Archean outcrops in Stearns, Benton, and Morrison counties, including the valuable quarries of St. Cloud, Sauk Rapids, and Watab. The greater part of this area is hornblendic granite, and exhibits no laminated or gneissic structure. It has considerable variety of texture as to its coarseness of grain and readiness to be quarried and wrought into any required form. Mostly its color is light-gray, but upon some extensive tracts it has a red tint similar to that of the celebrated granite of Aberdeen, in Scotland. In other portions of this district, micaceous granite, gneiss, and mica-schist are the common rocks, sometimes associated with hornblendic granite. Their strike is usually to the northeast or east-northeast. At Little Falls and Pike Rapids, on the Mississippi, and for several miles to the south, west, and north, as also in northern Todd County, and along the falls of the St. Louis above Fond du Lac, and thence northeastward, is a group of rocks quite different from the foregoing, its range of variation being from highly cleavable clay-slate, and from mica-schist, inclosing many crystals of staurolite and sometimes garnet and iron pyrites, to very compact, tough, and massive diorite. Comparing these rocks with the divisions of the Archean recognized in Canada and elsewhere, the granites and gneisses appear to represent the Laurentian, while the slate, staurolitic schist, and diorite are probably Keewatin.

VICINITY OF THE LAKE OF THE WOODS, RAINY LAKE, AND NORTHWARD.

Belts of granite, gneiss, schists, quartzites, and slates, belonging to the Archean group, alternate with one another, trending to the east or northeast, along the international boundary from the Lake of the Woods to Lake Superior. In the region about the Lake of the Woods they have been described very fully by Dr. A. C. Lawson.[1] The group is there divisible into two systems, the older being the Laurentian granitoid gneisses, and the newer a series of schists, quartzites, and slates, named by Lawson the Keewatin series. In later publications by Dr. Lawson on the geology of the Rainy Lake region,[2] his descriptions show that subsequent to the deposition of a measured thickness of 2 miles of mica-schists and granulitic gneisses, named by him the Coutchiching series, well developed about Rainy Lake, and of the Keewatin series north of Rainy Lake and about the Lake of the Woods, the whole Archean group in this district, comprising a vast thickness of sedimentary and volcanic rocks, and perhaps below these including a part of the first-formed crust of the globe, was subjected to metamorphism from the heat of the earth's interior, whereby the lowest beds observed, to which the name Laurentian is restricted by Lawson, were so fused that portions of them were extravasated through the overlying Coutchiching and Keewatin beds. Such division remains yet to be worked out for nearly all of the Archean area east and north of Lake Winnipeg, but is reported and mapped by Dr. Robert Bell in the country bordering the Hayes and Nelson rivers.

BOUNDARY OF THE ARCHEAN TOWARD THE WEST.

Though the western boundary of the Archean area in Minnesota is mainly covered by drift and by remnants of Cretaceous beds beneath the drift, it is somewhat definitely known for a distance of 160 miles from New Ulm west, northwest, and north, to the south end of Lake Agassiz. Crossing the Minnesota River from the north at New Ulm, it runs westerly about 40 miles, and thence northwesterly across Redwood, Yellow Medicine, and

[1] Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. I, 1885, Part CC.

[2] Am. Jour. Sci. (3), Vol. XXXIII, pp. 473–480, June, 1887. Geol. and Nat. Hist. Survey of Canada, Annual Report, Vol. III, for 1887–88, Part F.

Lac qui Parle counties almost parallel with the Minnesota River, but gradually approaching nearer to it and curving north to the mouth of Big Stone Lake. Thence, beneath a veneer of the Cretaceous shales and overlying glacial drift, it passes north-northeasterly to the west part of Grant County, where a well at Herman, 189 feet deep, encountered Archean rocks at a depth of 132 feet. This well first went through 124 feet of till, and then through 7 or 8 feet of fine-grained, buff magnesian limestone. The remaining 57 feet were quartzose granite, with red feldspar, white micaceous quartzite, and mica-schist of several varieties.[1]

Farther to the north, through Minnesota, this boundary is more conjectural because of the almost entire absence of exposures of the bed-rocks. Entering the area of Lake Agassiz east of Red Lake, it turns to the northwest and traverses a region wholly drift-covered, passing not far west of the Lake of the Woods.

North of the international boundary this limit of the Archean area extends a little west of north to the south end of Lake Winnipeg, a few miles east of the mouth of the Red River, and thence, continuing in the same direction, it follows the east shore of Lake Winnipeg along its whole extent to the mouth of the lake. The farther course of this line, according to the observations of Sir John Richardson and later explorations by Dr. Bell and others, of the Geological Survey of Canada, is west-northwest from the mouth of Lake Winnipeg and the west side of Great Playgreen Lake to the south side of Beaver Lake and Lac la Rouge, a distance of 275 miles, and thence it curves gradually to the northwest, crossing the Churchill at the north extremity of Isle à la Crosse Lake.

LOWER SILURIAN FORMATIONS.

In journeying from south to north along the Red River Valley, the first rock exposures found are Lower Silurian strata, chiefly magnesian limestones, which outcrop in Manitoba at numerous localities 12 to 20 miles north-northeast of Winnipeg, and similar outcrops, probably in part of Upper Silurian age, which rise above the general surface of drift 5 to 20 miles northwesterly from Winnipeg and at about the same distances west of

[1] Geol. and Nat. Hist. Survey of Minnesota, Sixth Annual Report, for 1877, p. 29; Final Report, Vol. II, 1888, p. 503.

the river. Farther north Lower Silurian rocks are exposed on many of the islands of Lake Winnipeg and along its western shore, but no exposures of the underlying Cambrian beds, which are penetrated by the artesian well at Grafton, N. Dak., have been found in this region. Against the western border of the folded and eroded Archean rocks the Lower Silurian formations repose with nearly horizontal stratification. Their general dip, varying from a few feet to 10 feet or more per mile, is westward, at right angles with the axis of Lake Winnipeg and the line of junction of the Archean and Paleozoic rocks.

Descriptions of the outcrops of Silurian and Devonian strata in Manitoba will prepare us to consider afterwards the sections of artesian wells farther south, which give evidence that Silurian formations immediately underlie the drift upon a large portion of the Red River Valley, on both sides of the international boundary and of the river, where no rock exposures exist.

Outcrops on Lake Winnipeg.—Near Grindstone Point, on the west side of Lake Winnipeg, 60 miles north from the south end of the lake, Hind observed a section of 18 feet of level limestone overlying 20 feet of sandstone, and refers it, upon the evidence of its fossils, to the Chazy epoch.[1] Beds of limestone, shale, and sandstone are also described by Hind on Deer Island, about 8 miles south of Grindstone Point, being apparently the same strata as at that locality; and Panton reports an extensive outcrop of limestone on the west part of Big Island, a few miles east from Deer Island, and other exposures of the same on Punk Island, 3 or 4 miles to the north. Black Bear Island, a few miles northwest from the Narrows at Dog Head, and Berens or Swampy Island, about 40 miles farther north, also contain low outcrops of limestone, which Panton, who refers them to the same formation with the foregoing, found sparingly fossiliferous on the former but richly so on the latter of these islands.[2]

[1] Report of the Assiniboine and Saskatchewan Exploring Expedition, 1859, p. 86. These beds seem equivalent with the well-defined limestone stratum, about 30 feet thick, richly fossiliferous, which has been commonly called the Trenton limestone in southeastern Minnesota, but which is recently referred by Mr. E. O. Ulrich to the Chazy or perhaps the Black River formation (Geol. and Nat. Hist. Survey of Minn., Fourteenth Annual Report, for 1885, p. 57).

[2] "Notes on the geology of some islands in Lake Winnipeg," by J. Hoyes Panton. Transactions of the Historical and Scientific Society of Manitoba, January 28, 1886.

The basal sandstone of these sections is the lowest formation exposed in this basin above the Archean rocks. It is regarded by Mr. J. B. Tyrrell, of the Canadian Geological Survey, who has recently examined the lake region of Manitoba, as of the same age with the Chazy limestone of New York and the St. Peter sandstone of the Upper Mississippi. He reports its thickness to be about 100 feet, consisting of "white quartzose sandstone, with generally well-rounded grains, running down, at the bottom, into a quartzose conglomerate."[1]

The overlying limestone, called the Trenton formation by Whiteaves and Tyrrell, appears to represent both the Trenton and Galena formations of the Mississippi Valley. It is described by Tyrrell as "consisting at the bottom of a mottled buff and gray dolomitic limestone, found at Big and Swampy islands, etc., and probably also at East Selkirk, above which are other horizontal and evenly bedded limestones and dolomites, amounting in all to a few hundred feet, and all more or less rich in fossils."[2]

Next in ascending order, these authors identify the Hudson River formation, the highest member of the Lower Silurian system, "represented by less than 100 feet of fossiliferous shales and dolomites," at Stony Mountain, at Clarks Point and Harbor, on the west shore of Lake Winnipeg, and, 10 miles south of the last-named locality, on the Little Saskatchewan River from 1 to 3 miles above its mouth.

East Selkirk.—Dolomitic limestone, having a light-buff or cream color, delicately and very irregularly streaked and mottled with light yellowish brown, is quarried in three localities near East Selkirk, on the Red River, about 20 miles north-northeast of Winnipeg. It has been much disturbed by glacial agencies, and most of the quarrying is of large detached blocks, which have been removed slightly from their original position and are embedded in the drift. In one of the excavations a thickness of 10 or 12 feet of the stone is seen in place, having a horizontal stratification, at an elevation approximately 730 to 740 feet above the sea. It contains abun-

[1] "Three deep wells in Manitoba." Trans. Roy. Soc. Canada, Vol. IX, sec. 4, 1891, p. 91. Summary Report of the Geological Survey of Canada for 1891, p. 18.

[2] J. B. Tyrrell, as before cited. J. F. Whiteaves, "The Orthoceratidæ of the Trenton limestone of the Winnipeg Basin." Trans. Roy. Soc. Canada, Vol. IX, sec. 4, 1891, pp. 77-90.

dant fossils, from which Mr. Whiteaves decides its age to be that of the "Galena limestones of the west, equivalent to the Utica shales."[1]

Lower Fort Garry.—About 5 miles southwest from these quarries, similar limestone is exposed on the west bank of the Red River, at Lower Fort Garry, commonly called the "Stone fort," and along a distance of a half mile to the south. It rises 15 to 20 feet above the river, its top being about 730 feet above the sea. This also contains many fossils, among which are several species, according to Panton, that are not found at East Selkirk, but occur at Stony Mountain. The same formation has another low exposure on the Red River, about 4 miles farther south. From the former of these outcrops, close to the fort, Owen collected fossils which he pronounced identical with those of the Upper Magnesian or Galena limestone of Wisconsin and Iowa.[2]

Stony Mountain.—Twelve miles north-northwest of Winnipeg, and an equal distance west of Lower Fort Garry, is the hill called Stony Mountain, well described by Panton as "like an island of limestone raised above the surface of the surrounding prairie some 60 feet. * * * It is several miles in circumference and resembles in outline the shape of a horseshoe. The west and north sides are quite steep, and along the escarpments the exposed edges of the strata are easily observed, while the east gradually slopes to the prairie level." The highest beds at the quarries on the west side of Stony Mountain are hard, brownish-gray, dolomitic limestone, about 40 feet thick (from 825 to 785 feet, approximately, above the sea), showing only few and obscure fossils, chiefly corals; next is a reddish-gray limestone, with clayey partings, about 10 feet, very fossiliferous, containing many brachiopod shells; and beneath these beds a well at the penitentiary penetrated 60 feet of partially cherty shales, varying in color from yellow to red.

Little Stony Mountain.—Eight miles south of Stony Mountain and 5 miles west-northwest of Winnipeg, an outcrop of limestone, known as Little Stony Mountain, has been quarried for lime-burning. The surface here rises 30 or 40 feet in a half mile, from east to west, to the limekiln and

[1] Descriptive Sketch of the Physical Geography and Geology of the Dominion of Canada, by A. R. C. Selwyn and G. M. Dawson, 1884, p. 37.

[2] Report of a Geological Survey of Wisconsin, Iowa, and Minnesota, 1852, p. 181.

quarries, which are about 800 feet above the sea, and thence it holds nearly this height westward. The limestone, shown to a depth of about 10 feet, is apparently the same as that forming the upper part of Stony Mountain. It lies in beds mostly 1 to 2 feet thick, horizontal, or in part dipping 1 to 2 degrees to the south-southwest.

Stonewall.—At Stonewall, 5 miles northwest of Stony Mountain, a hard and cherty limestone has been extensively quarried, exposing a vertical section of 17 feet. The upper layers of this rock to a thickness of 7 or 8 feet are white and fossiliferous, but it gradually changes below to a red stratum which has no fossils.

From his study of the fossils collected in these outcrops on the Red River and westward, Mr. Panton concludes that their ascending stratigraphic order is the same as their geographic order from east to west, and writes of the series as follows:

> The Selkirk rock has a most comprehensive group of fossils, there being representatives of several beds, but taking them as a whole the Trenton fossils are best represented. The rocks at Lower Fort Garry seem to indicate a transition bed between those of East Selkirk and the lower layer at Stony Mountain. They contain forms common to both. The fossils of the lower layers at Stony Mountain bear a marked resemblance to those found in the Hudson River group elsewhere, while the higher dolomitic beds and those of Stonewall probably border on the Niagara formation.[1]

UPPER SILURIAN AND DEVONIAN FORMATIONS.

West of these Lower Silurian strata, rocks of Devonian age, mostly pale-gray or buff magnesian limestones, occur on Lakes Manitoba and Winnipegosis, as reported in 1884 by Dr. G. M. Dawson; "and it is probable," he wrote, "that the intervening formations will be found to be extensively developed in the Lake Winnipeg region as it is more fully examined."[2]

Subsequent exploration of this region by Mr. J. B. Tyrrell has resulted in the discovery of Upper Silurian strata, containing fossils characteristic

[1] "Gleanings from outcrops of Silurian strata in the Red River Valley." Transactions of the Historical and Scientific Society of Manitoba, November 27, 1884.

[2] Descriptive Sketch of the Physical Geography and Geology of Canada, p. 37.

of the Niagara formation, on the lower part of the Saskatchewan River and on the east side of Lakes Manitoba and Winnipegosis. In the gorge of the Grand Rapids of the Saskatchewan this formation, according to Tyrrell, "consists in its lower portion of about 60 feet of buff, yellow, and white limestone, brecciated at the bottom and ripple-marked toward the top. Some bands are highly fossiliferous. * * * The upper portion of the formation consists of a considerable thickness of a compact or porous dolomite, often containing many impressions of salt crystals. * * * The highest beds at Stonewall may belong to this terrane."[1]

Overlying the typical Niagara dolomites, Mr. Tyrrell finds, near the northeastern angle of Lake Manitoba, "a few feet of thick-bedded stromatoporoid magnesian limestone holding *Pycnostylus Guelphensis*," which he thinks to be probably referable to the Guelph formation, next above the Niagara in the Upper Silurian series.

The succeeding strata of this district, in ascending order, shown to be soft shales in the sections of wells at Rosenfeld and Morden, have not been found in outcrops. These beds doubtless represent higher formations of Upper Silurian age and the base of the Devonian system, which latter seems to be identified by fossils of the Morden section.

Devonian strata are reported by Tyrrell on the western shores and islands of Lake Manitoba and Lake Winnipegosis, being especially well exhibited in the islands of Dawson Bay and of Swan Lake, which lies a few miles south of this bay. Above an exposure of a few feet of red shales, the Devonian series in these outcrops comprises 200 feet or more of fossiliferous magnesian limestone, an overlying thickness of 50 to 70 feet of calcareous shales, whose horizon is marked by many brine springs, and higher beds of richly fossiliferous limestone.[2]

All the Paleozoic formations in the lake region of Manitoba, from the St. Peter sandstone to the highest Devonian beds exposed, are stated by Mr. Tyrrell to be "practically conformable and almost undisturbed through-

[1] "Three Deep Wells in Manitoba." Trans. Roy. Soc. Canada, Vol. IX, sec. 4, 1891, p. 91.

[2] J. B. Tyrrell, paper before cited; also, Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. IV, for 1888–89, pp. 21, 22A. J. F. Whiteaves, "Descriptions of some new or previously unrecorded species of fossils from the Devonian rocks of Manitoba," Trans. Roy. Soc. Canada, Vol. VIII, sec. 4, pp. 93–110, with seven plates.

out." At Point Wilkins, on the west side of Dawson Bay, the Dakota sandstone, forming the base of the Cretaceous series which underlies the drift farther west, was seen lying on the eroded surface of the horizontally stratified Devonian limestones.

Along the Saskatchewan, Silurian and Devonian strata, mainly limestones, reach from Lake Winnipeg to Fort à la Corne, about 12 miles below the junction of the south and north branches of this river. Thence to the northwest and north, a belt of these rocks, in large part almost horizontally bedded, skirts the west side of the Archean area to the Arctic Sea.

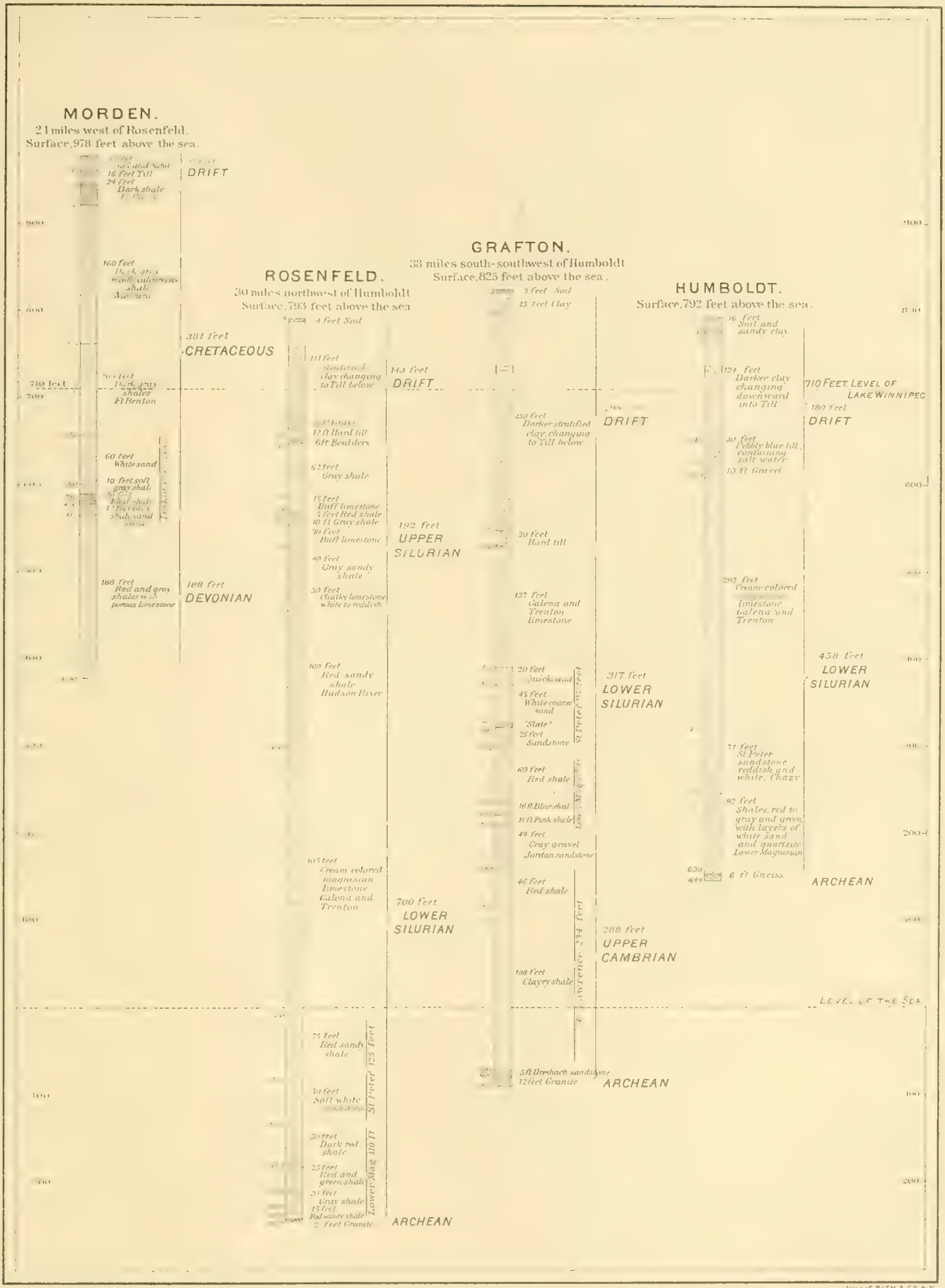
SECTIONS OF ARTESIAN WELLS IN PALEOZOIC STRATA.

Four deep borings for artesian water reveal the order and thickness of the several members of the Paleozoic group forming the floor of the Red River Valley beneath the drift in the vicinity of the international boundary. These wells, in their order from east to west, are situated at Humboldt in Minnesota, Grafton in North Dakota, and Rosenfeld and Morden in Manitoba. Notes of their sections are presented in the following pages, and their stratigraphic relationship is shown in Pl. XV.

The well at Morden penetrates only to the base of the Devonian or top of the Upper Silurian. The Rosenfeld well, entering the bed-rocks at a horizon near that where the Morden well left off, gives apparently a complete section of the Upper and Lower Silurian series, passing at its bottom through the Lower Magnesian formation, which is the base of the latter, lying next below the St. Peter sandstone. Another section of the Lower Silurian formations, from the Galena and Trenton to the Lower Magnesian, is supplied by the well at Humboldt; and the Grafton section, besides duplicating that of Humboldt, passes nearly 300 feet beyond in probably Upper Cambrian strata, referable to the Jordan, St. Lawrence, and Dresbach formations of the St. Croix series.

WELL AT HUMBOLDT, MINN.

Humboldt is a station of the Great Northern Railway, about 7 miles southeast of St. Vincent, at the farm of Mr. D. H. Valentine, on which this well is situated. It is on the flat plain of the Red River Valley, 6 miles



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SECTIONS OF WELLS AT HUMBOLDT, MINN; GRAFTON, N.D; AND ROSENFELD AND MORDEN, MANITOBA.

east of the river and 5 miles south of the international boundary. The elevation of the surface is 792 feet above the sea, being a few feet above the highest flood stage of the Red River. On account of the saltness of its water, an analysis of which is given in Chapter X, the well is not used.

Prof. N. H. Winchell has reported this section,[1] shown by samples from the boring, a summary of which is as follows:

Section of an artesian well, Humboldt, Minn.

	Feet.
Soil and very fine sandy clay, stratified	16
Moister and darker, more impervious clay, apparently a downward continuation of the foregoing, but probably including pebbles and bowlders, at least sparingly, in its lower portion, being there bowlder-clay or till	124
Pebbly blue till, containing salt water in small quantity at 165 feet below the surface	30
Drift gravel and sand, mainly a gray sand, but containing pebbles up to an inch in diameter, mostly of limestone; supplying an abundant artesian flow of salt water	10
Cream-colored magnesian limestone, of grain and texture like the Lower Magnesian in southeastern Minnesota [and equally like the Galena or Upper Magnesian and Trenton formation in Manitoba], showing near its base some intermixture of grains of white quartz	295
Sandstone, composed of rounded quartz grains, reddish in its upper part for 25 feet, white in its central part, from both of which the artesian flow of salt water increased, and faintly reddish in its lowest 10 feet	71
Shales, varying in color from red and brown to gray and green, with occasional siliceous layers that vary from white sand to slightly calcareous, grayish quartzite	92
Gneiss or granite, composed of opaque gray quartz, flesh-colored orthoclase, also a white feldspar and black mica, "evidently one of the Laurentian granites as seen at the Lake of the Woods," into which the boring extended	6
Total	644

Drift deposits here reach a depth of 180 feet, below which are 458 feet of strata referable to the Trenton, Chazy, and Calciferous series of the Lower Silurian system.

[1] Geol. and Nat. Hist. Survey of Minnesota, Thirteenth Annual Report, for 1884, pp. 41–46.

Next beneath the drift is a thick formation of magnesian limestone, shown by comparison with the other wells to be the Galena and Trenton strata, classed together as one formation under the second of these names by Whiteaves and Tyrrell, which outcrops at a distance of 75 to 85 miles northward, in the vicinity of Lower Fort Garry and East Selkirk, Manitoba. Its top and bottom at Humboldt, however, are respectively 612 and 317 feet above the sea, the entire formation here being thus beneath the level of Lake Winnipeg. In southeastern Minnesota, southwestern Wisconsin, and adjoining portions of Iowa and Illinois, the Galena and underlying Trenton limestones together range from 200 to 300 feet or more in thickness.

The sandstone next below, having a thickness of 71 feet, is evidently the equivalent of the St. Peter sandstone, referable to the Chazy epoch, which in southeastern Minnesota underlies the Trenton limestone, and ranges in thickness there from about 75 feet to 164 feet. Its continuation in Wisconsin, as described by Chamberlin and Irving, averages probably between 80 and 100 feet thick, varying from a maximum of 212 feet down to a fraction of 1 foot. In this and adjoining States, according to Irving, it is continuous "over a region whose diameters are 500 and 400 miles."[1]

Beneath this the Humboldt well penetrated 92 feet of shales, partly arenaceous and calcareous, which correspond to the Lower Magnesian or Shakopee limestone of southeastern Minnesota, ranging from 96 feet in thickness at Shakopee to 200 feet in Houston County, while in Wisconsin it is from 65 to 250 feet thick. The reports of the geological surveys of these States regard this formation as of Upper Cambrian age, but Walcott, in his more recent review of the Cambrian,[2] assigns the Lower Magnesian limestone wholly or mainly to the base of the Lower Silurian system. Its eastern equivalent is the Calciferous sandrock of New York.

The entire Cambrian and Algonkian systems are wanting in this section, and the Lower Silurian strata rest directly on the Archean crystalline rocks.

[1] Geology of Wisconsin, Vol. I, pp. 145–150; Vol. II, p. 555.

[2] U. S. Geol. Survey, Bulletin No. 81, 1891, p. 363.

WELL AT GRAFTON, N. DAK.

The city of Grafton is also on the Red River Valley plain, being situated 12 miles west of the river and 40 miles south of the international boundary, at an elevation of 825 feet above the sea. Its distance from Humboldt is about 38 miles to the south-southwest. The following record of the boring here was made by the engineer in charge during the progress of the work, and was supplied to me by the mayor, Mr. J. Tombs, at the time of my visit to Grafton in the survey of the shore-lines of Lake Agassiz. It has been published by the Dakota commissioner of immigration.[1]

Section of an artesian well, Grafton, N. Dak.

	Feet.
Black loam	3
White clay	25
Blue clay	250
Hardpan	20
Limestone	137
Quicksand	20
White, coarse sand	45
Slate	3
Sandstone, yielding a copious flow of brackish water	25
Red shale	60
Blue shale	16
Pink shale	11
Gray gravel	49
Red shale	46
Soapstone [clayey shale]	188
Sandstone, yielding a small flow of very salt water	5
Granite	12
Total	915

Glacial drift, doubtless mostly till, with a thin covering of lacustrine and alluvial clay, reaches to the depth of 298 feet.

The limestone next encountered, with a thickness of 137 feet, evidently is the lower portion of the thick formation of limestone of Galena and

[1] Resources of Dakota, 1887, p. 188.

Trenton age, found next beneath the drift in the Humboldt well, its upper part here having been lost by erosion.

The St. Peter sandstone occupies a thickness of 93 feet.

Red, blue, and pink shales, representing the Lower Magnesian formation, ensue, with a thickness of 87 feet.

The next stratum, 49 feet thick, is probably the equivalent of the Jordan sandstone, the highest division in the St. Croix series of the Upper Cambrian. Its thickness in southeastern Minnesota ranges from 40 to 116 feet, and in Wisconsin, where it is known as the Madison sandstone, it is from 30 to 60 feet thick.

The succeeding shales, having a thickness of 234 feet, appear to represent the St. Lawrence formation, the second in the St. Croix series, which in southeastern Minnesota varies from 128 to 213 feet in thickness.

Beneath the shales, the thin bed of water-bearing sandstone, lying on the granite, may be a trace of the Dresbach sandstone, a third division of the St. Croix, which has a thickness of 50 to 80 feet or more in southeastern Minnesota. The brine rising from this bed was analyzed by Prof. Henry Montgomery, of the University of North Dakota, and was found to be more saline than sea water.

Samples of the borings in the lowest 12 feet were submitted to Prof. N. S. Shaler, who pronounced them to be granite or gneiss, being the Archean bed of the ocean in which the overlying Paleozoic strata were deposited.

The water used from this well is taken from the St. Peter sandstone, the lower part of the bore having been filled. The diameter of the pipe is 6 inches, and the flow, according to three measurements in 1886 and 1887, during the first year after the completion of the well, was 800 gallons per minute.

WELL AT ROSENFELD, MANITOBA.

Rosenfeld is situated 14 miles north of the international boundary and 11 miles west of the Red River, being 30 miles northwest of Humboldt, and about 54 miles distant, in a direction slightly west of north, from Grafton. Like Humboldt and Grafton, it is on the flat plain of the Red

River Valley, and the elevation is the same as at Humboldt, within 1 foot, the railway at Rosenfeld, 3 feet above the surface at the well, being 796 feet above the sea. A summary of the section of this well, according to records and samples of the boring supplied by Mr. W. E. Swan, who drilled it,[1] is as follows:

Section of an artesian well, Rosenfeld, Manitoba.

	Feet.
Black soil	4
Fine silt or clay, alluvial and lacustrine in its upper portion, but below probably including a considerable thickness of bowlder-clay or till	111
Sand and gravel	10
Bowlder-clay ("hardpan")	12
Bowlders	6
Gray shale	62
Cream-colored or buff limestone	15
Red shale	5
Gray shale	10
Cream-colored limestone, beneath which was encountered a small artesian flow of salt water	30
Fine gray sandstone or sandy shale	40
Chalky limestone, varying in color from white to pale greenish and reddish gray	30
Red shale, containing much subangular quartz, in grains which are very irregular in size, some being quite coarse	160
Cream-colored magnesian limestone, beneath which came an additional artesian flow of salt water	305
Red shale, with much quartz in subangular grains	75
Soft sandstone, consisting of rounded and polished quartz grains, white, but reddish in the drillings from its upper portion, apparently because of admixture of the overlying shale; yielding a large artesian flow of salt water, the supply of which was increased to four times its previous quantity	50
Dark-red shale, with greenish-gray interlaminations	50
Reddish and greenish shale	25

[1] Published by Prof. N. H. Winchell in the Fourteenth Annual Report of the Geol. and Nat. Hist. Survey of Minnesota, for 1885, p. 15; and by Dr. G. M. Dawson, "On certain borings in Manitoba and the Northwest Territory," Trans. Roy. Soc. Canada, Vol. IV, sec. 4, 1886, pp. 85–91. Dr. Dawson supplements the brief record kept by Mr. Swan with many descriptive notes from his examination of the samples; and his identification of the lower formations, which this well has in common with the Humboldt and Grafton wells, is here followed. The strata above the Galena limestone were referred by Dawson wholly to the Hudson River epoch; but comparison with the Morden well indicates that they probably include not only Hudson River beds, but also the Niagara and other Upper Silurian formations, nearly or quite to the base of the Devonian.

	Feet.
Bluish and gray shale	20
Red shale or clay, inclosing much quartz sand	15
Granite or gneiss, chiefly composed of quartz and red feldspar in rather small crystals	2
Total	1,037

Alluvial and lacustrine silts and drift deposits reach a depth of 143 feet, the top of the bed-rock being 60 feet below the level of Lake Winnipeg. Examining the succession of strata penetrated below, we confidently recognize the thick limestone formation which extends between the depths of 495 and 800 feet as the same that is found with nearly as great thickness in the Humboldt well. It is referable, as Dr. Dawson concludes, to the Galena limestone, passing below into the Trenton. In the distance of 30 miles from Humboldt this limestone sinks somewhat more than 300 feet, averaging between 10 and 11 feet per mile. Comparison with the Grafton well, in which the base of this formation lies 73 feet higher than at Humboldt, indicates an approximately west-northwest direction for the maximum dip of the strata here, so that probably they sink at about the same rate, nearly 11 feet per mile, in the distance of 24 miles from Rosenfeld west to Morden, as from Humboldt northwest to Rosenfeld. Such inclination from the top of the section under the drift at Rosenfeld would coincide very nearly (as shown in Pl. XV) with the bottom of the Morden well, from which Mr. Tyrrell reports fossils belonging to the lower part, probably the base, of the Devonian series.

From these considerations, it appears that the 192 feet of shales, limestones, and sandstone shown by this section next below the drift must represent the whole Upper Silurian series of this district, and that the lower 100 feet of this thickness are probably the Guelph and Niagara formations. The lowest of these limestones, 30 feet thick, seems to be the equivalent of the limestone of Stonewall and the top of Stony Mountain.

The Lower Silurian series includes the next 160 feet of red shale, belonging to the Hudson River formation; the 305 feet of Galena and Trenton limestone; the underlying red shale and St. Peter sandstone, together 125 feet thick; and, finally, 110 feet of shales, occupying the place of the Lower Magnesian limestone.

WELL AT MORDEN, MANITOBA.

Morden is due west of Rosenfeld at a distance of 24 miles, lying on the border of the broad plain which extends from the Red River to the Pembina Mountain. Its elevation is 978 feet above the sea. A well, reported by Tyrrell, was drilled here to the depth of 600 feet, during the winter and spring of 1889–90, with the hope of obtaining artesian water. Its section was alluvial sand and fine gravel, 15 feet; till, 16 feet; gray Cretaceous shales, referred to the base of the Fort Pierre formation and the next lower Niobrara and Fort Benton formations, 289 feet; the white Dakota sandstone, 92 feet; and red and gray shales, with porous limestone, representing, as shown by their fossils, probably the base of the Devonian system, 188 feet. The westward dip of the strata in the Humboldt and Rosenfeld wells carries them beneath the bottom of the Morden well. No artesian flow was obtained at Morden, but from the top of the Dakota sandstone strongly saline water rose to within 6 feet of the surface.

CRETACEOUS FORMATIONS.

Cretaceous beds lie on the west border of the Archean rocks in Minnesota; and farther north, along the west side of the lower part of the Red River Valley and of Lakes Manitoba and Winnipegosis, they rest upon the Lower and Upper Silurian and Devonian strata that form the floor of this broad, flat valley, beneath its glacial, lacustrine, and fluvial deposits. Thence northwestward to the Mackenzie and the ocean Cretaceous beds border and overlie the west part of the Silurian and Devonian belt. West of Lake Agassiz the Cretaceous area has a width of 600 to 700 miles, including the entire region of the elevated plains, and terminating at the east base of the Rocky Mountains.

Marine series of the Upper Missouri.—In the region of the Upper Missouri River, formations belonging to the middle and later portions of the Cretaceous period are well developed. Meek and Hayden there identified five members of this system, in descending order as follows:[1] The Fox Hills formation, gray, ferruginous, and yellowish sandstone, and arena-

[1] Report of the U. S. Geological Survey of the Territories, 1870, p. 87.

ceous shales, 500 feet; the Fort Pierre formation, dark-gray and bluish shales and plastic clays, 700 feet; the Niobrara formation, lead-gray calcareous marl, passing down into light-yellowish and whitish limestone, 200 feet; the Fort Benton formation, dark-gray laminated shales and clays, sometimes alternating near the upper part with seams and layers of soft gray and light-colored limestone, 800 feet; and the Dakota formation, yellowish, reddish, and occasionally white sandstone, with, at places, alternations of various-colored shales and beds and seams of impure lignite, 400 feet. Leaves of dicotyledonous trees, including many genera still existing, are found in the Dakota formation; also a few species of fresh-water or brackish-water and marine shells. The formations here enumerated above this are marine deposits, as shown by plentiful fossils throughout the greater part of the series.

More recent classifications by King, White, and Eldridge unite the two members of this series next above the Dakota, naming them together the Colorado formation; and in like manner the succeeding two still higher are united and named the Montana formation.[1] For the purpose of the present chapter, however, it will be more convenient to use the older designations.

In the South Saskatchewan basin.—North of the international boundary, the development of these portions of the Cretaceous system in the region of the Bow and Belly rivers, which unite to form the South Saskatchewan, is reported by Dr. George M. Dawson as follows: The Fox Hills sandstone, in some parts of the district well defined as a massive yellowish sandstone, but inconstant, 80 feet; the Fort Pierre formation, neutral-gray or brownish to nearly black shales, marine, 750 feet; the Belly River formation, an extensive fresh-water and brackish-water series, consisting of sandy argillites and sandstones, the upper portion characteristically pale in tint, the lower generally darker and yellowish or brownish, probably of the same age with the Niobrara formation, 910 feet; and lower dark shales, observed on the upper part of Milk River, regarded as representing the Fort Benton member of the Upper Missouri section, 800 feet. The lowest or Dakota formation is not recognized in that district. Valuable beds of lignite are

[1] C. A. White, "Correlation Papers—Cretaceous," U. S. Geological Survey, Bulletin No. 82.

found in the Belly River series and at the base and top of the Fort Pierre formation. "The Belly River series," Dawson writes, "appears to correspond precisely to that occupying a similar stratigraphical position on the Peace River, and there designated the Dunvegan series. These indicate the existence of a prolonged interval in the western Cretaceous area during which the sea was more or less excluded from the region, and its place occupied for long periods by lagoons or fresh-water lakes."[1]

Along the Manitoba escarpment.—The Cretaceous series forming the Manitoba escarpment and underlying its base has been recently studied and described by Mr. J. B. Tyrrell, of the Canadian Geological Survey.[2] He divides the Fort Pierre formation into two parts, naming the upper part, about 500 feet in thickness, the Odanah series. This division "consists almost entirely of greenish-gray clay shale, which, when wet and in place, is soft enough to be easily cut with a knife, but on drying becomes quite hard and brittle. It occupies all the top of the Pembina and Riding mountains, but farther north no exposures of this series were seen, the country throughout being very thickly covered with drift. No fossils of any kind were found in this terrane."

The lower part of the Fort Pierre shales, named the Millwood series, also mainly about 500 feet thick, and attaining a maximum of 664 feet in the well bored at Deloraine, "consists of soft, dark-gray clay shales, with nodules of ironstone in which many species of typical Pierre fossils have been found. The terrane is well exposed at Millwood, 18 miles above Fort Ellice, on the Assiniboine River, and it may also be seen in the gorges cut by the Ochre and Wilson rivers on the northeastern face of the Riding Mountain, in the gorge of North Pine River in the Duck Mountain, and * * * on the eastern face of Porcupine Mountain."

The Niobrara formation, as recognized by Tyrrell in borings on the Vermillion River at the northeastern base of the Riding Mountain escarp-

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[1] Geol. and Nat. Hist. Survey of Canada, Report of Progress for 1882–83–84; and Descriptive Sketch of the Physical Geography and Geology of Canada, 1884.

Sir William Dawson, Whiteaves, and Cope find the fossils of the Belly River series "identical with those of the Laramie." Am. Naturalist, Vol. XXI, p. 171, February, 1887.

[2] "The Cretaceous of Manitoba," Am. Jour. Sci. (3), Vol. XL, pp. 227–232, September, 1890; and "Foraminifera and Radiolaria from the Cretaceous of Manitoba," Trans. Roy. Soc. Canada, Vol. VIII, sec. 4, 1890, pp. 111–115.

ment, and at Morden and Deloraine,[1] varies in thickness from 128 to 545 feet. It comprises gray, principally calcareous shales, with "a band of light-gray chalk, or mottled-gray chalk marl, about 200 feet in thickness, outcropping along the foot of the Porcupine, Duck, and Riding mountains, but lying below what is generally known as the Pembina escarpment on the eastern face of the Pembina Mountain. * * * The Niobrara is generally harder and more resistant than the terranes either above or below it, and it often forms little abrupt cliffs in the midst of an otherwise gently sloping country. It is, however, by the constant presence of great numbers of foraminifera that this terrane can be identified with the greatest ease either in natural exposures or in the mud or small fragments of rock taken from the wells bored with a percussion drill. These drillings, as a rule, appear very uninviting to the geologist, but in the present case, when they are carefully washed free from the impalpable clay that forms a large part of their bulk, and examined under the microscope, they are found to determine the Niobrara horizon with almost as much accuracy as if good hand specimens of the rock had been obtained."[2]

In these borings the Fort Benton formation is represented by a stratum of gray shales, from 105 to 178 feet thick, underlain by the Dakota sandstone, which had a thickness of only 19 feet on the Vermillion River, and, with interbedded shales, was found to be 92 feet thick at Morden, resting in both these wells on Devonian strata. Elsewhere in this district, outcrops of the Dakota sandstone, and wells penetrating it, show that its thickness ranges from 50 to 150 feet.

The brackish- and fresh-water Laramie formation.—The marine Cretaceous strata of the Upper Missouri country are overlain by the highest member of this system, the Laramie formation, which was deposited in brackish and fresh water. This series covers a broad belt in North Dakota and Montana, and stretches southward to Mexico and northwestward into Assiniboia and Alberta. It is also well developed, but with interruptions, along the Mackenzie to the Arctic Sea. The paleontologic characters of the Laramie beds caused it to be long held in dispute whether they

[1] "Three Deep Wells in Manitoba," Trans. Roy. Soc. Canada, Vol. IX, sec. 4, 1891, pp. 91–104.

[2] Trans. Roy. Soc. Canada, Vol. VIII, sec. 4, 1890, p. 113.

should be classed with the Cretaceous or the Eocene, since they contain reptilian fossils of Cretaceous types, mollusks' allied partly with the Cretaceous and partly with the Eocene, and a flora resembling that of the Miocene in Europe. From the presence of beds of lignite coal, the name Lignitic was formerly often applied to this formation.

In the Missouri and Saskatchewan region the Laramie series consists mainly of sandy shales and sandstones. The similar strata in the vicinity of the Bow and Belly rivers, referred to the Laramie by Dawson, have a thickness of 5,750 feet, and are wholly fresh-water deposits except near their base. On the Missouri River this series reaches from near Bismarck westward by Fort Union and across the Yellowstone to the Milk and Musselshell rivers. At Sims, on the Northern Pacific Railroad, about 40 miles west of Bismarck, it contains a layer of lignite 8 feet thick, which is extensively mined. Northward the Laramie series occupies the upper portion of the basin of the Souris or Mouse River, and forms the Missouri Coteau to the Canadian Pacific Railway and the South Saskatchewan, and probably will be found continuous northwest along this coteau to the North Saskatchewan. Near the base of Turtle Mountain, which beneath its thick covering of drift is an extensive outlying area of Laramie strata, also on the Souris, and on the Bow and Red Deer rivers, head streams of the South Saskatchewan, the lower part of this formation bears workable seams of lignite, apparently on nearly the same horizon with the mine at Sims, in the central part of North Dakota.

The western plains a lacustrine and land area since the early part of the Laramie epoch.—Miocene conglomerate, sandstone, and sandy clays, of fluvial and lacustrine deposition, are found lying on the Laramie and other Cretaceous formations in the Hand Hills, northeast of Red Deer River, and in the Cypress Hills, between the South Saskatchewan and Milk rivers. They are remnants of strata that probably once thinly overspread considerable portions of the upper Saskatchewan region. Five hundred miles southeast from the more southern of these localities an extensive area of fresh-water Tertiary deposits, of Miocene and Pliocene age, begins on White River, in the southwestern part of South Dakota, and reaches southward through Nebraska to western Kansas. No marine Tertiary formations are known in this interior portion of the continent. Since the early stages of the Laramie epoch, the bed of the Cretaceous ocean now forming the great belt of plains that stretches west from the lake district of Manitoba, the Red River Valley, and eastern Nebraska and Kansas, to the Rocky Mountains, has not been submerged beneath the sea.

FORT PIERRE SHALES WEST OF LAKE AGASSIZ.

The ascent upon Cretaceous strata, at the south a massive ridge and at the north a bold escarpment, on the western border of the valley in which Lake Agassiz lay, called in successive portions the Coteau des Prairies, Pembina, Riding, and Duck mountains, and the Porcupine and Pasquia hills, has mostly so thick and continuous a covering of glacial drift that only few exposures of the underlying strata are seen, chiefly where channels have been eroded by streams. Throughout their extent of 800 miles the ridge and escarpment appear to consist mainly of the Fort Pierre formation, presenting a thickness of several hundred feet of dark shales, mostly soft and somewhat sandy. Under the Fort Pierre beds are similar shales belonging to the Niobrara and Fort Benton formations, succeeded below by the Dakota sandstone. The overlying drift varies commonly from 10 or 20 feet to more than 100 feet in depth.

Southwestern Minnesota and the Coteau des Prairies.—Outcrops of the Cretaceous strata on the Coteau des Prairies, and in Minnesota east of this highland, are rare and usually of small extent, both in area and in the vertical thickness exposed; but these beds are also occasionally penetrated by wells near the east base of the coteau, and at the mission school, 1½ miles north-northwest of the Sisseton Agency, on the eastern slope of the coteau and about 1,500 feet above the sea, a well boring passed through the drift and entered soft shale or clay, probably the lower part of the Fort Pierre formation, at the depth of 138 feet. The outcrops mentioned east of the Coteau des Prairies appear to belong mostly to the lower divisions of the Upper Missouri series. They include sandstones of the Dakota formation on the Cottonwood River, from its mouth to a distance of 30 miles west, yielding numerous species of fossil leaves; beds of shale, with thin seams of lignite and lignitic clay, occurring in the bluffs of the Minnesota River about 15 and 30 miles northwest of New Ulm, referred by Prof. N. H. Winchell to the Fort Benton formation; similar deposits about 70 miles farther north, on the Sauk River in Stearns County, identified as this formation by Meek; and shales, with layers of concretionary limestone, in the Minnesota Valley, at the mouth of the Cottonwood, close to New Ulm, which Professor Winchell refers provisionally to the Niobrara formation. In the western outcrops on the Cottonwood, lignite-bearing shales and the sandstone containing impressions of leaves occur together, and the same is true of the shales with limestone and the leaf-bearing sandstone at the mouth of this river; so that possibly all these beds on the Cottonwood and Minnesota rivers may belong to one formation, which must then be the Dakota, according to Lesquereux's determinations of its fossil leaves.

There is evidence, however, that the ocean extended east nearly across Minnesota in later stages of the Cretaceous period, for Cretaceous fossils and shale have been found in the glacial drift, apparently not far removed from their original beds, at Lime Springs, Iowa, less than 5 miles south from the south line of Fillmore County, Minn., including sharks' teeth closely like *Otodus appendiculatus* Ag., bones, teeth, and scales of teleost fishes, *Ammonites* (two species), *Ostrea*, *Inoceramus*, etc., regarded by Dr. C. A. White as Upper Cretaceous, "as late as any yet recognized in any part of North America."[1] A hundred and seventy-five miles northwest from this locality a perfect tooth of *Otodus appendiculatus* Ag. has been found on a sand bar near the mouth of Two Rivers, tributary to the Mississippi, in Morrison County, Minn. Other sharks' teeth and fragments, belonging to different species, have also been found in that vicinity and on the south branch of Two Rivers, in Stearns County, at a distance of about 8 miles to the southwest. These indicate that marine Cretaceous beds, probably of the same age with the fossils at Lime Springs, underlie the drift somewhere in central Minnesota; though it is possible that they have been wholly eroded, their fossils being now contained in the drift. At the mouth of Two Rivers, fresh-water shales, probably of similar middle Cretaceous age with the lignite-bearing beds of the Sauk and Minnesota rivers, are exposed to the height of a few feet above the level of the

[1] Proc. A. A. A. S., 1872, Vol. XXII, pp. 187–192.

Mississippi, containing *Margaritana* and *Unio*, with a thin seam of lignite and lignitic clay. All the Cretaceous deposits of western Minnesota, except in the high Coteau des Prairies, now exist only as a somewhat thin and often discontinuous sheet, ranging in thickness up to maxima of probably nowhere more than 100 to 300 or 500 feet, on the Archean, Algonkian, and Silurian rocks. They are doubtless remnants of the base of a considerable thickness of strata, perhaps originally including the entire Cretaceous series of the Northwest, from the Dakota to the Laramie.

A section of the drift and Cretaceous beds forming the eastern footslope of the Coteau des Prairies is reported by Prof. N. H. Winchell from a well at Tracy, about 60 miles west of New Ulm, 619 feet above the Minnesota River at that place, and 1,403 feet above the sea-level. Till extends from the surface to the depth of 120 feet; next is fine gravel, largely of limestone, 5 feet, including also fine sand and soil-like matter, believed by Professor Winchell to be "a remnant of the old soil which accumulated on the Cretaceous rocks during the Tertiary age;" under this is fine blue clay, 20 feet; then a second bed of gravel, 20 feet, containing pebbles of buff limestone and of gray and dark or reddish quartzite, also of gray conglomerate or coarse sandstone, ranging in size from an inch in diameter to sand grains, with much slag and traces of lignite, from which characters, according to Professor Winchell, this bed "can be supposed to have accumulated on the Cretaceous after the withdrawal of the Cretaceous ocean, the slag coming from the combustion of the lignites contained in the strata." From the bottom of this gravel, at the depth of 165 feet, Cretaceous beds of clay, shale, and sandstone reach 525 feet, having a prevailingly dark color for 446 feet, but mostly white for the lower 79 feet. In descending order, they are fine blue clay, 12 feet; fine greenish-blue sandstone, 20 feet; dark-gray shale, 213 feet; again, fine greenish-blue sand, 60 feet; blue clay or shale, 43 feet; quartzitic white sandstone, with concretionary pyrite, 32 feet; fine gray sandstone, 5 feet; again, blue clay or shale, 30 feet; a second layer of quartzitic and pyritous white sandstone, 7 feet; dark, unctuous, fine clay, 24 feet; white kaolinic clay, becoming reddish, then bluish and gritty, 8 feet; white and gray quartz sand, partly cemented by pyrite and mixed in its lower part with kaolinic clay, 18 feet;

white kaolin, clouded with blue clay, and containing some grit, 25 feet; and white quartzitic sandstone, 28 feet, containing kaolinic material in its lower part, "apparently resulting from the decay of grains of feldspar after deposition in the sandstone."[1]

The thickness of 446 feet of principally dark beds, lying between 1,238 and 792 feet above the sea, probably corresponds to the Fort Benton shales and Dakota sandstone, containing lignite and impressions of leaves, on the Cottonwood and Minnesota rivers, where their elevation is approximately 800 to 1,000 feet above the sea. Under these the thickness of 79 feet of mostly white kaolinic clay or shale and sandstone, constituting the base of the Dakota formation here, appears to be the same with the deposits of white and greenish clay, often sandy and gritty, which lie in water-worn hollows of the Cambrian strata along the lower part of the Minnesota River. These earliest Cretaceous sediments were evidently derived from erosion of decomposed surfaces of the adjoining Archean gneiss and granite. Not all of this decayed and kaolinized rock was worn away then nor by the later erosion of the Glacial period; for at many places in the Minnesota Valley, along the distance of nearly 50 miles between Granite Falls and Fort Ridgely, it forms the upper 10 to 20 or 30 feet of the Archean outcrops. At 713 feet above the sea-level the Cretaceous deposits of Tracy rest on reddish granite of Archean age, into which this well was drilled 34 feet, to a total depth of 724 feet.

In the village of Browns Valley, situated between Lakes Traverse and Big Stone, in the channel of which Lake Agassiz outflowed southward, a well has been sunk to the depth of 465 feet, extending from 975 to 510 feet, approximately, above the sea-level. The general surface on each side of this valley or channel is about 1,100 feet above the sea, 125 feet of glacial drift having been eroded above the site of the well. After passing through an undetermined thickness of alluvial and drift deposits, this well penetrates dark-bluish, hard clay or shale to the depth of 360 feet; a black layer of lignitic shale, 2 feet; gravel and sand, alternating with layers of blue clay, 58 feet; quartzitic sandstone, 5 feet, from above and beneath which artesian flows of water are obtained; greenish, micaceous, and kaolinic

[1] Geol. and Nat. Hist. Survey of Minnesota, Fourteenth Annual Report, for 1885, pp. 351–353.

shale or clay, 20 feet; and white and gray sandy shale or sandstone, 20 feet, in which the well stopped, not reaching the Archean rocks.[1] These strata above the source of the artesian water are probably equivalent to the dark beds of the Tracy well, while the lower strata correspond to the white and kaolinic lower beds there.

Comparing the elevations of the top of the kaolinic deposits in these wells, there is seen to be a slight dip of the strata toward the north-northwest, amounting to about 240 feet in the distance of 112 miles from Tracy to Browns Valley. Another comparison is afforded by a well near Sleepy Eye, which is 45 miles east of Tracy and 1,034 feet above the sea, penetrating 182 feet of drift; then 79 feet of white and gray Cretaceous clay, containing one thin stratum of brownish-red clay, together corresponding apparently to the lowest 79 feet of the Cretaceous beds in the Tracy well, and lying, like those beds, on Archean red granite.[2] These observations indicate a slight westward dip, amounting to about 60 feet, in the Cretaceous strata between Sleepy Eye and Tracy. The resultant inclination satisfying both these sets of observations is a dip of about 3 feet per mile to the northwest, being thus directed away from the ridge of Algonkian quartzite, 1,300 to 1,700 feet above the sea, which outcrops in northern Cottonwood County, on the east flank of the Coteau des Prairies, and in Pipestone and Rock counties, on its west side.

Above the strata thus far described, a hard, gray, somewhat calcareous and concretionary sandstone, probably representing the Niobrara formation, is seen in a few low outcrops near Alta Vista, in the northeast corner of Lincoln County, and within 7 miles eastward, having an elevation approximately 1,175 to 1,150 feet above the sea. These outcrops are 30 to 35 miles northwest from Tracy, and occupy nearly the same stratigraphic horizon with the gravel bed, between 145 and 165 feet in depth, in the well at that place. The only organic remains detected in this sandstone are particles of lignite and traces of wood.

Clay or shale, containing fossils characteristic of the Fort Pierre and Fox Hills formations, the upper members of the marine Cretaceous series, has been encountered in numerous instances by wells in the same region,

[1] Geol. and Nat. Hist. Survey of Minnesota, Fourteenth Annual Report, p. 14.
[2] Ibid., p. 15.

within 7 miles north and 20 miles southeast from Alta Vista, along the foot of the steep eastern ascent of the Coteau des Prairies, at elevations from 1,150 to 1,250 feet above the sea. Perhaps some of these wells have reached Cretaceous strata in place; but others evidently have been wholly in the glacial drift, containing disrupted and transported masses of Cretaceous shale with fossils. The frequency of these fossils in the drift indicates that Upper Cretaceous marine strata originally covered much of this district and supplied a large part of the drift, and that they probably underlie the drift in the Coteau des Prairies. The list of fossils thus found includes *Baculites ovatus* Say, *Placenticeras* (*Ammonites*) *placenta* Dekay, both these represented by abundant specimens, chiefly fragments; *Scaphites nicolletii* Morton, *Nucula cancellata* M. & H., and an *Inoceramus* which may be *I. problematicus* Schlot.[1] Twenty-five miles distant to the southwest and west the crest of the Coteau des Prairies attains a height of 1,950 to 2,000 feet above the sea, rising 800 feet above the outcrops and wells here noted. This massive highland, beneath its mantle of drift, which probably varies from 50 to 250 feet in thickness, doubtless consists mainly or wholly of the Fort Pierre and Niobrara clays and shales, dipping very slightly to the west and northwest. Because of the soft character of these beds, they are not exposed in any projecting knob or ridge; and their resemblance in material and color to the bowlder-clay or till, which is derived in large part from them, makes their exposures less liable to be noticed if they are anywhere cut into by ravines.

Along the Sheyenne River.—The Fort Pierre shales have plentiful exposures in the bluffs of the Sheyenne River, from where it flows by the Cretaceous hills west and south of Devils and Stump lakes, covered partly with morainic drift, as described in the next chapter, to the most southern bend of this river, where it enters the area of Lake Agassiz. A sheet of till, varying from 10 to 50 feet or more in thickness, sometimes with overlying beds of gravel and sand, forms the upper part of the Sheyenne bluffs, and their lower portion consists of the dark-gray, easily disintegrating, sandy shales of this formation to heights varying from 50 to 175 feet above the river. There are many excellent sections of both the shales and the

[1] Geol. and Nat. Hist. Survey of Minnesota, Final Report, Vol. I, 1884, p. 600.

drift, where the slope has been so lately undermined that the shale forms continuous cliffs from a few hundred feet to a quarter or half of a mile in length.

Fossils are infrequent, but would doubtless be detected in many places by careful search. On the western slope of a hill, partially bared of drift and consisting of this shale, near the west line of section 33, township 139 north, range 58 west, 8 miles south of Valley City and about 1½ miles west of the Sheyenne, I found *Inoceramus sagensis* Owen, fragments of other lamellibranchs, and *Baculites ovatus* Say. These were on nearly the average level of the surrounding country, at a height of about 175 feet above the river, or 1,350 feet above the sea.

In the vicinity of the southern bend of the Sheyenne are scanty exposures of Cretaceous beds which contain lignite and may belong to the Fort Benton formation. The lowest outcrop, situated just within the highest shore-line of Lake Agassiz, is in the southeast quarter of section 32, township 135, range 54, about 20 rods west of Edward Bowden's house. Here the east or right bank of the Sheyenne shows the following section, in descending order: Soil and gray clay, with slight intermixture of gravel, 2 to 3 feet; very coarse iron-rusty gravel, from 1 inch to 1 foot thick, containing cobbles of limestone, granite, and a partly decayed gneiss, of all sizes up to 6 and 12 inches in diameter; gray till, very compact, 1 to 1½ feet; fine gravel and sand, about 6 feet, containing in some portions very plentiful flakes and fragments of lignite from an eighth of an inch to 2 or 3 inches long; and hard, dark-bluish Cretaceous shale, seen only to the depth of a few feet and hidden below by the talus, containing near its top a layer of lignite about 3 inches thick, at the height of 25 or 30 feet above the river, and approximately 1,060 feet above the sea. Springs issue from the river bank, a few rods farther southeast, at the top of this shale. Mr. Bowden reports another outcrop of a thin seam of lignite, perhaps belonging to the same layer, some 8 miles distant from this toward the south-southwest, occurring in a ravine tributary to the Sheyenne, about a mile west of its most southern bend. From the second to the first of these localities the river falls 20 feet, and these outcrops of lignite differ little in their elevation above the sea-level.

In the escarpment and plateau of Pembina Mountain.—Sections cut by the head streams of the Goose and Turtle rivers, in the highland between the Red River Valley and Devils Lake, and the similar erosion of the Pembina Mountain by the branches of Park River and by the Tongue, Little Pembina, and Pembina rivers, show that, beneath the drift, this long escarpment and the plateau which it bounds consist of dark, sandy shale, horizontal or nearly so in stratification, and nearly uniform in character for a great thickness. Gravel of this shale abounds in the channels of the streams for many miles east of the escarpment, and is found sparingly in the drift southward to the Coteau des Prairies. It is commonly called "slate" by the people of this region; but no portions observed possess the hardness and texture deserving this name, and no slaty cleavage is exhibited.

The highest outcrops of this formation seen by me, close to the west shores of Lake Agassiz, are on the plateau that extends westward from the top of the Pembina Mountain, where this is channeled by the North Branch of Park River in the vicinity of Milton. Along a distance of 5 miles from northwest to southeast through the north part of township 159 north, range 57 west, this stream cuts 75 to 125 feet into the shale, its top being 1,500 to 1,550 feet above the sea. It is overlain by only 5 to 25 feet of till, which continues equally thin, as shown by watercourses and wells penetrating to the shale, for 15 to 30 miles westward and northwestward, and, excepting two or three morainic belts, upon all the country southwest to Devils Lake. The surface about Milton is moderately undulating and rolling, with the crests of its higher portions 25 to 40 feet above the depressions. From this plateau an irregular descent, amounting to about 100 feet per mile, occupies the east part of this township and the edge of that next east, falling in 3 miles to the upper shore-line of Lake Agassiz, which here is approximately 1,200 feet above the sea.

The deepest part of the gorge of the North Branch of Park River is in sections 4, 9, and 10, township 159, range 57, where it is 125 to 150 feet deep and from a quarter to a half of a mile wide, with numerous fine exposures of the shale from the base to the top of the bluffs, except the thin capping of drift. In these places the stream, flowing at the base of the bluff, removes the talus which elsewhere conceals its lower portion, and the section rises with cliff-like steepness at an angle of 60° to 75°. Excepting occasional thin beds, the whole thickness of the formation here exposed is hard gray shale, more or less sandy, divided into layers from an eighth of an inch to 2 or 3 inches thick, and much jointed, so that it crumbles into small fragments on the weathered surface. Rarely a bed a few inches thick, having the general dull-gray color, is harder and less jointed, owing to its cementation by carbonate of lime; and occasionally the ordinary shale is blackened by the deposition of iron rust and of manganese oxide as films in the jointage seams, the thickness of the portion thus colored being usually only a few inches, but in one place, half way up the north bluff, 3 or 4 feet. Gypsum was observed only in minute crystals in thin fissures coinciding with the planes of stratification, and in the form of satin spar, filling the mold from which some shell, commonly *Inoceramus*, has been dissolved away. Fossils are very infrequent, but by careful search *Baculites ovatus* Say and *Scaphites nodosus* Owen were found, each represented by a single specimen; also numerous *Inoceramus* casts, mostly *I. sagensis* Owen, besides casts and fragments of other lamellibranchs, not yet identified; and the teeth of fishes, apparently *Pachyrhizodus latimentum* Cope and *Lamna mudgei* Cope, or a smaller species.[1] The teeth occur somewhat plentifully in a remarkably hard layer, 6 inches to a foot thick, about 50 feet above the stream. With them this hard layer contains softer lumps, of somewhat irregular form, from one-third to three-quarters of an inch in diameter, of light-gray color inside, with a greenish exterior, which are probably coprolites. The other fossils were found in the shale fragments forming the talus, and their place in the section was not ascertained. Although few, they supply decisive evidence that this is the Fort Pierre formation.

The lowest exposure of this shale observed along the course of the Pembina Mountain in North Dakota is 21 miles north of the preceding, on the Pembina River, at the "fish trap," a rude weir of brush and poles, in the northeast corner of the northwest quarter of section 30, township 163, range 57. Here the river falls 7½ feet in about 40 rods, its elevation being

[1] For aid in the identification of these fossils, and of those collected on the Pembina River, I am indebted to Dr. C. A. White, of this Survey.

estimated about 1,050 feet above the sea. On each side, within a mile, the plateau of the Pembina Mountain, which the river cuts through, rises 400 to 450 feet higher. A bluff 150 feet high ascends steeply from the fish trap on the southwest side, and at the time of my first visit, in August, 1885, was newly exposed by slides, being shown to be fissile, dark-gray shale to the height of 100 feet, capped by glacial drift. The shale of this lower part of the Fort Pierre formation is more sandy, softer, and darker than that of its upper part, seen on the North Branch of Park River, and it further differs noticeably in having few joints. It is horizontally laminated, and, where it has been somewhat dried on the surface of the bluff, is easily separated in layers from a quarter of an inch to 1 inch thick; but at a depth of only 2 or 3 feet within its mass, where it is moist, no lamination is discernible. In this shale crystals of selenite 2 or 3 inches long are frequent, and the same mineral occurs in its crevices and seams. No lignite is found here, nor in any of the other outcrops of this formation along the whole extent of the Pembina Mountain to the south and north.

My second visit to this locality was made in August, 1886, to search for fossils, though none were found the year before. Only the upper 20 feet of the shale was visible in place at this later time, as the lower part, previously exposed almost to the level of the river, was concealed by the talus of fallen shale and drift. A portion of the shale beds 2 to 3 feet thick, about 10 feet below their top in this section and 90 feet above the river, not distinctly contrasted in color or texture with the beds above and below, was found to have an odor resembling that of petroleum, and to contain sparingly, on the planes of bedding, impressions of *Scaphites nicolletii* Morton, of which about a dozen specimens were collected, and occasional casts and fragments of *Inoceramus* and *Ostrea* species, one being probably *Inoceramus sagensis* Owen. From a mass of shale in the talus numerous cycloid fish scales, and a vertebral bone, 1$\frac{3}{4}$ inches in diameter, belonging to some selachian fish, were obtained. If the formation is level in its stratification from south to north, as seems to be the case, this outcrop presents a portion of it approximately 200 to 300 feet lower than the bottom of its exposures on the North Branch of Park River.

About three-quarters of a mile east from the fish trap, this snale is exposed to a height of 75 feet above the Pembina River in a bluff on its northeast side. Its highest outcrop examined by me in this vicinity is Heart Mound,[1] a peculiar hillock with very steep sides and smoothly rounded top, situated on a broad, uneven terrace of Pembina Mountain, near the center of section 6, township 163, range 57, 3½ miles north of the fish trap and 2 miles south of the international boundary. The base and top of this hillock are, respectively, about 1,360 and 1,390 feet above the sea. Some have erroneously supposed it an artificial mound. Glacial drift, containing granitic bowlders up to 4 or 5 feet in diameter, thinly covers its northeast side; but the other sides and the crest of this knob consist of shale similar to that on the North Branch of Park River, showing that it is an outlier of the Fort Pierre beds that form higher land, drift-covered, about a mile westward. Heart Mound has been left thus isolated by the erosion of these beds from the surrounding area.

The thickness of the Fort Pierre formation in the northeast part of North Dakota, according to these observations, is at least 300 or 400 feet; but it doubtless considerably exceeds this, for there is no indication that these exposures mark its upper and lower limits. Wells in Langdon, 17 miles northwest of Milton and 1,610 feet above the sea, after passing through only 12 to 15 feet of till, enter this shale. With the underlying Niobrara and Fort Benton formations, which in this part of the State differ little in lithologic characters from the Fort Pierre, a thickness of 1,403 feet of dark-gray shales was penetrated by the Devils Lake artesian well before reaching the top of the Dakota sandstone, which there is 39 feet above the sea-level. In Fort Pierre outcrops on the North Branch of Turtle River, 1½ miles north of Niagara and about 1,375 feet above the sea, *Baculites ovatus* Say was found in abundance. The eroded eastern edge of the Fort Pierre shale forms the long, high escarpment of the "Second" Pembina Mountain, as the eroded border of the Pembina delta at Walhalla forms the almost equally notable, though much shorter, "First Mountain."

[1] Commonly called by English-speaking immigrants "the Indian Mound," but more properly named as above, in accordance with the usage of the French voyagers and residents, who, probably translating the aboriginal name, call this mound and the small area of prairie around it La Baie du Cœur.

But till or bowlder-clay, containing frequent granitic bowlders up to 5 or sometimes 8 feet in diameter, thinly covers the shale, so that good exposures of it are rarely seen, excepting in the bluffs cut by streams.

In western Manitoba and Assiniboia.—Dr. George M. Dawson gives the following summary of observations of the Cretaceous formations in the district bordering the west side of Lake Agassiz north of the international boundary, as obtained in the Geological Survey of Canada:

The character and thickness of the different members of the Cretaceous in the Manitoba region have not been worked out in detail, owing to the extent of the drift covering and scarcity of sections. * * * In the flat country of the Red River Valley no exposures of the Cretaceous rocks are found, and it is below the alluvium of this region that the older subdivisions probably occur. The western margin of the valley is formed by the escarpment of the second prairie steppe, and here, in the so-called Pembina Mountain, and in its continuation to the northwestward, the Cretaceous beds are first met with. About 25 miles north of the forty-ninth parallel, where the Boyne River cuts through the Pembina escarpment, beds clearly referable to the Niobrara group are known to occur, and precisely resemble, both lithologically and in their included fossils, those of the corresponding Nebraska division. The rock is generally a cream-colored limestone, chiefly composed of shells of *Inoceramus* and *Ostrea congesta*, but in places a white chalky material, which under the microscope is resolved into a mass of foraminiferal shells, coccoliths, and allied minute organisms. This exposure, though probably small in extent, enables the outcrop of the Niobrara to be defined at a point nearly 400 miles beyond the farthest northern locality known previous to its discovery. Still farther north, along the outcrop of the Cretaceous, at Swan River and Thunder Hill, west of Lake Winnipegosis, limestones and marls containing fossils like those of the last-mentioned locality, and evidently of Niobrara age, are again found, and other outcrops of these, and possibly of older beds, may probably be discovered in this vicinity.

With these exceptions, however, the Cretaceous rocks known to occur between the Red River Valley and the Lignite group of the Souris region belong exclusively to the Pierre group of the Cretaceous, while the Fox Hill group, which should intervene between this and the lignite-bearing series, has not in this district been recognized, and is, not improbably, but feebly developed. The Pierre rocks * * * consist of dark-colored grayish, bluish, or blackish shales, generally homogeneous in character through great thicknesses, and seldom containing fossils of any kind, though frequently charged with selenite crystals and holding nodular layers of poor limestone. Exposures of these beds are found in the Pembina escarpment on the Pembina River and its tributaries, and on the Assiniboine, where the thick drift deposits have been cut through. The clays or shales are generally quite characteristic in appearance, and where they are found it may be taken for granted that the lignite-bearing formation has either been removed by denudation or has from the first been wanting. Though usually in appearance quite horizontal, these beds must have a slight westerly dip, which carries them beneath the Lignite group of the Souris River.[1]

Since this was written, Mr. J. B. Tyrrell has examined the Fort Pierre, Niobrara, and Lower Cretaceous formations in this district, as already cited, and has determined their thicknesses, chiefly made known by deep well borings. Rocks belonging to the Niobrara formation have also been examined and described by Director Selwyn, of the Geological Survey of Canada, on the southeast or right bank of the Assiniboine, in section 36, township 8 north, range 11 west, about 4 miles east from the mouth of the Cypress River, at an elevation approximately 950 feet above the sea. "The outcrop extends along the bank of the river for about 500 yards, and consists of beds of highly fossiliferous sandy limestones, brown freestone, and dark, almost black, soft shales. The sandstone and limestone, when broken or struck, emit a strong odor of petroleum."[2]

From my own notes of this locality I may add that the most conspicuous stratum, in which some quarrying has been done, is a light-yellowish, hard, sandy limestone, exposed from the low-water line of the river to a height of about 8 feet. It is horizontally stratified in layers from an inch to a foot in thickness. Fossil shells, chiefly *Ostrea congesta* Conrad, occur frequently throughout its whole thickness, being most abundant 3 or 4 feet below its top, where they sometimes form nine-tenths of the rock. With these are occasional specimens of *Belemnitella manitobensis*, a species recently described by Mr. Whiteaves.[3] This stratum along the greater part of its extent is overlain by till 20 feet or more in thickness, which in turn is overlain by the delta deposits of gravel and sand that the Assiniboine here brought into the west side of Lake Agassiz. But at the south end of its exposure, where the limestone sinks beneath the river, it is seen to be conformably overlain along a distance of some 25 rods by soft, dark shale, probably the base of the Fort Pierre formation, portions of which contain

[1] Geol. and Nat. Hist. Survey of Canada, Report of Progress for 1879–80, pp. 14, 15 A.

[2] Ibid., Annual Report, new series, Vol. I, for 1885, p. 38 A.

[3] Ibid., Contributions to Canadian Palæontology, Vol. I, p. 189, Pl. XXVI, 1889.

very abundant casts of *Inoceramus problematicus* Schlot. Scales of fishes are also found in both the limestone and shale.[1]

The Tiger Hills, extending westward from the north end of the Pembina Mountain, consist of the Fort Pierre shales, eroded in massive rounded elevations and overlain by drift from a few feet to 50 feet or more in thickness, much of which has the rough contour and abundant bowlders characteristic of terminal moraines. Thence southward to the international boundary the shale is frequently encountered at moderate depths in digging wells; and here and there remnants of its highest beds form isolated hills, which show that much erosion has taken place during a former baseleveling of the surrounding plain country. Pilot Mound, in section 20, township 3, range 11, about a third of a mile in diameter at its base and rising steeply 80 feet above the general level to a rounded summit about 1,630 feet above the sea, thus consists of the hard upper portion of this shale formation, thinly covered with drift. Star Mound, a more massive and moderately sloping elevation, situated in sections 22, 23, 26, and 27, township 1, range 10, about 15 miles southeast of Pilot Mound, is of the same character. The base of this hill extends three-fourths of a mile from east to west and a third of a mile or more from north to south; and it rises with a very regular oval form to a small plain 30 to 40 rods long from east to west and half as wide at its top, which is 100 feet above the adjoining country and about 1,650 feet above sea-level.

At the Niobrara outcrop on the Assiniboine the base of the Fort Pierre formation is about 950 feet above the sea; on the Vermillion River it is stated by Tyrrell to be at 1,205 feet; and on the Swan River it is probably not higher than 1,200 or 1,300 feet. Above these elevations the Fort Pierre shales form the upper portion of Riding and Duck mountains and of the Porcupine and Pasquia hills, reaching to the depth of several hundred feet beneath the glacial drift along the entire course of this great escarpment.

The records of common and artesian wells in Chapter X contain further notes of the Cretaceous formations underlying the drift on the Red

[1] My thanks are due to Mr. J. F. Whiteaves, of the Canadian Geological Survey, for his kind assistance in the identification of these fossils. A series of the variable small *Ostrea* obtained at this locality, and from the same formation on the Boyne and in the district of the Riding and Duck mountains and northward, was submitted by him to Dr. C. A. White, who refers them to *O. congesta* Conrad.

River Valley plain south and southwest of the Silurian area. Tracts of the Dakota sandstone probably supply the brackish water which is found by many wells in this valley, similar to the water derived from this sandstone by deep artesian wells at Tower City and Devils Lake, along the James River, and on higher land in South Dakota west of the James Valley.

FORMER EXTENT OF CRETACEOUS BEDS EASTWARD ON THE AREA OF LAKE AGASSIZ.

East from the foot of the highlands of Pembina, Riding, and Duck mountains and the hills farther north, Cretaceous strata have not been found, so far as I have learned, in Manitoba, nor in the region north and northeast from Lake Winnipeg to Hudson Bay. It seems quite certain, however, that Cretaceous beds continuous from this escarpment originally extended east a considerable distance, probably so far as to cover the area now occupied by Lake Winnipeg. As Hind and Dawson have pointed out, it was by the erosion of their eastern portion that this steep line of highlands was formed;[1] and it may be expected that thin remnants of them will yet be found in central and eastern Manitoba.

The eastward continuation of the Cretaceous formations in southern and central Minnesota, indicated by numerous outcrops, has been noticed in the preceding pages. Further evidence of their former extent is afforded in the north part of this State by Mr. Horace V. Winchell's discovery of Cretaceous shales in place on the Little Fork of Rainy River,[2] and by the frequent occurrence of lignite in the drift upon the country south of the Lake of the Woods and between Rainy Lake and Vermilion Lake. Possibly this lignite may be of interglacial age, like beds that are found between deposits of till in southeastern Minnesota, in the basin of the Moose River, tributary to James Bay, and in other places; but Prof. N. H. Winchell thinks that more probably its origin is from lignite-bearing Cretaceous

[1] H. Y. Hind, Report of the Assiniboine and Saskatchewan Exploring Expedition, Toronto, 1859, pp. 168, 169; Narrative of the Canadian Exploring Expeditions, London, 1860, Vol. II, pp. 48, 55, and 265. G. M. Dawson, Geology and Resources of the Forty-ninth Parallel, 1875, pp. 253, 254.

[2] Geol. and Nat. Hist. Survey of Minnesota, Sixteenth Annual Report, for 1887, pp. 403–9, 431, 434.

strata such as outcrop on the Sauk and Minnesota rivers. Concerning the eastern limits of Cretaceous beds in this State he writes:

> A line drawn from the west end of Hunters Island, on the Canadian boundary line, southward to Minneapolis, and thence southeastwardly through Rochester to the Iowa State line, would, in general, separate that part of the State in which the Cretaceous is not known to exist from that in which it does. It is not intended to convey the idea that the whole State west of this line is spread over with the Cretaceous, because there are many places where the drift lies directly on the Silurian or earlier rocks, but throughout this part of the State the Cretaceous exists at least in patches, and perhaps once existed continuously.[1]

SOURCES OF THE CRETACEOUS DEPOSITS.

Deposits of Cretaceous clay are found in waterworn hollows of the Lower Magnesian or Shakopee limestone forming the walls of the channel or valley of the Minnesota River at numerous places in Blue Earth, Le Sueur, and Nicollet counties. It is thus known that before the Cretaceous period, when western Minnesota and the region of the Upper Missouri were depressed and covered by the sea, a deep channel had been cut by some river in the Lower Silurian and Cambrian strata of the Minnesota Valley; but the small width of this channel indicates that the stream then flowing here, probably westward, was not larger than the present Minnesota River This and many other streams of similar size, flowing into the Cretaceous ocean as it spread to the east over the former land surface of Iowa, Minnesota, and Manitoba, contributed part of the detritus which made its vast mass of sediments, probably averaging a quarter of a mile in depth over most of its area. These beds could be supplied only by extensive and deep denudation upon the land areas both west and east of the Cretaceous mediterranean sea.

The very great disturbances of the region on the west in the elevation of the Cordilleran Mountain ranges, since the Cretaceous period, make it impossible to trace there the course of the larger tributaries to this sea. On the east half of the continent the principal drainage system, carrying its vast freight of detritus west to the Cretaceous ocean, is probably marked

[1] Bulletins of the Minnesota Academy of Natural Sciences, Vol. I, p. 348. Geology of Minnesota, Final Report, Vols. I and II.

by the chain of great lakes from Ontario to Superior, the west end of which is close to the east border of the submerged belt. At that time, and onward through the Tertiary era, much of this eastern land area appears to have been elevated at least several hundred feet above its present level, so that streams eroded the deep basins which are now occupied by these lakes, but then had a continuous westward descent. It seems probable also that other great tributaries may have flowed westward and southward into the Cretaceous sea, bringing sediments eroded from the areas of Hudson Bay, Lake Athabasca, and Great Slave and Great Bear lakes. The absence of Mesozoic and Tertiary formations on the east border of the continent north of the southern coast of New England shows that from the Gulf of Maine to Labrador and Hudson Bay the land during these eras stood higher above the sea-level than now. So long-continued high elevation, probably culminating at the beginning of the Glacial period, enabled streams to erode the fjords of Maine, Newfoundland, and Labrador, the gulf and estuary of the St. Lawrence, the deep channel of the Saguenay, and the broad straits and bays dividing the lands of the Arctic archipelago and separating them from Greenland.

DENUDATION OF THE CRETACEOUS AREA.

EROSION OF THE PLAINS TO A BASELEVEL.

Rains, rills and rivulets, creeks and rivers have been slowly but constantly wearing away the Cretaceous formations since their elevation above the sea and the drainage of the immense Laramie lake, which for a long period covered much of their area. When these marine and lacustrine deposits were first raised to be dry land, they had a monotonously flat surface; and they probably extended east, as we have seen, over the entire basin of the Red River of the North and of the great lakes of Manitoba, from which they now reach to the Rocky Mountains. The greater part of the present Cretaceous area, though eroded far below its original surface, is flat, undulating, or only moderately rolling, and constitutes a broad expanse of plains with very slow ascent westward. But here and there isolated areas of much higher hilly land, as the Turtle Mountain, consist of remnants of horizontal Cretaceous strata which elsewhere have suffered denudation over all the surrounding country. The plains have been formed by the erosion of this vast area to a uniform baselevel, excepting only the isolated hilly tracts of comparatively small extent, which serve to show that on the eastern part of the plains, in North Dakota and southwestern Manitoba, a thickness of not less than 500 to 1,000 feet of the Laramie, Fox Hills, and Fort Pierre formations has been carried away. Around the Highwood and Crazy mountains, in central Montana, according to Prof. W. M. Davis[1] and Dr. J. E. Wolff,[2] the corresponding erosion of the plains in horizontally bedded Cretaceous formations has been 3,000 to 5,000 feet.

When the depth and great extent of this denudation are compared with those of the subsequent erosion which formed the Red River Valley and the lowland adjoining the Manitoba lakes by the removal of the former eastern part of the Cretaceous plains to the limit of the great escarpment west of Lake Agassiz, the early baseleveling seems probably to have occupied the Eocene and Miocene periods, with nearly all of the Pliocene, comprising nine-tenths or a longer portion of the whole Tertiary era. Its duration apparently coincided, as to both beginning and end, with the Tertiary or Somerville cycle of partial baseleveling which Davis and Wood have studied in Pennsylvania and northern New Jersey and believe to have affected a large area of the other Eastern States.[3] The termination of the denudation forming the plains of the Cretaceous area, and their uplift to undergo the erosion of the Red River Valley and of the present Assiniboine and Saskatchewan valleys, were probably also contemporaneous with the great epeirogenic[4] movement which in California, according to Mr. J. S. Diller, ended a long cycle of baseleveling that had extended through the whole of Cretaceous and Tertiary time, and raised a part of that baseleveled district at the beginning of the Quaternary era to form the lofty

[1] Mining Industries of the United States, Tenth Census, Vol. XV, pp. 710, 737, 745.

[2] Notes on the Petrography of the Crazy Mountains and other localities in Montana Territory, p. 16. Bull. Geol. Soc. Am., Vol. III, 1892, pp. 445–452.

[3] National Geographic Magazine, Vol. I, 1889, pp. 183–253; Vol. II, 1890, pp. 81–110. Proceedings, Boston Society of Natural History, Vol. XXIV, 1889, pp. 365–423.

[4] A term proposed by Gilbert, equivalent with continent-making. "The process of mountain formation is *orogeny;* the process of continent formation is *epeirogeny.*" U. S. Geol. Survey, Monograph I, Lake Bonneville, 1890, p. 340.

Sierra Nevada.[1] Again, the same record of long-continued baseleveling, followed by uplift and a new cycle of rapid valley erosion, is found by Powell and Dutton in the plateaus and Grand Canyon of the Colorado.[2] The denudation above these plateaus, when compared with the studies thus noted in other regions and with the total erosion of the canyon, seems to have required not only the Eocene and Miocene periods but also most of the Pliocene; for the ratio of the denudation to the canyon-cutting must be nearly or quite as great as that between the duration of the entire Tertiary era and the comparatively short time since its close. Instead of referring the division of these parts of the history of the Grand Canyon district to the beginning of the Pliocene, as was done provisionally by Dutton, it may therefore mark the final stage of the Pliocene and the inauguration of the Glacial period, with high elevation of all the northern part of this continent and of the glaciated northwestern portion of Europe.[3]

LATER EROSION OF THE TROUGH OF LAKE AGASSIZ.

At the time of uplifting of the plains near the end of the Pliocene period, this great baseleveled region appears to have stretched from the Rocky Mountains to the Archean hills on the eastern border of Lake Agassiz, and to have included also the expanse of flat or only moderately undulating country which slowly falls from Lake Winnipeg and the upper part of the Nelson River toward Hudson Bay. The Tertiary drainage of this district, from the present sources of the Saskatchewan, Red, and Rainy rivers to Hudson Bay and Strait, probably formed a great river flowing through the Appalachian-Laurentide mountain belt in the deep valley which is now submerged to form this strait, and emptying into the Atlantic between Labrador and Cape Farewell. The depression of the lower part of this basin beneath the sea seems to me referable to the time of the culmination and departure of the Quaternary ice-sheet. Between the Ter-

[1] U. S. Geol. Survey, Eighth Annual Report, pp. 428–432. Compare also articles by Prof. Joseph Le Conte, Am. Jour. Sci. (3), Vol. XIX, pp. 176–190, March, 1880; Vol. XXXII, pp. 167–181, Sept., 1886; Vol. XXXVIII, pp. 257–263, Oct., 1889.

[2] Exploration of the Colorado River of the West, 1875. Geology of the eastern portion of the Uinta Mountains, 1876. U. S. Geol. Survey, Monograph II, Tertiary History of the Grand Cañon District, 1882. Am. Jour. Sci. (3), Vol. XXXII, pp. 170, 171, Sept., 1886.

[3] Am. Geologist, Vol. VI, pp. 327–339, 396, Dec., 1890. Am. Jour. Sci. (3), Vol. XLI, pp. 33–52, Jan., 1891; Vol. XLVI, pp. 114–121, Aug., 1893.

tiary baseleveling and this subsidence a widely extended epeirogenic uplift of North America intervened. To this period of late Pliocene and early Quaternary elevation belong the erosion of the canyons of the Colorado and its tributaries, of the canyons on the slopes of the Sierra Nevada, and much river channeling of the plains east of the Rocky Mountains.

The eastern margin of these plains, which probably extended, as before noted, over the whole area of Lake Agassiz, was then subjected to renewed erosion, removing the mostly soft Cretaceous strata upon a width of a hundred miles or more and to a depth westward of several hundred feet. Previous to this new cycle of active work by the streams, Riding and Duck mountains stood above the general level, like Turtle Mountain and other isolated high areas farther west; and the maximum depth of the late stream-cutting by which the trough of the Red River Valley and Lake Agassiz was formed is approximately measured by the height of the Pembina Mountain escarpment, which rises 300 to 400 feet from its base to its crest along its extent of about 80 miles. The greater part of this erosion we must attribute to the probably long time of elevation preceding, and finally at its climax producing, the ice-sheet of the Glacial period. So far as can be discerned, the entire hydrographic basin of Lake Agassiz may have continued, through all these vicissitudes of changes of levels, excepting when it was wholly or partially ice-covered, to be drained in the same north and northeast direction as during the Tertiary era and at the present day.[1]

In the progress of denudation by the Tertiary baseleveling and by the later erosion of the hollow which was to hold Lake Agassiz, some of the Cretaceous strata have proved more durable than those next above and below, and consequently have had a more important influence on the topography. This is especially noteworthy in the case of the Fort Pierre formation, which forms the upper and main part of the great escarpment that borders the west side of Lake Agassiz from the Coteau des Prairies north-northwest to the Saskatchewan River. East of the Red River Valley in Minnesota the similar but less prominent ascending slope from the flat

[1] Am. Geologist, Vol. XIV, pp. 235–246, Oct., 1894. Bulletin Geol. Soc. of America, Vol. VI, pp. 17–20, Nov., 1894.

valley plain doubtless also consists of Cretaceous shales, perhaps chiefly the Niobrara and Fort Benton formations, beneath the envelope of glacial drift. Farther east and southeast, through northern and central Minnesota, it seems certain that at least many Cretaceous knobs and hills thus far had escaped the general Tertiary and early Pleistocene denudation, but most of them were leveled during the Ice age and mingled with the glacial drift. Westward from the Pembina and Manitoba escarpment the Fort Pierre formation generally constituted the preglacial surface, and is now the floor on which the drift lies, until it is succeeded by the Laramie series. This again includes especially enduring beds, which have caused the preservation of extensive outlying areas, as the Turtle Mountain and probably other masses of hills farther north, situated many miles east of the principal Laramie outcrop. In the same way that the Fort Pierre formation makes the escarpment west of the valley of the Minnesota and Red rivers and the Manitoba lakes, the Laramie beds, underlying the drift, make the greater part of the equally prolonged terrace-like highland of the Coteau du Missouri from South Dakota northwesterly through North Dakota, Assiniboia, and Saskatchewan. Numerous outliers exist, however, east of the main course of this coteau, in the region crossed by the North Saskatchewan River.

The course of the preglacial rivers flowing from the Cretaceous area west of Lake Agassiz, after the late Pliocene uplifting of the continent, probably coincided approximately with the present avenues of drainage throughout the region north of the international boundary, in the Assiniboine, Saskatchewan, and Athabasca basins. In North and South Dakota, the present channel of the Missouri River, as shown by Gen. G. K. Warren[1] and by Prof. J. E. Todd, dates only from the Glacial period, this great stream having been turned aside by the ice-sheet to the west and south from its preglacial course, which may have occupied the valley of the James or Dakota River, nearly parallel with the Missouri of to-day, or perhaps continued east to the most southern bend of the Souris River, or to the Sheyenne and Red rivers. Professor Todd finds also in the topography of that region evidence that in preglacial time the great tributaries coming from the west to join this part of the Missouri, namely, the Cannon

[1] Annual Report of the Chief of Engineers, U. S. Army, for 1868, pp. 307-314.

Ball River, the Grand and Moreau rivers, then united, the Cheyenne, and the White River, flowed east to the James Valley; and he is inclined to believe that from that valley the great stream formed by these affluents passed northeast to the Red River of the North and Hudson Bay.[1] That the greater part of the excavation of the trough of Lake Agassiz could be accomplished by a river of such size during the Lafayette period of continental elevation, following the Pliocene period and inaugurating the Ice age, may be readily believed when we compare it with the Lafayette erosion of the Mississippi, which from Cairo southward, along an extent of about 500 miles, formed a channel 200 to 300 feet deep and averaging 60 miles wide.[2]

Tertiary and early Quaternary erosion had sculptured the grand features of the basin of Lake Agassiz, and its whole extent probably had approximately the same contour immediately before the accumulation of the ice-sheet as at the present time. The surface of the feldspathic Archean rocks was doubtless in many places decomposed and kaolinized as it is now seen where they are uncovered in the Minnesota Valley, and as such rocks are frequently changed to a considerable depth in regions that have not been glaciated. On these and all the other rock formations the ordinary disintegrating and eroding agencies of rain and frost had been acting through long ages. Much of the loose material thus supplied had been carried by streams to the sea, but certainly much also remained and was spread in general with considerable evenness over the surface, collecting to the greatest depth in valleys, while on ridges or hilltops it would be thin or entirely washed away. Except where it had been transported by streams and consequently formed stratified deposits, the only fragments of rock held in this mass would be from underlying or adjoining rocks. The surface then probably had more small inequalities than now, due to the irregular action of the processes of weathering and denudation, which are apt to spare here and there isolated cliffs, ridges, and hillocks; but most of these minor features of the topography have been obliterated by glacial erosion or buried under the thick mantle of the drift.

[1] Proc., A. A. A. S., Vol. XXXIII, 1884, pp. 381–393, with map.

[2] Am. Naturalist, Vol. XXVIII, pp. 979–988. Dec., 1894. Bulletin, Geol. Soc. of America, Vol. V, 1894, pp. 87–100.

CHAPTER IV.

THE GLACIAL PERIOD AND ITS DRIFT DEPOSITS.

REVIEW OF THE GLACIAL PERIOD IN NORTH AMERICA.

In the latest geologic period, immediately preceding the Recent and present period in which we live, the north part of our continent was deeply enveloped in snow and ice. Every year the snowfall was greater than could be melted away in summer, and its depth gradually increased till its lower portion was changed to compact ice by the pressure of its weight. This pressure also caused the vast sheet of ice to move slowly outward from the region of its greatest thickness toward its margin.

Among the proofs of this Glacial period, it is first to be observed that the surface of the bed-rocks in the northern drift-covered portion of the United States, and thence north to Hudson Bay and the Arctic Ocean, bears fine scratches and markings, called striæ, like those which are found beneath the glaciers of the Alps. Only one cause is known which can produce markings like these, and this is the rasping of stones and bowlders frozen in the bottom of a moving mass of ice accumulated upon the land in a solid sheet of great extent and depth. As these striæ are found upon the rocky surface of British America and our own country to a southern limit that coincides approximately with the course of the Ohio and Missouri rivers, we must conclude that an ice-sheet has covered these regions.

The superficial material that overlies the bed-rock within the northern glaciated area has everywhere been plowed up and worked over by the slowly moving ice-sheet, and at its disappearance the greater part of this glacial drift was left in a deposit of clay, sand, gravel, and bowlders, mixed in a confused mass, which is called till. The thickness of the till upon much of the bed of Lake Agassiz is from 50 to 200 feet, but in some tracts it is only from 5 or 10 to 20 or 30 feet. Throughout nearly all of this lacustrine area lying in Minnesota and North Dakota it forms a sheet of such great extent and thickness that exposures of the underlying older rocks are very rare or wholly absent, none being known in the Minnesota portion of the basin of the Red River.

By the directions in which the bowlders have been carried from their original ledges, and by the courses of the glacial striæ, it is known that in the northern United States and the southern part of the Dominion of Canada the ice moved in general from north to south. In the eastern provinces and in New England its current was prevailingly southeastward, and the border of the ice-sheet was pushed into the Atlantic. In the region of the Great Lakes, and from the Laurentide highlands, James Bay, and the south half of Hudson Bay westward nearly to the Rocky Mountains, the ice-flow was mostly to the southwest and south. For example, glacial currents moving southwestward spread upon eastern Minnesota a red till, thus colored by the hematite, or anhydrous sesquioxide of iron, contained in its portion eroded from the red quartzite, sandstone, and shales of Lake Superior; but in western Minnesota the ice flowed southward from Lake Winnipeg to Big Stone Lake and thence southeast into northern Iowa, spreading a blue till, with many limestone bowlders derived from outcrops of Silurian limestone strata near Winnipeg.

Besides the striæ, till, and transportation of bowlders, another proof that the drift was formed by vast sheets of land ice is supplied by terminal moraines, or hills, knolls, and ridges of drift heaped along the ice border. These moraines are found stretching in remarkably curved and looped courses across the Northern States from Nantucket and Cape Cod to North Dakota. The outermost bounds the areas that were overspread by the ice-sheet during the late part of the Glacial period, which Professor Chamberlin has named its East Wisconsin stage;[1] and others mark the lines where the ice border paused or readvanced during its subsequent general recession.

[1] "Preliminary paper on the terminal moraine of the Second Glacial Epoch," by T. C. Chamberlin, in the Third Annual Report of the U. S. Geol. Survey, pp. 291–402. "Glacial phenomena of North America," forming two chapters in J. Geikie's The Great Ice Age, third edition, 1894, pp. 724–775, with maps.

THE CONTINENTAL ICE-SHEET.[1]

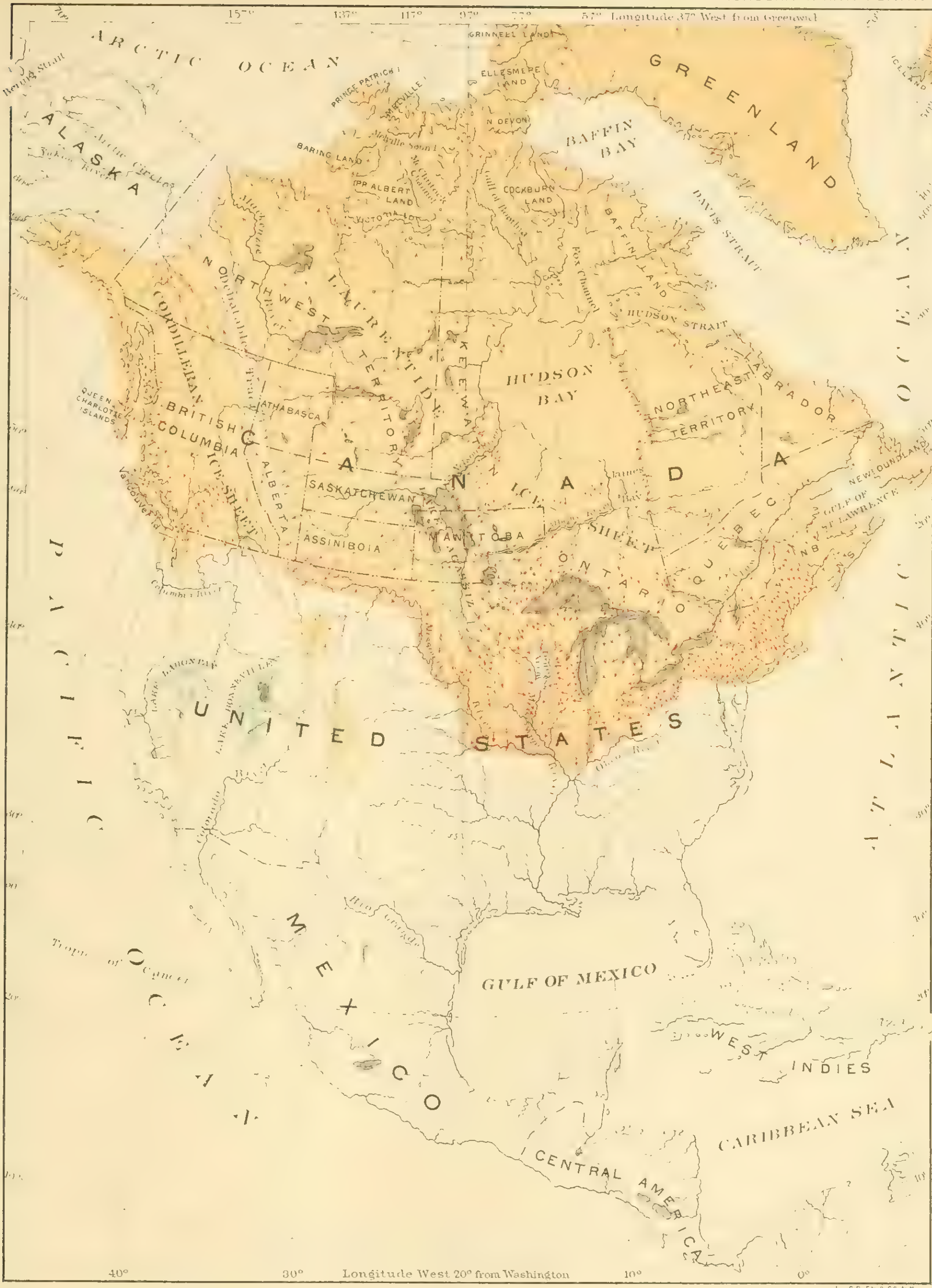
The relation of Lake Agassiz to the ice-sheet leads us to inquire more particularly what were its boundaries, area, and thickness, its centers of outflow, the manner of its final departure, and the areas probably occupied by its latest remnants.

Boundaries.—The extreme southern limit of the glacial drift and of the ice-sheet during its greatest extent, and the division between the earlier drift, belonging to the Kansan and East Iowan stages of the Glacial period, and the later drift, belonging to its East Wisconsin stage, during which Lake Agassiz existed, have been delineated by Professor Chamberlin,[2] and are again here presented in Pl. XVI, combining the results obtained by many observers during the past twenty-five years. The southern margin of the drift and of the maximum ice extension is shown to lie wholly within the United States, excepting that it is indented at the eastern foot of the Rocky Mountain range by an angle which barely touches the forty-ninth parallel. Dr. Dawson's recent map of the extent of the drift in the western part of Canada, however, places the apex of this angle south of the international boundary, along which he has had exceptional opportunity for examination.[3] But the limit of the ice-sheet in the Wisconsin stage, or the time of formation of the outermost prominent moraines, is found north of this boundary from the one hundred and fourth to the one hundred and fourteenth meridian; that is, across southern Assiniboia and Alberta, from the Coteau du Missouri to the Rocky Mountains. The abundance of lakelets held in hollows of the drift and the small amount of change in the drift contour since the departure of the ice-sheet indicate that during its time of accumulation of marginal moraines in these provinces it reached south to the Wood Mountain and Cypress Hills and to Lake Pakowki and the upper portion of Milk River.

[1] The greater part of this discussion of the extent and thickness of the ice-sheet is from the author's previously published articles, "Glacial Lakes in Canada," Bulletin, G. S. A., Vol. II, 1891, pp. 243–274; and "Glaciation of Mountains in New England and New York," Appalachia, Vol. V, 1889, pp. 291–312 (also in the Am. Geologist, Vol. IV, Sept. and Oct., 1889).

[2] U. S. Geol. Survey, Seventh Annual Report, Pl. VIII. The Great Ice Age, third edition, 1894, Pl. XV.

[3] Trans. Royal Society of Canada, Vol. VIII, sec. 4, 1890, Pl. II.



MAP OF THE GLACIATED AREA OF NORTH AMERICA.

Scale, about 550 miles to an inch.

Areas covered by Land Ice during the Quaternary Era | Quaternary Lakes Bonneville and Lahontan and the Glacial Lake Agassiz

Glacial Currents known by Striæ | Glacial Currents known by Drift Transportation or otherwise inferred

Note.- The dotted southern part of the drift area in the Mississippi and Missouri river basins represents the drift of the early Kansan and East Iowan stages of glaciation. The northern boundary of this tract notes the extent of the ice-sheet at the time of beginning of its moraine-forming or East Wisconsin stage.

Including this Canadian part of the southern limit of the Wisconsin stage of the ice-sheet, its course at the beginning of its time of formation of the series of marginal moraines, several of which were formed contemporaneously with the existence of Lake Agassiz, may be briefly noted as follows: From Nantucket, Marthas Vineyard, Block Island, and Long Island it runs west-northwestward across northern New Jersey and northeastern Pennsylvania, to an angle near Salamanca, N. Y., about 50 miles south of Buffalo and the eastern end of Lake Erie; thence it passes southwestward into southern Ohio; thence west-northwestward and northward in numerous loops through Indiana, northeastern Illinois, and Wisconsin, to an angle less than 75 miles southeast of the western end of Lake Superior; thence southward to Des Moines, Iowa; thence north-northwestward to the head of the Coteau des Prairies; again southward to the Missouri River and the northeastern edge of Nebraska; thence northwestward, very irregularly lobate, through South Dakota and North Dakota, to Wood Mountain, in the southern edge of Assiniboia; thence westward by the Cypress Hills to the Rocky Mountains on the international boundary; and thence, in lobes determined by the mountainous character of the country, across northwestern Montana, the narrow northern extremity of Idaho, and the northeastern edge and the central and western parts of Washington, to the Pacific coast on the latitude of 48°, Puget Sound and the Strait of Juan de Fuca being wholly inside the glaciated area.

Along the shores of British Columbia and southern Alaska the ice-sheet pushed through gaps of the Coast Range and terminated in the sea from the Strait of Juan de Fuca and Vancouver Island northwestward to the vicinity of the Copper River and Prince Williams Sound.[1] But most of Alaska and a portion of the adjacent Northwest Territory of Canada had too little snowfall or were otherwise affected by climatic conditions unfavorable for glaciation. The northwestern limit of the continental ice-sheet, as determined by Russell,[2] McConnell,[3] and Dawson,[4] passes

[1] G. M. Dawson, in Quart. Jour. Geol. Soc., London, Vol. XXXVII, 1881, p. 278; Trans., Roy. Soc. of Canada, Vol. VIII, sec. 4, 1890, Pl. II

[2] Bulletin, G. S. A., Vol. I, pp. 140, 146–148.

[3] Ibid., p. 544.

[4] Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. III, for 1887–88, pp. 132 B and 149 B.

northeastwardly from the Coast Ranges about Mount St. Elias, to cross the Yukon and Pelly near the meridian 136° 15′, and thence extends nearly due north to the Arctic Ocean, close west of the mouth of the Mackenzie.

The scanty observations which have been gathered in the Arctic Archipelago concerning the transportation of drift from the Archean area of the Northwest Territory northward to Baring Land, from the region of the Coppermine River northward to Prince of Wales Strait, from North Somerset 100 miles or more toward the northwest and northeast, and from south to north in Smith Sound,[1] indicate that the greater part of this archipelago was enveloped by the continental ice-sheet, and that from Baffin Land, North Devon, Ellesmere Land, and Grinnell Land it was continuous eastward to the ice-sheet of Greenland.

On the Atlantic coast it filled Hudson Strait with an eastward outflow, as determined by Dr. Robert Bell;[2] Labrador was wholly ice-covered, excepting the upper portion of the mountain range south of Cape Chidley, which, 70 miles from the cape, attains an elevation of about 6,000 feet above the sea;[3] Newfoundland, enveloped by the farthest eastward portion of this ice-sheet, was glaciated radially outward into the ocean on the north, east, and south;[4] and thence southwestward the border of the ice-sheet, passing beyond the shore-lines of Nova Scotia, New Brunswick, and Maine, probably reached, at its time of maximum area, to the irregular submarine ridges and plateaus of the Fishing Banks, which consist of Tertiary strata, more or less overspread with morainic and iceberg drift deposits, extending from Newfoundland to Cape Cod and Nantucket.

Area and thickness.—The part of North America and outlying islands which were covered by the ice-sheet and are now overspread with its drift amount to about 4,000,000 square miles, as shown on Pl. XVI. The

[1] G. M. Dawson, Geol. and Nat. Hist. Survey of Canada, Annual Report, Vol. II, for 1886, pp. 56–58 R.

[2] Geol. and Nat. Hist. Survey of Canada, Report of Progress, 1882–84, p. 36 DD; Annual Report, Vol. IV, for 1888–89, p. 111 E.

[3] A. S. Packard, Memoirs of the Boston Society of Natural History, Vol. I, 1866, pp. 219, 220; The Labrador Coast, 1891.

[4] John Milne, Quart. Jour. Geol. Soc., London, Vol. XXX, 1874, pp. 725–728.

thickness of the ice-sheet, known by the limits of glaciation on mountains, increased from a few hundred feet in the vicinity of its border to about 1 mile at a distance of 200 to 250 miles inside the border, both in New England and in British Columbia; and from these data and from the courses of glacial movement and distribution of the drift, it is computed to have ranged from 1 to 2 miles or more—that is, from 5,000 to 10,000 or 12,000 feet—in its central portions. Probably two-thirds of a mile, or about 3,500 feet, is an approximate estimate of the average thickness, or, in other words, mean depth of the ice-sheet at its stage of maximum development. Since in its recession the ice became the barrier of Lake Agassiz, and the probable influence of its mass in producing changes in the relative levels of the land and of lakes and the sea will therefore be considered in a later part of this report, we may profitably review here the evidences that it attained so great extent and depth.

Measures of the thickness of the ice-sheet and of the rates of slope of its surface in New England and New York are supplied by its drift and striæ on Mount Katahdin, the White Mountains, the Green Mountains, the Adirondacks, and the Catskills.

Prof. C. H. Hitchcock,[1] Prof. C. E. Hamlin,[2] and others have shown that the upper limit of the drift on Mount Katahdin is about 4,700 feet above the sea. The top of this mountain, which rises 500 feet higher, is covered with fragments riven from the underlying rock by frost; but it appears to be destitute of drift, and probably formed an island projecting out of the continental mer de glace during the stage of maximum glaciation. If we compare the slope of the surface of the ice-sheet with the present sea-level, the average ascent from the glacial border in the Atlantic to Katahdin, across a probable distance of about 200 miles, was approximately 25 feet per mile. The greatest thickness attained by the ice upon the country surrounding the base of Katahdin was about 4,000 feet, or four-fifths of a mile.

The most noteworthy observations on the glaciation of the White Mountains are those of Dr. Edward Hitchcock in 1841, marking the upper

[1] Sixth Annual Report of the Secretary of the Maine Board of Agriculture, 1861.

[2] Bulletin of the Museum of Comparative Zoology at Harvard College, Vol. VII, 1881.

limit of the usual drift deposits, striæ, and ice-worn ledges about 1,000 feet below the top of Mount Washington; and of his son, Prof. Charles H. Hitchcock, who in 1875 found glacially transported bowlders on the very summit of this mountain, 6,293 feet above the sea.[1] The ice-sheet, therefore, at one time overtopped even this highest peak of the eastern portion of its area. Very rare bowlders and small fragments of gneiss foreign to Mount Washington, which in its upper part is andalusite mica schist and gneiss, occur above the limit of the ordinary drift action, as similar foreign rock fragments are found very scantily on the high portion of Katahdin to within 600 or 500 feet below its highest point. But on Mount Washington the drift fragments are scattered thus scantily quite to its summit, near which Professor Hitchcock has obtained two bowlders, each weighing about 90 pounds. One of these is in the museum of Dartmouth College, and the other in that of the Boston Society of Natural History. These bowlders were transported by a glacial current moving from northwest to southeast, and in the distance of probably 15 miles from their parent ledges to the top of the mountain they were carried upward about 5,000 feet.

Before this discovery, while it was believed that Mount Washington and adjacent portions of the same range rose above the ice-sheet at its time of greatest thickness, Prof. James D. Dana had computed, from the slope of the ice surface thus known, and from the courses of striation and transportation of bowlders in Canada, that the elevation of the surface of the ice-sheet over the northern border of New England was about 8,000 feet, and over the Canadian watershed between the St. Lawrence and Hudson Bay 13,000 feet above the present sea-level, giving to the ice an average thickness of about 5,000 feet in the region of the White Mountains, 6,500 feet on the international boundary, and not less than 12,000 feet on the Laurentide highlands.[2] It still appears to be true that the upper limit of the ice-sheet was about 1,000 feet below the summit of Mount Washington during the greater part of the Ice age, and that Dana's estimates of the thickness of the ice farther north are very probable. There seem to be good reasons for believing that the land at length sank beneath this heavy

[1] Geology of New Hampshire, Vol. III, 1878.

[2] Am. Jour. Sci. (3), Vol. V, pp. 198–211, March, 1873.

burden; and to that time I would refer the complete glacial envelopment of Mount Washington, as well as the transportation of the highest, very scanty drift on Katahdin. This depression of the earth's crust led to changes of climate, from the rigorous conditions causing glaciation to mild temperatures by which the ice was finally melted; but at first the subsidence was perhaps attended by an increase in the thickness of the ice, whose surface may have been maintained by the snowfall during a short time, geologically speaking, at its former altitude, while the area of the White Mountains sank the 1,000 feet which would envelop the top of Mount Washington in the ice-sheet. The mountain was not thus ice-covered so long that the glacial current could sweep away much of the abundant frost-riven débris, nor conspicuously emboss any projecting knobs of rock, nor bring many bowlders and fragments of foreign drift. In the 220 miles from the terminal moraine of Long Island, Marthas Vineyard, and Nantucket, north to Mount Washington, the slope of the ice surface therefore averaged in its maximum about 30 feet per mile, compared with the present sea-level and height of the mountain, but was only about 25 feet per mile through the greater part of the Glacial period. It is presumable, however, that in a process of subsidence of the land, only the thickness of the ice-sheet, and not the slope of its surface, was increased when the mountain became wholly ice-covered.

Supplementing the reports of the Geological Survey of Vermont, Mr. Edward Hungerford published in 1868 a valuable paper on the glaciation of the Green Mountains,[1] from which most of the following notes are derived, their order being from north to south. Striæ on the summit of Jay Peak, 4,018 feet above the sea, bear S. 40° E. Very large transported bowlders occur on the top of Mount Mansfield, with striæ bearing S. 23° to 28° E. This mountain, the highest in Vermont, attains the elevation of 4,430 feet. Masses of quartz contained in the mica-schist of the top of Camels Hump, 4,088 feet in height, show fine lines of striation, noted in three places, S. 10° W., the same with variation to due south, and S. 35° E. It is also to be remarked that the rounded northwest side of Camels Hump and its precipitous cliff on the south and southeast afford evidence of glacial

[1] Am. Jour. Sci. (2), Vol. XLV, pp. 1-5, Jan., 1868. These and other bearings noted in this volume are referred to the astronomic meridian.

erosion. Killington Peak, 4,221 feet high, has similar rounded outlines, forming a "well-defined northern stoss side;" and Mr. Hungerford observed numerous small bowlders of foreign rock within 20 feet of the highest point. He concludes that all these summits, the highest in Vermont, were enveloped by the ice-sheet.

The glacial current crossed the Green Mountain range from northwest to southeast and south. It transported bowlders of the Burlington red sandstone across the range near Camels Hump, where they were carried upward 3,000 feet above their source, and deposited them in the Quechee Valley, near the Connecticut River, and in Hanover, N. H., about 60 miles from their starting point.

The Adirondack group culminates in Mount Marcy or Tahawus, 5,344 feet above the sea; and Mount McIntyre, at 5,113 feet, is next in elevation. Mr. Verplanck Colvin, in charge of the Adirondack Survey, states that the summit of Marcy is contrasted with the other high peaks in its being destitute of glacial drift; but its embossed and rounded ledges, as he observes, indicate glacial erosion there, although its striæ have been obliterated by weathering.[1] This summit lies about 125 miles west and a few miles south of Mount Washington, and its distance north from the terminal moraine on Long and Staten islands is about 235 miles. The average slope of the surface of the ice-sheet from its termination to the Adirondack Mountains was, therefore, not less than 23 feet per mile; and from the Catskills, where the upper limit of glaciation is known, it was not less than 17 feet per mile. How much it may have exceeded these figures can not be determined, but what we know of Katahdin and Washington shows that the peak of Marcy doubtless lacked only a little of rising above the ice-sheet at its time of maximum thickness. In this connection it is to be remarked that the change from a northward ascent of about 30 feet per mile south of the Catskills to an average of 17 feet per mile, or slightly more, for the next 130 miles to the Adirondacks is analogous with the slopes of the Greenland ice-sheet, and with the northward ascent of the ice-surface assumed by Dana in the computation before mentioned, namely, an aver-

[1] Seventh Annual Report of the Topographical Survey of the Adirondack Region, to the year 1879.

age of 10 feet per mile for the distance from the international boundary to the watershed north of the St. Lawrence.

In New Jersey Prof. John C. Smock's observations show that the ice-sheet covered the highest point of the State, which lies near its most northern angle, at an elevation of 1,804 feet. Its distance north from the terminal moraine is about 31 miles. The New York Highlands and the Shunemunk and Shawangunk mountains are also glaciated to their crests. But in the Catskill Mountains Professor Smock finds that the glacial drift and striæ extend upward only to an elevation approximately 3,000 feet above the sea.[1] Their limit is thus 1,000 feet below the highest summits, Slide Mountain, the culminating point of this group, having, according to Guyot's determination, an altitude of 4,205 feet. The distance from Slide Mountain south to the terminal moraine on Staten Island at the sea-level is 105 miles. The ice-sheet in this distance had an average slope of nearly 30 feet per mile, or slightly less than a third of a degree; and a considerable area of the Catskills rose above its surface at its time of maximum thickness and extent.

Farther to the west the continental glacier stretched in a vast expanse, unbroken by any projecting mountain or highland, to the basin of Lake Agassiz, and, excepting a single group of hills which rose above it, I believe that the same ice expanse continued to the Rocky Mountains, whose summits, as will be presently shown, appear also to have been wholly ice-enveloped in the region of the Peace River and northward.

The upper portions of the Cypress Hills, in southwestern Assiniboia, of the Hand Hills, in eastern Alberta, and of the Three Buttes or Sweet Grass Hills, in the north edge of Montana, rose above the glaciation which spread drift on all the surrounding country. Mr. R. G. McConnell writes of this region as follows:

> The western part of the Cypress Hills is entirely unglaciated, and must have formed an island in glacial times projecting about 400 feet above the surface, as no drift or other mark of glacial action was observed within that distance of the summit, and as this part has a height of about 4,800 feet above the sea, this would give the surface of the glacial sea or glacier, disregarding Post-Tertiary changes in elevation,

[1] Am. Jour. Sci. (3), Vol. XXV, pp. 339–350, May, 1883.

a height of 4,400 feet above the present sea-level. The Hand Hills are stated by Mr. Tyrrell to be unglaciated above a height of 3,400 feet,[1] and as these hills are situated N. 40° W. from the western end of the Cypress Hills, at a distance of about 150 miles, a line connecting the bases of the driftless parts of the two plateaus would incline toward the northwest at a rate of 6.7 feet per mile, and would have an average elevation above the present surface of about 1,550 feet. Drift was also observed by Dr. G. M. Dawson on the West Butte [of the Sweet Grass Hills] at an elevation of 4,660 feet, or 1,260 feet above the level at which it disappears in the Hand Hills, which are in nearly the same meridian, and 260 feet above the same point in the Cypress Hills. These differences in level, divided by the difference in latitude of the several elevations, afford evidence of a Post-Tertiary depression of the plains to the north in this region, relatively to those in the vicinity of the forty-ninth parallel, of about 7.2 feet per mile. The glacial sea or continental glacier is also shown, by subtracting the elevations given above from the present level of the surface, to have had a maximum depth in the plains surrounding the Cypress Hills of 2,000 feet, and to have averaged about 1,500 feet.[2]

On the Rocky Spring plateau, 25 miles west-southwest from the West Butte, the upper limit of the drift is reported by Dr. Dawson to have an elevation of about 4,100 feet. The descending slope of the ice-sheet thus indicated for this distance is 22 feet per mile.

In New England, as before noted, we are indebted to Prof. C. H. Hitchcock for the proof that the ice-sheet enveloped the top of Mount Washington, which has a height of 6,293 feet; and in British Columbia Dr. George M. Dawson finds that it covered mountains 5,000 to 7,640 feet high, and he estimates that its highest central part upon that province "had an elevation of at least 7,000 feet above the mean elevation of the interior plateau, which would be equivalent to an elevation of about 10,000 feet above the present sea-level, or probably 11,000 feet above the sea-level of the time."[3] Between these eastern and western areas of great known thickness of the ice, as determined by the height of glacial drift and striæ on mountains, probably the ice-sheet across the interior of Canada at one time attained a thickness of a mile or more on a central belt several

[1] Mr. Tyrrell, in the later Annual Report of the Canadian Geol. Survey, Vol. II, for 1886, p. 145 E, gives this as "about 3,200 feet." [W. U.]

[2] Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. I, for 1885, pp. 75 and 76 C. Also see Dr. George M. Dawson's descriptions of the superficial deposits and glaciation of the Bow and Belly rivers, ibid., Report of Progress for 1882-83-84, pp. 139-152 C.

[3] Trans., Roy. Soc. Canada, Vol. VIII, sec. 4, p. 28.

hundreds of miles wide, reaching from the Rocky Mountains and the Upper Mackenzie to Reindeer Lake and Lake Winnipeg, the southwestern part of Hudson Bay, James Bay, the Laurentide highlands, and the southern part of Labrador.

This proposition, however, differs widely from the opinions of Mr. J. B. Tyrrell, who thinks that a narrow unglaciated tract (designated on Pls. II and XVI as a "debatable tract") borders the eastern base of the Rocky Mountain range in Canada,[1] and of Dr. Dawson, who doubts that an ice-sheet has ever existed on a much wider area stretching from the Rocky Mountains far eastward across the Peace and Saskatchewan plain country nearly to Lake Athabasca and the lakes of Manitoba.[2] It is needful, therefore, that the evidences of glaciation in that district should be definitely and particularly stated. Without considering here the methods of formation of the various drift deposits, it may make my views more readily understood to add that I agree perfectly with Mr. Tyrrell in referring all deposits of bowlder-clay or till directly to the agency of land ice, without modification or aid by water; while Dr. Dawson, on the other hand, refers all these deposits of till to a glacio-natant origin—that is, to deposition from floating ice supplied from glaciers and borne over the till-covered areas during their submergence by lakes or the sea.

LAURENTIDE AND CORDILLERAN CENTERS OF OUTFLOW.

The prevailing courses of glaciation and dispersal of the drift lead me to recognize, with Dr. Dawson, the existence of two central areas upon which the ice was accumulated in greater depth than elsewhere, and from which consequently it flowed outward on all sides.[3] One of these areas

[1] Bulletin, G. S. A., Vol. I, pp. 396, 400, 401.

[2] Trans., Roy. Soc. Canada, Vol. VIII, sec. 4, pp. 54–74.

[3] Dr. George M. Dawsen, Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. II, for 1886, pp. 56–58 R; Geol. Magazine, (3), Vol. V, pp. 347–350, Aug., 1888; Am. Geologist, Vol. VI, pp. 153–162, Sept., 1890; Transactions, Royal Society of Canada, Vol. VIII, sec. 4, 1890, pp. 3–74, with five maps.

Compare with Dr. Robert Bell's opinion, based on his observations throughout the eastern two-thirds of British America, that during the Ice age "the basin of Hudsons Bay may have formed a sort of glacial reservoir, receiving streams of ice from the east, north, and northwest, and giving forth the accumulated result as broad glaciers, mainly towards the south and southwest," and also to the northeast and east through Hudson Strait. Geol. and Nat. Hist. Survey of Canada, Report of Progress for 1882-83-84, pp. 36, 37 DD.

Also see an article by Prof. E. W. Claypole, on "Glaciers and glacial radiants in the Ice age," Am. Geologist, Vol. III, pp. 73–94, Feb., 1889.

embraced the Laurentide highlands, James Bay, a portion of Hudson Bay, and the western part of the Archean region from Lakes Superior and Winnipeg to Great Slave and Great Bear lakes. From this large northeastern or Laurentide center of outflow the ice-sheet crept southward, eastward, and northward to the limits of glaciation before noted. Westward the ice from this area outflowed, as I believe, to the limit of Archean bowlders on or near the base of the Rocky Mountains, where I find, from Dr. Dawson's observations of the drift in Alberta and on the Peace River, that it abutted against and was confluent with ice outflowing eastward and southeastward from the Rocky Mountains. The other area whence currents of the ice-sheet flowed radially in every direction was the northern central part of British Columbia; and the portions of the ice-sheet pouring outward respectively from these two centers have been named by Dawson the Laurentide and Cordilleran glaciers. Toward the south, west, and northwest the Cordilleran outflow extended to the boundaries of our glaciated area; but eastward, pouring through passes of the Rocky Mountains, and in the Peace River region probably overtopping the highest summits, which there are only about 6,000 feet above the sea, the Cordilleran ice pushed across a narrow belt adjoining the mountains to a maximum distance of nearly a hundred miles, and there (on land about 2,500 feet above the sea) became confluent with the Laurentide ice, the two united currents thence passing in part to the south and in part to the north from the interior tract where the confluent ice was thickest.

JUNCTION OF THE LAURENTIDE AND CORDILLERAN DRIFT.

Taking up the particular description of localities where the junction of the Laurentide and Cordilleran drift has been observed, we may begin at the international boundary and proceed northward. Laurentian erratics and drift are stated by Dawson to extend quite to the foot of the Rocky Mountains near the forty-ninth parallel, and to occur between the forty-ninth and fiftieth parallels, "stranded on the surface of moraines produced by the large local glaciers of the Rocky Mountains."[1]

In Montana, within 30 miles southward from the forty-ninth parallel, Prof. G. E. Culver finds that ice was accumulated so thickly west of the

[1] Trans., Roy. Soc. Canada, Vol. VIII, sec. 4, p. 57; Am. Geologist, Vol. VI, p. 162, Sept., 1890.

main eastern range of the Rocky Mountains that it outflowed eastward through the passes, carrying diorite bowlders from ledges west of the watershed to a distance of several miles on the plains at the eastern base of the mountains. No Laurentian drift was observed there, but in the valley at the head of St. Marys River, a tributary of the Belly River, on longitude 113° 30′, 5 to 20 miles south of the international boundary, shore-lines of a glacial lake, which was probably formed by the neighboring barrier of the Laurentide ice-sheet on the northeast, occur up to the height of at least 800 feet above the present St. Marys lakes, or approximately 5,400 feet above the sea.[1]

In the neighborhood of Calgary, which is the western limit of Laurentian bowlders and till, Dawson reports somewhat farther westward a deposit resembling bowlder-clay, in which the stones "are entirely those of the mountains or sandstone blocks from the underlying beds." Accordingly, he declares that the absence of Laurentian erratics west of Calgary is probably to be accounted for "by the existence of Rocky Mountain glaciers of sufficient size in this region to fend off the eastern glaciating agent." Again, he mentions, west of Calgary, "heavy glacial striation in a southward or southeastward direction * * * about 13 miles east of the mountains, in a region of wide valleys and low foothills."[2]

On the Peace River, in its course close east of the Rocky Mountains, and on its tributary, Pine River, Dawson reports drift containing a large proportion of "hard quartzite pebbles like the more resistant materials of the axial range of the Rocky Mountains. These are mingled with a preponderating number of fragments of the softer sandstones of the country, and embedded in a whitish or cream-colored silty clay, not unlike the material representing the bowlder-clay over wide districts west of the Rocky Mountains. No Laurentian or other fragments of eastern origin were observed in this region." Continuing eastward, these drift deposits become more conspicuous, attaining in places a thickness of 150 feet. On reaching the D'Echafaud River, about 100 miles from the mountains,

[1] "Notes on a little-known region in northwestern Montana," Transactions, Wisconsin Academy of Science, Arts, and Letters, Vol. VIII, pp. 187–205, with map, Dec. 30, 1891.

[2] Geol. and Nat. Hist. Survey of Canada, Report of Progress, 1882–84, pp. 146 C, 151 C; Annual Report, new series, Vol. I, for 1885, p. 167 B.

though "no change in the character of the drift deposits was noted, * * * Laurentian pebbles and bowlders were for the first time seen in considerable abundance. * * * East of this point * * * the surface is thickly covered with drift deposits, so much so that exposures of the underlying rocks are, as a rule, only found in the larger river valleys."[1] No better evidence could be desired by a glacialist, accounting for the formation of the bowlder-clay by the agency of land ice, to demonstrate the confluence here of two currents of the ice, one flowing eastward from the Cordilleran area and the other flowing westward from the Archean area, whose nearest portion is on Lake Athabasca, about 400 miles distant.

Near the divide between the Liard and Yukon River systems, Dawson found drift on the summit of an isolated mountain 4,300 feet above the sea and about 1,000 feet above this part of the Pacific-Arctic watershed.[2] This, however, is on the west side of the Rocky Mountains proper, which, as defined by Dawson, constitute the northeastern marginal range of the broad mountainous Cordilleran belt. With this definition, the Rocky Mountains are intersected by the Mackenzie River south and west of Great Bear Lake.

Farther northward the Laurentide or eastern portion of the ice-sheet pushed northwestward to the extreme limit of the drift. "The till near the lower ramparts of the Mackenzie," according to Mr. R. G. McConnell, "is in approximately the same latitude as the northern boundary of the Archean area on the east, and the gneissic bowlders which it contains must have traveled either directly west or northwest in order to reach their present situation." He therefore infers that "the ice from the Archean gathering grounds to the east poured westward through the gaps and passes in the eastern flanking ranges of the Rocky Mountains until it reached the barrier formed by the main axial range, when, being unable to pass this, it was deflected northwestward in a stream from 1,500 to 2,000 feet deep down the valley of the Mackenzie and thence out to sea."[3]

All the testimony thus gathered concerning the line of junction and the limits of the eastern and western drift seems to the present writer to

[1] Geol. and Nat. Hist. Survey of Canada, Report of Progress, 1879–80, pp. 139, 140 B.

[2] Ibid., Annual Report, Vol. III, for 1887–88, p. 119 B.

[3] Bulletin, G. S. A., Vol. I, p. 543.

amount to full and convincing proof that the ice of the Laurentide and Cordilleran areas of outflow became confluent, and at its culmination stretched as one continuous ice-sheet from the Atlantic to the Pacific, enveloping the northern portion of the Rocky Mountains in their comparatively low development within the basin of the Mackenzie and Peace rivers, and overspreading the whole of the Dominion of Canada southward, except the highest parts of the Rocky, Selkirk, and Coast ranges.

COMPARISON WITH THE PRESENT ICE-SHEET OF GREENLAND.

An ice-sheet similar to that of North America in the Glacial period now covers the Antarctic lands, and another is spread over the interior of Greenland. The latter has been so far explored within the past ten years by Nordenskjöld, Peary, and Nansen as to give us a knowledge of its slopes and the altitude of its surface, with which the ancient ice-sheets of North America and Europe may be most instructively compared.

The first long journey on the Greenland ice-sheet was accomplished by Nordenskjöld in 1883, going eastward from Aulatsivik Fjord, close south of Disco Bay, near latitude 68° 20′ north. At a distance of about 73 miles from the head of this fjord and edge of the inland ice Nordenskjöld reached an altitude of 4,950 feet; and at a probable distance of 45 or 50 miles farther, crossed by Lapps on the peculiar snowshoes called "ski," the barometers indicated a height of 6,386 feet. The average ascent of the ice surface here in the first 73 miles, including the more rapid rise near the margin, is about 68 feet per mile, or slightly less than three-quarters of a degree; but in the next 45 miles of estimated distance it is reduced to 32 feet per mile, or about a third of a degree.[1]

A second important journey on the inland ice of Greenland was by Lieut. R. E. Peary and Christian Maigaard in 1886, going east from the head of Pakitsok Fjord, on the northeast part of Disco Bay, in latitude 69° 30′ north. These explorers advanced to an estimated distance of about 100 miles from the edge of the ice, attaining an altitude of about 7,500 feet.[2]

[1] Science, Vol. II, pp. 732–738, with map, Dec. 7, 1883. For the more accurate final computations and estimates of distances and altitudes, see The First Crossing of Greenland, by F. Nansen, 1890, Vol. I, pp. 494–499, with map; Vol. II, pp. 467, 468.

[2] Bulletin of the American Geographical Society, Vol. XIX, 1887, pp. 261–289.

Two years later, in 1888, Dr. Fridtjof Nansen crossed this ice-sheet from east to west between latitude 64° 10′ and 64° 45′ north. The width of the ice here is about 275 miles, extending into the ocean on the east, but terminating on the west about 14 miles from the head of Ameralik Fjord and 70 miles from the outer coast-line. For the first 15 miles in the ascent from the east, rising to the altitude of 1,000 meters, or 3,280 feet, the average gradient was nearly 220 feet per mile. In the next 35 miles an altitude of 2,000 meters, or 6,560 feet, was reached; and the average gradient in this distance, between 15 and 50 miles from the margin of the ice, was thus about 94 feet per mile, or a slope very slightly exceeding 1 degree. The highest part of the ice-sheet, about 112 miles from the point of starting, was found to have an altitude of 2,718 meters, or about 8,920 feet. Its ascending slope, therefore, in the distance from 50 to 112 miles was about 38 feet per mile. Thence descending westward, the gradients are less steep, averaging about 25 feet per mile for nearly 100 miles to the altitude of 2,000 meters, about 63 feet per mile for the next 52 miles of distance and 1,000 meters of descent, and about 125 feet per mile for the lower western border of the ice.[1]

Lieutenant Peary, in an expedition from Inglefield Gulf, near latitude 78°, on the northwest coast of Greenland, starting early in May and returning August 6, 1892, crossed the northwestern and northern parts of this ice-sheet, reaching altitudes of 5,000 to 8,000 feet, and determining approximately the northern boundary of the ice from Petermann Fjord to the eastern coast at Independence Bay, in latitude 81° 37′ and longitude 34° west from Greenwich.

In comparing the slopes and altitudes of the upper limits of glaciation on mountains in Maine, New Hampshire, and New York, with the ice in Greenland, we observe the remarkable contrast that the former show gradients only about half as steep as the latter. Mount Washington, as before noted, indicates an average gradient of only about 25 feet per mile for the rise of the ice surface along a distance of 220 miles from its margin during the principal part of the Glacial period; to Mount Katahdin in a similar distance it appears to have risen somewhat less steeply, or per-

[1] The First Crossing of Greenland, Vol. II, pp. 464–466, with section and maps.

haps nearly the same; and to the Catskills the apparent ascent was only 30 feet per mile for the distance of 100 miles from the ice border. But in Greenland all of the four journeys on the inland ice find it to ascend with much steeper slopes, attaining the altitude of the summit of Mount Washington at distances which vary from 50 to 125 miles from its edge. Nor does the less area of the Greenland ice explain its steeper gradients, for it probably has a length of more than 20 degrees from south to north, or over 1,400 miles, with a width of 200 to 600 miles, and an area of about 600,000 square miles, or one-seventh as much as the later ice-sheet of North America.

Apparently the conditions for outflow of the ice from this area are similar and equally favorable with those which prevailed on our continent in the Glacial period. The comparison therefore suggests that the present elevation of the glaciated portion of this continent is probably much changed from that which it had during its epochs of glaciation. If the North American ice-sheet during its stages of growth and culmination attained steep slopes and high altitudes near its borders comparable with the Greenland ice, the records of glaciation on our mountains show that during the time of accumulation of the ice and until it attained its maximum extent the glaciated area was uplifted as a high continental plateau, with the same principal topographic features of mountains, valleys, and general contour as in preglacial and postglacial times, but having in its outer 100 or 200 miles slopes of probably 20 to 30 feet per mile, descending from the plateau of the interior of the ice-enveloped country to its margin.[1]

Similar uplifting seems also to have affected the glaciated northwestern portion of Europe, for there, too, the slopes and height of the limits of the drift resemble those of North America rather than the Greenland ice-sheet. Prof. James Geikie finds that the surface of the ice which moved westward from northern Scotland across the Minch and the Hebrides had a descent of 25 feet per mile; "but slight as that incline was," he remarks, "it was probably twice as great as the slope of the mer de glace that filled up the German Ocean."[2] Mr. T. F. Jamieson therefore concludes that when the

[1] The Ice Age in North America, p. 595.

[2] Quart. Jour. Geol. Soc., Vol. XXXIV, p. 681, Nov., 1868.

ice-sheets of Scandinavia and Scotland were being accumulated these countries stood far above their present height, the maximum uplift being at least equal to 4,080 feet, which is the depth of Sogne Fjord, the longest and deepest fjord of Norway.[1]

At the end of the Glacial period, however, the glaciated regions are known to have been mostly depressed somewhat below their present level. This change seems to be well accounted for by the vast weight of the ice-sheet itself, causing the land to sink finally beneath its load; and the subsequent rise of the land is an expression of the buoyancy of the earth's crust when it had been relieved by the disappearance of the ice. The preglacial elevation may well have produced a cool climate throughout the year, with abundant snowfall and resulting ice accumulation; and the subsidence of the burdened land would cause rapid melting of the ice upon its borders and thence backward progressively over its whole area.

RECESSION OF THE ICE-SHEET.

During the departure of the ice its melting was due to the influence of sunshine and rains, the latter being doubtless brought then, as now, by great storms sweeping across the continent in an eastward and northeastward course. In consequence, the borders of the ice-sheet appear to have been pushed back generally in the same northeastward direction, beginning on the west in the region of the Missouri and upper Mississippi rivers and of the Red River of the North, and yielding successively or almost contemporaneously the region of the Laurentian lakes, New England, and the eastern provinces of Canada.[2] Thus Lake Agassiz was formed in the Red River Valley, and the basins of the Laurentian lakes became filled by glacial lakes outflowing southwestward to the Mississippi, until the outlet from Lake Ontario by the Mohawk and Hudson rivers was uncovered from the ice. Along the valley of the St. Lawrence the glacial current, which had before passed southeast transversely across it to the coast of New England, was, during this recession of the border of the ice-sheet, deflected toward the southwest, conforming to the law that the glacial motion near the edge of the ice turned perpendicularly toward its boundary.

[1] Geol. Magazine (3), Vol. VIII, pp. 387–392, Sept., 1891.

[2] Compare Proc., A. A. A. S., Vol. XXXII, 1883, pp. 231–234; and Geology of Minnesota, Vol. I, p. 641.

Extensive and thick beds of gravel, sand, and clay or fine silt, called stratified or modified drift, were deposited along the avenues of drainage from the glacial boundary, especially during its rapid final recession. The dissolution of the ice, with accompanying rains, produced extraordinary floods along all the rivers flowing away from the waning ice-sheet; and these were heavily laden with detritus set free from the lower part of the ice in which it had been held, and brought down by the rills and small and large streams formed on the melting ice surface. Other portions of the englacial drift were let down as an upper deposit of till, which lies in a loose, unstratified mass upon the subglacial till or ground moraine. The abundant deposition of drift, both stratified and unstratified, during the final melting of the ice-sheet, was first brought into due prominence by Prof. James D. Dana,[1] who denominated this the Champlain epoch, deriving the name from its marine beds adjoining Lake Champlain.

On the Atlantic Coast the Champlain subsidence of the land below its present level is known, from fossiliferous marine beds overlying the till, to have been slight in northeastern Massachusetts, 150 to 230 feet in New Hampshire and Maine, nothing or of small amount in Nova Scotia, but considerable, with increase from east to west, along the lower St. Lawrence Valley, being 375 feet opposite the Saguenay and 560 feet at Montreal, but thence diminishing southward along Lake Champlain and westward in the upper St. Lawrence and Ottawa valleys. The country southwest of Hudson Bay sank 300 to 500 feet; Labrador, 1,000 to 1,500 feet; and western Greenland and Grinnell Land, 1,000 to 2,000 feet. Again, in British Columbia and the Queen Charlotte Islands Dr. Dawson and others find proofs of submergence, ranging up to 200 or 300 feet, while the glacial conditions still endured.

This closing stage of the Glacial period was immediately succeeded by a time of great erosion of the valley deposits of stratified drift, as soon as the continued glacial recession beyond the drainage areas of the rivers cut off the supply of water and of drift that had been derived from the melting ice. The resulting excavation of the glacial flood-plains has left remnants of those deposits in conspicuous terraces along all our river val-

[1] Am. Jour. Sci. (3), Vol. V, p. 198, and various papers in Vol. X.

leys which lead southward within the glaciated region or on its southern border; and postglacial time, extending to the present day, is therefore named by Dana the Recent or Terrace epoch. It is to be remarked, however, that much of the terracing of the valley drift was doubtless done speedily after the retreat of the ice from any basin, while yet adjacent drainage areas on the north were receiving from it thick flood-plain deposits. The Glacial, Champlain, and Terrace epochs thus overlap, the second being wholly and the third partially included within the Glacial or Pleistocene period, if continental areas are considered; but for any limited district, as a single river basin, the sculpturing of the terraces took place chiefly after the departure of the ice beyond its watershed.

Latest glaciation far north.—In the latest stages of the glacial recession the ice-sheet probably became divided into three remnants, one covering northern British Columbia and contiguous portions of the Northwest Territory and Alaska, another occupying the region west, northwest, and north of Hudson Bay, stretching northward to the large islands of the Arctic Ocean, and a third covering Labrador and the country north of the St. Lawrence. The present glaciers of British Columbia and southern Alaska, the broad Malaspina glacier or ice-sheet, described by Russell, between the St. Elias Range and the ocean, and the extensive ice-enveloped country seen by Russell in the view northward from Mount St. Elias, estimated by him to embrace not less than 30,000 square miles, are surviving representatives of glaciation which probably has been continuous in that region since the time of maximum extent and depth of the continental ice-sheet.[1] From the second of these areas glacial currents moved south-southwestwardly across the Churchill River and Reindeer and Athabasca lakes, partly obliterating the earlier westward striæ, and southeastwardly across Marble Island, in the northwestern part of Hudson Bay. This division of the North American ice-sheet is probably still represented by glaciers or a small ice-sheet in Baffin Land, on the coast of Fox Channel, from which its icebergs are carried southeastward into Hudson Strait.[2] Possibly the

[1] National Geographic Magazine, Vol. III, pp. 53–203, with 19 plates, May 29, 1891. Am. Jour. Sci. (3), Vol. XLIII, pp. 169–182, with map, March, 1892. Am. Geologist, Vol. IX, pp. 322–336, May, 1892.

[2] Dr. Robert Bell, Geol. and Nat. Hist. Survey of Canada, Report of Progress for 1882–83–84, p. 24 DD.

recession and final melting of the continental ice-sheet caused it to extend over lands within the Arctic Circle which had not been covered by the ice when it reached farthest south. From the melting of its last remnants moisture-laden winds doubtless have carried portions of it across Baffin Bay and Davis Strait to be deposited again in the ice-sheet that still covers the interior of Greenland.

GLACIAL CURRENTS WITHIN THE BASIN OF LAKE AGASSIZ.

Table of courses of glacial striæ.—The directions of the currents of the ice-sheet are shown by its tracks, the furrows and striæ which bowlders and gravel frozen in the base of the moving ice engraved upon the bed-rocks over which they passed. From these courses of movement of the ice, the areas of its thickest accumulation and consequent outflow are known. In some districts, also, changes in the outlines of the ice border and in its slopes and currents during its final retreat are indicated by deflected glacial striæ which run across the earlier courses. Occasionally two or more sets of striæ are found intersecting on the same rock surface, but more frequently the earlier and later sets are preserved on separate portions of the same or contiguous rock-outcrops.[1] The testimony of these records is so important concerning the barrier which held Lake Agassiz that a table is presented as an appendix of this volume, noting the courses of striæ which have been reported upon all the country from Hudson Bay, Lake Superior, and Minnesota westward and northward across the basin of this glacial lake.

Converging lobes of the ice-sheet in Minnesota and Manitoba.—The southwestward striation in northeastern Minnesota and the southeastward striation in the central and southern part of that State belong to two convergently flowing lobes of the ice-sheet, partly corresponding to its portions which earlier inclosed the driftless area of southwestern Wisconsin and united in a continuous area of ice farther south The central

[1] A most valuable classification of the various types of glacial striation, planation, and embossment, with discussion of their methods of origin and of their significance as evidence of the prevailing ice currents and of deflections during the glacial recession, is given in Professor Chamberlin's memoir, "The rock-scorings of the great ice invasions," Seventh Annual Report, U. S. Geol. Survey, for 1885–86, pp. 147–248, illustrated by 50 figures in the text, mostly engraved from photographs.

line of the western of these ice-lobes coincided nearly with the Red and Minnesota rivers and the upper Des Moines, its southern end being near Des Moines, in central Iowa. This may be named the Minnesota lobe of the ice-sheet. Farther west the Dakota lobe stretched from the Souris basin and the region of Turtle Mountain south across the east half of North and South Dakota to Yankton, its central line being along the valley of the James or Dakota River. In Manitoba the glacial currents, passing to the Minnesota and Dakota ice-lobes, moved to the south-southeast and south, as noted at several localities on the Winnipeg River above Lac du Bonnet, on Lakes Winnipeg, Winnipegosis, Manitoba, and St. Martin, at Stonewall and Stony Mountain, and on the Assiniboine; and these currents are remarkably contrasted with the southwestward striæ of the contiguous region of the Lake of the Woods and the country extending thence east and north. These converging striæ in western and eastern Manitoba probably were engraved mostly during the recession of the glacial boundary, when Lake Agassiz was extended over the greater part of the Red River Valley. On the east this lake appears to have been bounded by a vast ice-lobe outflowing from the region of Lake Superior and James Bay southwest and south to the Lake of the Woods and Lake Itasca, representing the earlier convergent ice-lobes of the northeastern and of the western and southern portions of Minnesota, while on the west it was bounded by the representative of the Dakota ice-lobe, then outflowing from the region of Lake Manitoba and Riding Mountain southward to the terminal moraine of Pilot Knob, the north side of Devils Lake, Turtle Mountain, and the Tiger, Brandon, and Arrow hills.

Transportation of bowlders.—Nearly everywhere the greater part of the drift is derived from formations not far distant, varying from a few miles to 25 or 50 miles away, in the direction from which the ice-sheet moved; but mingled with this material from comparatively near sources are other portions, both of the fine detritus and of the small and large rock masses, which have been transported longer distances, as the Archean bowlders of northern Montana and the upper Saskatchewan district, derived from the Archean belt east and north of Lake Winnipeg and about Reindeer Lake.

The least distance from the most western of these bowlders to the margin of the Archean belt is about 550 miles. Other bowlders of Archean origin which must have traveled nearly or quite as far occur in Kansas, Missouri, and Illinois, on the southwestern part of the drift-bearing area of the United States. The method of transportation of all these is believed by the writer to have been wholly by the slow currents of land ice.

Dr. Robert Bell observes that the bowlders and pebbles of the drift on the west coast of Hudson Bay, near the mouth of the Churchill, and on the lower part of the Nelson, consist largely of rocks like those of the opposite eastern coast of Hudson Bay, which is 500 miles distant.[1] But the farthest known transportation of rock fragments in the drift, recorded in part by Dr. Bell, whose observations are supplemented by my own, is from James Bay southwest to North Dakota and Minnesota. The rock thus recognized is a "dark gray, granular, siliceous felsite or graywacke, * * * characterized by round spots, from the size of a pea to that of a cricket ball or larger, of a lighter color than the rest of the rock, which weather out into pits of the same form." It occurs in situ, as reported by Dr. Bell, on Long Island, off Cape Jones, on the east coast of Hudson Bay where it is narrowed to form James Bay, having there a southwestward strike and probably continuing under the sea for some distance in that direction. He notes that the abundance of pebbles and bowlders of this rock is the most remarkable feature of the drift on the west coast of James Bay and along the Attawapishkat, Albany, and Kenogami rivers, and that its fragments have been found by him as far west as Lonely Lake and southward to Lake Superior.[2] Farther to the southwest and south I have observed fragments of it, usually only a few inches but in some instances a foot or more in diameter, occurring very rarely in the drift in the northeastern part of North Dakota, where the largest piece ever found by me was about 30 miles south of the international boundary and 50 miles west of the Red River, and at numerous localities in Minnesota, where it extends at least as far south as Steele County, 75 miles south of St. Paul and 1,000 miles southwest of its outcrop north of James Bay.

[1] Geol. Survey of Canada, Report of Progress for 1878–79, pp. 22, 23 C.

[2] Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. II, for 1886, p. 36 G.

DRIFT DEPOSITS ON THE LACUSTRINE AREA AND THE ADJOINING REGION.

The accompanying map (Pl. XVII) exhibits the diverse formations of drift, lacustrine, and alluvial deposits, described in this and following chapters, occurring within the somewhat thoroughly examined prairie portion of Lake Agassiz, with considerable tracts of the adjoining country.

Pl. III, in Chapter I, drawn on a smaller scale, shows a greater extent of the terminal moraines, and the courses of glacial striæ (as noted in Appendix A), upon almost the entire hydrographic basin of Lake Agassiz, with a large area eastward to Hudson Bay and the upper Laurentian lakes.

Derivation of the drift from preglacial residuary detritus and from glacial erosion.—The loose superficial material provided by preglacial weathering and stream erosion was generally plowed up and removed by the ice-sheet, being carried forward in the direction of its motion and mingled with other material similarly gathered along the path of the glacial current. Besides the gravel and finer alluvial detritus of valleys and a mantle of residuary clay, more or less enveloping all the country, occasional bowlders and rock masses were supplied on the higher lands by the irregular action of the preglacial denudation, ready to be borne along and deposited in the glacial drift. But the ice-sheet commonly did more than to remove the loose material before existing, as is shown by rock surfaces embossed, planed, and striated by glacial erosion. In general, far the greater part of the drift was thus worn off, and most of its bowlders were torn and plucked away, from the rock floor over which the ice-sheet moved, grinding it with the drift material contained in its basal portion under the pressure of the enormous weight of thousands of feet of ice. The large proportion of limestone present in the sand and finely powdered rock of the drift in regions of limestone formations demonstrates, as Professor Chamberlin has shown, that the drift was chiefly derived from glacial wearing of the bed-rocks.[1]

[1] U. S. Geol. Survey, Third Annual Report, p. 312, and Sixth Annual Report, memoir by T. C. Chamberlin and R. D. Salisbury, "The driftless area of the Upper Mississippi," pp. 241, 247, 255; and Am. Jour. Sci. (3), Vol. XXVII, p. 388, May, 1884. Compare "Composition of the till or bowlder-clay," by W. O. Crosby, Proceedings of Boston Society of Natural History, Vol. XXV, 1890, pp. 115–140.

MAP OF THE DRIFT DEPOSITS ON THE SOUTHERN PORTION OF THE BASIN OF LAKE AGASSIZ.

Scale, about 42 miles to an inch.

Till. Terminal Moraines. Modified Drift with tracts of Till. Deltas of Lake Agassiz. Other Lacustrine and Alluvial Deposits.

It should be added, however, that the depth of the glacial erosion was probably nowhere so great as to change the principal and grander topographic features of the preglacial contour. The most important influence of glacial action upon the topography was usually the removal or partial wearing away of comparatively small projecting knobs, and the filling up of depressions and valleys, bringing the surface to a more uniform contour than before the Ice age.

Thickness of the drift.—The thickness of the sheet of superficial deposits overlying the bed-rock upon the area of Lake Agassiz is shown by wells to vary from about 125 feet to 260 feet or more in Minnesota, commonly from 200 to 300 feet in North Dakota, and from 50 feet or less to 250 feet or more in Manitoba.

At Herman and Moorhead, Minn., the entire depth of the drift is found to be, respectively, 124 and 220 feet. Several other deep wells in this State, none of them apparently extending to the base of the drift, show its thickness to be at least 260 feet at Campbell, 217 feet at Ada, 190 to 205 feet near Crookston, 253 feet at South Angus, and 165 feet at St. Vincent.

Wells in North Dakota pass into the strata underlying the drift at the depth of 220 feet in Fargo, 250 feet in Casselton, 310 feet near Grandin and Kelso, and 298 feet at Grafton. A well at Grand Forks, 265 feet deep, appears not to have reached the bottom of the drift.

In Manitoba the thickness of the drift at West Selkirk is 65 feet; in Winnipeg and St. Boniface it varies from 30 to 80 feet; near Niverville it is from 65 to 100 feet; in Dominion City, near Letellier, and on the Low farm, west of Morris, it is at least 170 to 250 feet, and in West Lynne at least 108 feet; at Rosenfeld it is 143 feet; near Carman it is about 100 feet; and 7 miles west of Portage la Prairie, 158 feet. From these records it seems probable that the thickness of these deposits upon the flat plain of the Red River Valley in Manitoba averages about 100 feet, considerably exceeding this, to a maximum of 150 to 250 feet, along the central part of this area south of the Assiniboine, but not probably averaging more than 50 feet in the lower part of the valley between Winnipeg and Lake Winnipeg, where the higher portions of the bed-rock rise to the surface. On the Archean area of the east part of Lake Agassiz plentiful rock-outcrops occur about Rainy Lake and the Lake of the Woods, westward along the Canadian Pacific Railway nearly to the Whitemouth River, and in the country east of Lake Winnipeg; and it is probable that the average thickness of the superficial deposits in that extensive district is not more than 30 to 50 feet. West of Lake Agassiz many portions of the plateau bordered by the Pembina Mountain and the Tiger Hills have only a small depth of drift, ranging from a few feet to 20 or 30 feet, but in some places the drift appears to extend deeper, as shown by stream valleys, and its average thickness may be 40 feet or more.

Southward from Devils Lake, upon the expanse crossed by the Sheyenne and James rivers, the drift covering its eastern portion, along the Sheyenne, continues thin, varying from 10 or 20 to 50 feet or more; but farther west, along the James, it is again of considerable depth, averaging probably 100 feet, and ranging commonly from 50 to 150 feet on moderately undulating tracts. Throughout this plain-like expanse, as generally upon other parts of the country adjoining Lake Agassiz, the drift-sheet receives an addition of probably 30 to 60 feet along the course of its numerous admirably developed marginal moraines.

TILL OR BOWLDER-CLAY.

Till, also called bowlder-clay, constitutes the greater part of the entire sheet of superficial deposits, both within the area of Lake Agassiz and upon the adjoining country. It usually lies on the striated bed-rock, and upon large areas it reaches thence upward to the surface; but elsewhere this unmodified glacial drift is covered by modified drift, the stratified gravel, sand, and clay deposited by streams which flowed down from the ice-sheet during its melting, or by lacustrine and fluvial sediments. Fully half of the area of Lake Agassiz in Minnesota and North Dakota has a surface of till. In the part of this lake area examined by me in Manitoba its proportion is less, because much of this district is covered by the Assiniboine delta and its associated lacustrine beds. Extensive tracts of till, however, occupy the surface on the north and east portions of the Manitoba area, as north of Neepawa, on the east side of the Big Grass Marsh, from the south end of Lake Manitoba eastward by Shoal Lake nearly to the Red River and Winnipeg and south to the Canadian Pacific Railway, from East Selkirk eastward along this railway, and 10 miles east of Emerson, where the flat plain of the Red River Valley is bordered by slightly higher land. Till also forms the surface of the terrace along the foot of the Pembina Mountain escarpment between the international boundary and Thornhill. Beneath the delta deposits of gravel and sand, and along the central portion of the Red River Valley, where the surface is commonly fine silt or clay, a sheet of till lies between these sediments and the bed-rock.

The till is the direct deposit of the ice-sheet, as is shown by its consisting of clay, sand, gravel, and bowlders, mingled indiscriminately in an unstratified mass, without assortment or transportation by water. Very finely pulverized rock, forming a stiff, compact, unctuous clay, is its principal ingredient, whether at great depths or at the surface. It has a dark, bluish-gray color, except in its upper portion, which is yellowish to a depth that varies from 5 to 50 feet, but is most commonly between 15 and 30 feet. This difference in color is due to the influence of air and water upon the iron contained in this deposit, changing it in the upper part of the till from protoxide combinations to hydrous sesquioxide. Another important difference in the till is that its upper portion is commonly softer and easily dug, while below there is a sudden change to a hard and compact deposit, which must be picked and is far more expensive in excavating. The probable cause of this difference in hardness was the pressure of the vast weight of the ice-sheet upon the subglacial till, while the upper part of the till was contained in the ice and dropped loosely at its melting. Upon each side of Lake Agassiz the till has a moderately undulating and rolling surface. Within the area that was covered by this lake it has a much smoother and more even contour, and its upper portion, owing to its manner of deposition in this body of water, sometimes shows an imperfect stratification, with a scantier intermixture of bowlders and gravel. Yet even where it has distinct lamination it usually is more like till than like ordinary modified drift, and contains stones and gravel through its entire mass.

The chief characters of the englacial upper portion of the till, as compared with the subglacial lower portion, are its looser texture, its more plentiful and larger bowlders, the prevailingly angular and subangular shapes of its bowlders and smaller rock fragments, whereas they are mostly worn smooth by glaciation in the lower till, and the usually more gravelly and sandy and less clayey composition of the englacial till, owing to the washing away of much of its finer material by superglacial drainage. To these originally inherent characters we must add the very noticeable postglacial change of color of the upper till already mentioned. This change has generally extended through the englacial till, stopping at the more impervious subglacial deposit. Between the two there is also frequently a layer of subglacial stratified gravel and sand, from a few inches to several feet thick. The extremes of thickness of the englacial till appear to range from almost nothing or only a few feet for minima to 40 feet or more for its maxima near massive terminal moraines and where great currents of the ice-sheet converged.[1]

Rock fragments and other drift inclosed in the ice at a considerable height above the ground were borne forward without attrition. The higher part of the englacial drift is thought by the present writer to have supplied most of the material forming the terminal moraines, which, therefore, have a remarkable profusion of bowlders and angular gravel. When the ice-sheet was finally melted, its inclosed bowlders were dropped, and they now lie frequently as conspicuous objects on both the lower and higher parts of the land. Scattered here and there in solitude on an expanse of prairie, or perched on the sides and tops of hills and mountains, they at first suggest transportation and stranding by icebergs or floe ice.

Bowlders and gravel from Archean and Paleozoic formations.—Bowlders are frequent or plentiful in the till throughout the area of Lake Agassiz, their abundance being nearly the same as in the least rocky parts of the till of New England, New York, and the country surrounding the Laurentian lakes. Their usual range in size extends up to a diameter of 4 or 5 feet; but in a few localities, especially in the course of morainic belts, they

[1] Bulletin, G. S. A., Vol. III, pp. 134-148. Am. Geologist, Vol. VIII, pp. 376-385, Dec., 1891.

were observed of all sizes up to 10 or 12 feet cube. Generally as large a proportion as 99 per cent of the bowlders exceeding 1 foot in diameter consists of Archean granite, gneiss, and schists, being derived from the Archean area on the northeast and north. With these are occasional limestone blocks, derived from the belt of Paleozoic limestones, constituting on the average perhaps nearly 1 per cent of the large rock fragments of the drift. The bedded and jointed character of the limestones has prevented their supplying many large bowlders in comparison with the more massive crystalline Archean rocks, while yet usually about half of the smaller cobbles and pebbles in the till and in gravel and sand deposits are from these Paleozoic limestones. Upon the Cretaceous area a considerable proportion of the gravel and cobbles is derived from the Fort Pierre shale, but this formation supplies no large blocks.

Northeastern limit of limestone drift.—East of Lake Winnipeg and northeast of a line drawn from this lake southeastward by Lac du Bonnet on the Winnipeg River and across the Lake of the Woods to the west end of Rainy Lake and onward to Vermilion Lake, both bowlders and gravel of limestone are absent or exceedingly rare. This line probably marks the farthest extent ever attained by the glacial currents which moved south-southeast in the vicinity of Winnipeg and at Black Bear Island, near the Narrows of Lake Winnipeg, carrying débris from the limestone region of the Manitoba lakes.

It is also very remarkable that the same line divides an area of very thin drift on its northeast side from the area of very thick drift which thence extends southwestward across all western Minnesota, the southern part of Lake Agassiz, and the region of the Sheyenne and James rivers to the Missouri Coteau.

Localities of very abundant and large bowlders.—The following localities may be mentioned as having especially abundant bowlders: On the slope of the Pembina Mountain, in township 3, range 6, Manitoba, between Morden and Thornhill, very plentiful and large bowlders are spread upon an area of several square miles, as noted in the description of the Tintah beaches. The sides of Star Mound, Manitoba, especially those facing the north and northeast, are strewn with a multitude of bowlders, nearly all granitic, of all sizes up to 5 feet in diameter or rarely larger. These were probably combed out of the ice-sheet in its passage over this hill. Comparatively few bowlders occur on the small flat area at its top. Pilot Mound, an equally prominent hill seen from this in looking northwest, is, like Star Mound, a knob of Cretaceous shale with thin covering of drift, but it has no such unusual profusion of bowlders on its slopes. Rock Lake, through which the Pembina flows, derives its name from the remarkable abundance of bowlders, mostly granitic, up to 6 feet or more in diameter, bordering its shores; and along a distance of 1 or 2 miles west from this lake the Pembina Valley is much encumbered with bowlders, which in some places are accumulated upon small morainic ridges and knolls.

The largest bowlder observed within the area of Lake Agassiz south of the international boundary has given name to White Rock station, in the northeast corner of South Dakota, 11 miles north of Lake Traverse. This bowlder, lying 50 feet west of the railway, at a distance of about 25 rods north of the station, measures 18 by 12 feet, with a height of 5½ feet. It is a medium-grained, massive, flesh-colored granite, weathering to a whitish gray.

Another bowlder of nearly equal size lies about 50 rods west of the Herman beach, in or near section 12, township 140, range 46, Minnesota, some 6 miles north of Muskoda. Its dimensions are 15 by 12 by 5 feet, and its top is 1,095 feet above the sea. It is gneiss, minutely porphyritic, with white feldspar crystals up to an eighth or a quarter of an inch long.

A somewhat larger block, exceeding any other noted during my survey of Lake Agassiz and the adjoining region, lies in the northwest quarter of section 9, township 1, range 4 east, Manitoba, on the low ridge 10 miles east of Emerson. It is dark-gray granitoid gneiss, 22 feet long, 8 to 14 feet wide, and projecting 2 to 5 feet above the surface. Among the other plentiful bowlders of that vicinity none was seen exceeding 7 or 8 feet in dimensions. Like many of the smaller bowlders throughout this prairie region, this block is surrounded by a slight depression 1 to 3 feet below the adjoining ground; and a careful examination shows that some of its projecting corners and edges are smoothly polished. These depressions were formed by the trampling and pawing of buffaloes in rubbing on the bowlders, which were thereby sometimes worn and polished as perfectly as could be done by art.[1]

TERMINAL MORAINES.

Exploration of the terminal moraines in the northeast edge of South Dakota, accumulated on the west margin of the Minnesota lobe of the ice-sheet, northward to the Head of the Coteau des Prairies, was included in the work of the writer during 1880 for the Minnesota Geological Survey. The three outer moraines are typically developed and distinctly separated in that portion of their course, as well as through the adjoining southwest part of Minnesota; and from their description for this district[2] they have been denominated by Professor Chamberlin the Altamont, Gary, and Antelope moraines. Besides these, nine others, to a total of twelve in all (as shown on Pls. III and XVII), lying along a large part of their extent in successive order from south to north, and apparently marking consecutive stages in a wavering recession of the ice-sheet, are recognized in Minnesota and receive names in the annual and final reports of the State survey from localities where they are notably prominent or distinct. In western Minnesota they seem to constitute a simple series, each in order advancing from south to north and northeast being of somewhat later formation than the one preceding; but in the central and eastern portions of the State, from the Leaf Hills southeast to Minneapolis and St. Paul, and in their course eastward into northern Wisconsin, consecutive moraines are merged together, and even the later are found overlapping the earlier in the series.

[1] Notes of the wide area over which such bowlders polished by buffaloes are found, and of other traces of these animals still visible on the prairies and plains, from which they have so recently vanished, are given in Geology of Minnesota, Vol. II, p. 516.

Occasionally a bowlder worn by the rubbing of buffaloes has been pushed back and forth by them while the surrounding hollow was being formed by their pawing and by the winds blowing away the dust from it, until the rock has been thus undermined and lowered evidently at least 3 or 4 feet below its original position, so that its top now lies beneath the general level of the land. Among several examples of this result seen by me, one may be noted which was found about 60 feet northwest of the quarter-section stake between sections 26 and 35, Mekinock, Grand Forks County, N. Dak. This bowlder, weighing several tons, measures about 7 feet in length and 5 feet in width, and stands up 1½ to 2 feet out of the ground; yet it is so situated in a bowl shaped hollow, 30 to 40 feet in diameter and 3 feet or more in depth, that the top of the rock is 1½ feet below the uniform level surface on all sides around the hollow. It is a light-gray, rather coarse-grained hornblendic granite, very compact and not affected by weathering; and its corners and edges are finely polished.

[2] Geol. and Nat. Hist. Survey of Minnesota, Ninth Annual Report, for 1880; Final Report, Vols. I and II.

Farther to the west the terminal moraines of South Dakota, and of North Dakota west of the James River and north to the Northern Pacific Railroad, have been mapped by Prof. J. E. Todd for the United States Geological Survey. To give a more complete view of these moraines through the region of Lake Agassiz, notes based on his map and several published papers are included in the present monograph. My observations of the outer moraines on the Coteau des Prairies from Iowa to the northeast part of South Dakota and on the Coteau du Missouri in the northwest part of North Dakota are thus connected and correlated through Professor Todd's exploration of the successive boundaries of the intervening Dakota lobe of the ice-sheet.

The moraines of the Tiger, Brandon, and Arrow hills in Manitoba, mapped by the writer in 1887, seem probably contemporaneous with the most northern morainic belts in Minnesota, and it is evident that in both districts they belong to the time of the uppermost in the series of the Herman beaches, the first and highest of the well-marked shore-lines of this glacial lake. Though these moraines of southwestern Manitoba and northern Minnesota are the tenth and eleventh, the latest formed, in the series of moraines here described, they mark a much earlier stage of the glacial retreat than the terminal moraine observed by Dr. Robert Bell[1] as crossed by the Hill, Nelson, and Churchill rivers, about midway between Lake Winnipeg and Hudson Bay, which may well belong to the time of the Campbell beaches or later, while the line of morainic islands reported by Mr. A. P. Low[2] along an extent of about 200 miles from south to north and north-northwest in James Bay was certainly formed after Lake Agassiz began to outflow northeastward, perhaps after it was lowered to its present representative, Lake Winnipeg.

The twelve moraines of Minnesota are doubtless correlative with the similarly numerous moraines, partly simple, with approximately parallel courses, and partly complicated in their arrangement by interblending and overlapping, which have been recently traced by Mr. Frank Leverett, passing southward from Wisconsin along the east side of the driftless area

[1] Bulletin, G. S. A., Vol. I, pp. 303, 306.

[2] Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. III, for 1887–88, pp. 25–36 J and 62 J.

and running in great loops, the boundaries of lobes of the ice-sheet, across Illinois, Indiana, and Ohio. These are embraced within a strip of country of similar width with that of Minnesota, Iowa, and the Dakotas, which, though 200 or 300 miles wide, is yet only a minor part of the drift-covered area of this continent. For the interior of this area the observations of Bell and Low give us good assurance that nearly an equal profusion of marginal moraines, recording step by step the wavering departure of the ice-sheet, await exploration in all the region northeast and north from Minnesota and the Great Lakes to Hudson Bay, and from northern Pennsylvania, New Jersey, Long Island, Marthas Vineyard, Nantucket, and Cape Cod to the Laurentide highlands, north of Montreal and Quebec.

EARLIER MORAINES FORMED BEFORE THE BEGINNING OF LAKE AGASSIZ.

When the North American ice-sheet attained its greatest area, and during its later Iowan and Wisconsin stages, its southern portion, from Lake Erie to the Missouri River, consisted of vast lobes, one of which, at the beginning of the Wisconsin stage of accumulation of moraines, reached from central and western Minnesota south to central Iowa. This Minnesota lobe then ended near Des Moines, and its margin was marked by the first or Altamont moraine, lying upon the Coteau des Prairies and in part forming its crest. When the second or Gary moraine was formed, it terminated on the south at Mineral Ridge, in Boone County, Iowa. At the time of the third or Antelope moraine it had farther retreated to Forest City and Pilot Mound, in Hancock County, Iowa. The fourth or Kiester moraine was formed when the southern extremity of the ice-lobe had retreated across the south line of Minnesota and halted a few miles from it in Freeborn and Faribault counties. The fifth or Elysian moraine, crossing southern Lesueur County, Minn., marks the next halting place of the ice. At the time of formation of the fifth moraine the south end of the ice-lobe had been melted back 180 miles from its earlier extent, shown by the Altamont moraine, and its southwest side, which at first rested on the Coteau des Prairies, had retired 30 to 50 miles to the east side of Big Stone Lake and the east part of Yellow Medicine County.

During its next stage of retreat the Minnesota ice-lobe was melted away from the whole of Lesueur County, and its southeast extremity was withdrawn to Waconia, in Carver County, where it again halted, forming its sixth or Waconia moraine. This records the position of the front of the ice-sheet immediately before its continued recession gave place for the beginning of Lake Agassiz. It will therefore be described somewhat in detail along its course adjacent to this glacial lake.

SIXTH OR WACONIA MORAINE.

Between the fifth and sixth moraines the southeast end of the Minnesota ice-lobe retreated from Elysian to Waconia, a distance of about 40 miles from south to north, uncovering the lower portion of the Minnesota Valley and finally draining the glacial lake of the Blue Earth and Minnesota basins, which had outflowed southward in its highest, early stages by Union Slough in Iowa to the East Des Moines River, and later to the east by the Cannon River. The advance of the east side of this ice-lobe at the time of the Kiester and Elysian moraines beyond its previous limit, by an incursion from Wright County to Chisago County and the edge of Wisconsin, had been followed by a withdrawal from the greater part of the area thus acquired, until at the time of the sixth moraine the most eastern portion of the ice margin was accumulating the prominent drift hills close east and north of Elk River, in Sherburne County. The glacial recession there from east to west and southwest between the Elysian and Waconia moraines appears to have been also about 40 miles. A long indentation of the ice-sheet, between its Minnesota and Lake Superior lobes, was melted back during the same interval, the apex of this reentrant angle being carried from southeastern Stearns County 50 miles west to Lake Whipple and Glenwood, in Pope County. But in some places the ice border north and east of Waconia had probably retreated no more than a few miles, and on the southwest side of the Minnesota lobe, in Redwood, Yellow Medicine, Chippewa, Swift, and Big Stone counties, there was only slight recession of the ice, and the Elysian and Waconia moraines seem to be blended, though they form together only inconspicuous marginal deposits.[1]

[1] Geology of Minnesota, Vol. II, pp. 642, 625, 440, 463, 464, 487, 488, 233, 415, 105, 106 [Waconia], 128 166, 213, 516; Vol. I, pp. 606, 621. (These citations are in the order from east to west for the areas severally described in the chapters of the Minnesota reports treating of separate counties.)

After passing northwest across Lake Traverse and the Head of the Coteau des Prairies, the Waconia moraine appears to be merged with the two preceding Elysian and Kiester moraines in the conspicuous belt of drift hills that extends from the line dividing South and North Dakota northward between Straubville and Crescent Hill, between Nicholson and Oakes, and along the east side of Bear Creek, to the southeast part of township 135, range 59. Thence it turns west and northwest a few miles, beyond which it runs again northward through the west part of township 136, range 59, the most northeastern of Lamoure County, where it forms a narrow belt of knolls and hills, rising 40 to 60 feet above the nearly level plain on each side.

In Barnes County, running 42 miles from south to north, this moraine is distinct and well developed, being divided from the next earlier and later moraines of the series by smoothly undulating and in large part nearly level belts of till, which vary in width from 2 to 3 miles to a maximum of about 8 miles on the west and 12 miles on the east, the separation from the seventh or Dovre moraine being on the average the wider of the two. The Waconia moraine enters Barnes County at the middle of the south side of township 137, range 59, and curving northeastward passes through sections 34, 26, and 24, in a belt of typical knolls and hills 25 to 75 feet high, very rough in their outlines and profusely strewn with bowlders, to the east line of this township, where the apex of a reentrant angle of this belt almost touches the Dovre moraine, which rises to equal or greater prominence in the adjoining township. A plain of overwashed gravel and sand, deposited just outside the ice border in the indentation of the Waconia moraine, is crossed by the road on the west line of sections 23, 14, and 11, township 137, range 59, thinly covering the underlying till, which is occasionally exposed, with its projecting bowlders, in slight depressions. Turning by a right angle, this moraine runs northwestward through sections 13, 11, and 3, rising 25 to 50 or 75 feet above the general level. In the northeast quarter of section 3, a lake bed, wholly dry in August, 1889, lies at the northeast base of these hills, and a belt about a half mile wide, next to the north, is moderately rolling till, beyond which a second belt of morainic hills similar to the foregoing and parallel with it, a fourth to a third of a mile wide, runs northwestward through the southwest quarter of section 35, township 138, range 59. This twofold condition of the Waconia moraine is observable along a distance of 3 or 4 miles. In sections 32 and 29 the moraine turns to the north and continues through the middle of the west half of this township in hills and short south-to-north ridges 25 to 60 feet above the adjoining nearly level inter-morainic surface of till. The width of the hilly belt here and north-northeastward through sections 33, 28, 21, and 22, township 139, range 59, is about a mile; but for the next 4 miles north it expands to a width of 2 or 3 miles and is conspicuously displayed in steep hills 50 to 150 feet high, to the apex of another reentrant angle in sections 33 and 34, township 140, range 59, 2 to 3 miles south of Hobart. Thence the moraine again turns by a right angle, taking a westward course, parallel with the Northern Pacific Railroad and about 2 miles south of it, through the south edge of township 140, range 60, where its hills cover an average width of 1 mile and rise 50 to 75 feet above the smoothly undulating expanse of till on each side.

The Northern Pacific Railroad crosses the Waconia moraine close west of Eckelson, where it has a width of about a mile, marked by a rolling and partly knolly contour, with elevations 25 to 50 feet above the hollows. Within a mile west of the morainic belt the railroad crosses an ancient watercourse, a fourth to a half of a mile wide, extending from north to south, occupied by a lake on the north side of the railroad and by a marsh on the south. Both are bordered by bluffs which rise steeply about 40 feet to the general level. This lake is one of a series that extends 6 miles south-southwest, occupying portions of this old watercourse, but intervening portions and its farther continuation southward are mostly filled with the glacial drift. Lake Eckelson and a series of smaller lakes, reaching 5 miles south to Walker Lake, mark a second and parallel watercourse, similarly enveloped in other portions by the general drift sheet. The north end of a third series or chain of lakes of the same kind, about 6 miles long, is crossed by the railroad a mile east of Sanborn; and a fourth is indicated by a long lake extending south from the railroad near Hobart. The first of these chains of lakes lies wholly outside the Waconia moraine, but the others are crossed by the east-to-west portion of this moraine south of Hobart, Sanborn, and Eckelson. They probably have had a history like that of the Spiritwood series of lakes, several miles farther northwest, and of the similar chains of lakes extending from north to south in Martin County, Minn., which are believed to occupy the unfilled parts of preglacial or perhaps interglacial channels of drainage.[1]

Beyond Eckelson this moraine extends north-northwestward as a rolling and knolly belt, inconspicuous in any distant view, to the southeast part of township 142, range 61, about 10 miles east of Spiritwood Lake. There it is moderately rolling and occasionally hilly, a third to a half of a mile wide, with more bowlders than the adjoining lower and only slightly undulating surface, both being till. Curving north-northeastward, it passes through sections 14, 12, and 1 of this township, being well marked in the east part of section 1 as a belt of low morainic knolls, a quarter of a mile wide. Onward through the next 6 miles northeast to the south part of section 11, township 143, range 60, this moraine forms a belt, a half mile to 1 mile wide, of knolls and scattered steep hills, partly composed of kame gravel and sand, with few bowlders, rising 40 to 75 feet above the general level, as conspicuously seen from Dazey. In section 11 its course seems again to be deflected nearly by a right angle, passing thence northwest and north through township 144, range 60, to the vicinity of the Helena farm in section 29, township 145, range 60; but along this distance it is marked only by a rolling contour, with no prominent elevations.

Continuing northward through Griggs County, the Waconia moraine becomes gradually more knolly and hilly, with increasing proportion of bowlders, to its magnificent development in townships 147 and 148, range 60, passing close east of Lake Sibley and west of the beautiful Lakes Addie and Jessie, to Red Willow Lake. Along the distance of 10 miles adjoining these lakes the irregularly piled masses of morainic drift, strewn with many bowlders, rise 100 to 200 feet above the lakes, giving a measure of boldness and even grandeur to the scenery, such as is rare in this plain and prairie region. West of Lake Sibley the fine agricultural tract of Blooming Prairie has a nearly level surface upon a width of about 10 miles, includ

[1] Geology of Minnesota, Vol. I, pp. 479-485, with Pl. 18.

ing township 146 and the south part of township 147, range 61, beyond which, northward, this smooth area of lowland, dividing the Waconia and Elysian moraines, narrows into a belt only about a mile wide in the southeast part of township 148, range 61, called Colemans Valley. At the north end of this valley, on the west side of Red Willow Lake, these two moraines meet, and thence pass in a united morainic belt west and northwest to the Washington Lakes, the Sheyenne River, and the Indian reservation south of Devils Lake.

MORAINES CONTEMPORANEOUS WITH LAKE AGASSIZ.

The seventh or Dovre moraine marks a pause in the glacial recession when the southeast end of the Minnesota ice-lobe rested on Kandiyohi County. At this time Lake Agassiz had begun to exist, the south end of the Red River Valley having been uncovered from the ice. Probably nearly all of the southern half of Minnesota was then divested of its ice mantle, while nearly all of the northern half was still ice-covered, the glacial boundary across the State passing in an approximately east-to-west course.

By its next recessions the ice border was withdrawn to the eighth or Fergus Falls moraine and the ninth or Leaf Hills moraine. These are partly merged together in the prominent accumulations of the Leaf Hills, which reach in a semicircle from Fergus Falls to the southeast, east, and northeast, a distance of 50 miles, marking the southern limits of this ice-lobe when it terminated half way between the south and north borders of Minnesota. During the formation of the tenth or Itasca moraine, and of the eleventh or Mesabi moraine, the ice border crossed the lake region at the head of the Mississippi. Farther north the twelfth or Vermilion moraine, discovered and mapped by the present writer in 1893 during work for the Minnesota Geological Survey, passes by the south side of Vermilion, Pelican, and Net lakes. Later moraines, formed at times of halt or readvance, interrupting the recession of the ice-sheet between northern Minnesota and Hudson Bay, have been observed in only a few places; but I believe that they exist and will be continuously mapped when the glacial drift of that wooded and very scantily inhabited region shall be fully explored. The many beaches of Lake Agassiz, all showing an ascent northward when compared with the level of the present time, but with this ascent gradually decreased during the successive stages of the lake, probably find their explanation in the manner of retreat of the ice in Canada, interrupted there, as farther south, by pauses and the formation of moraines.

The following are notes of the five moraines already mapped which cross the expanse of Lake Agassiz, being conspicuous upon each side of this lake, but faintly developed or lost on the lacustrine area:

SEVENTH OR DOVRE MORAINE.

The Dovre moraine is prominent in Stearns, Douglas, Pope, and Kandiyohi counties, Minn. Its distinctive name is taken from its hills in Dovre, Kandiyohi County, to which the southeast extremity of the Minnesota lobe of the ice-sheet had been withdrawn west-northwestward about 70 miles from Waconia during the interval between the sixth and seventh moraines. In Pope and Douglas counties an area about 25 miles wide, from Glenwood north to Miltona and Spruce Hill townships, was probably uncovered by this glacial recession. But considerable portions of the ice border in its general course at this time from east to west across central Minnesota had receded only a few miles between these moraines. Indeed, they seem to be merged together north of Richmond, in Stearns County, and from Barsness, in Pope County, to Mount Tom, about 9 miles north-northeast of the Dovre Hills. Again, in Big Stone County, a single belt of somewhat rolling till, 5 to 8 miles wide, seems representative of the Elysian, Waconia, and Dovre moraines combined. In the wooded country east from Little Falls, Minn., to the sources of the St. Croix River in Wisconsin, this moraine has not been definitely traced.[1]

Crossing Richland and Sargent counties, in the southeast corner of North Dakota, the Dovre moraine is well developed in knolls, hills, and short ridges of till, covering a belt from a half mile to 2 miles in width, with abundant bowlders and characteristically rough contour. On the southwest side of Taylor Lake, near Hankinson railway station, these rough

[1] Geology of Minnesota, Vol. II, pp. 642, 625, 581–585, 605, 446–448, 464, 475–478, 482–488 (including a general description of the characteristic features of the terminal moraines of Minnesota), 224–226 [Dovre], 233, 213; and Vol. I, p. 621. (The order of citation is geographical, from east to west.)

drift hills rise to heights 50 to 150 feet above this lake, or 1,100 to 1,200 feet above the sea. Thence a bowlder-strewn, rolling, and knolly surface, with numerous small lakes, extends west along the south side of the Great Northern Railway to prominent morainic hills, 50 to 100 feet in height, which extend about 7 miles from east to west close south of Geneseo and Cayuga. In the east part of township 130, range 54, this moraine curves to the north, passing about a mile west of Cayuga and Ransom, and north-northeastward through the northwest part of township 131, range 53. From near the northwest corner of this township it runs to the northwest diagonally across township 132, range 54, passing close west of Milnor, where its knolls and hills are 20 to 50 feet high, with abundant bowlders. The same northwestward course is continued through Ransom County, passing by Lisbon as a belt of knolls and hillocks crowning the southwest bluff of the Sheyenne Valley, to the conspicuous morainic hills (including "Bears Den Hillock") in the vicinity of Fort Ransom, rising 50 to 100 feet above the general level and 250 to 300 feet above the river.

At the time of accumulation of these hills the ice-sheet had retreated a few miles north from the Head of the Coteau des Prairies and 10 to 25 miles eastward from the moraine referred to the Kiester, Elysian, and Waconia stages, near Straubville and Nicholson and along Bear Creek. The northeastwardly sloping surface of the greater part of Sargent County was covered by a glacial lake, whose silt beds, confluent southwestward with those of Lake Dakota, are about 1,300 feet above the sea from Sargent and Straubville southward into South Dakota, to Newark, Kidder, and Burch, but decline eastward to about 1,250 feet on the south side of Silver and Sprague lakes. The surface of this glacial lake was 1,300 feet, or probably at first 1,310 feet, above the present sea-level, its outflow being southwestward across the bed of Lake Dakota to the James River. The channel of this outlet is doubtless distinctly traceable. On the north this lake received a large inflowing stream, the representative of the present Sheyenne River, which brought the waters that were discharged from the border of the receding ice-sheet and from the drainage of a considerable belt of the adjoining land along all the distance northward to the vicinity of Devils Lake and thence northwestward to the head of the Sheyenne. Even farther northwest, the glacial Lake Souris outflowed by this stream, as previously at its beginning it had found outlet during the time of the Elysian and Waconia moraines into the upper part of the James River, flowing through Arrow Wood and Jim lakes to Lake Dakota, so long as that lake existed.

This great affluent, which may be called the glacial Sheyenne River, is marked by a flat or in part moderately undulating belt of stratified gravel and sand, extending from the central part of the Fort Ransom military reservation southward by Marshall and Nicholson. It includes a width of $1\frac{1}{2}$ miles to the west and an equal distance to the east of Marshall, where it is bounded on each side by higher tracts of smooth till. Its height above the sea at Marshall is 1,343 feet, and at Nicholson, where it widens into the glacial lake of Sargent County, 1,309 feet. Two comparatively small channels, probably occupied by the stream in winter when glacial melting was at its minimum, were seen near the west side, on the wide alluvial belt, about $1\frac{1}{3}$ miles and 1 mile west of Marshall, each having a width of an eighth of a mile and a depth of about 15 feet. One of these channels, or the two interlocking and here and there separated by islands, is commonly known as the Big Slough, and has an extent of many miles from north to south.

During the recession of the ice from the compound moraine on the west line of Sargent and Ransom counties to the Dovre moraine, before described, the glacial lake grew as fast as the land became uncovered, extending gradually east around the northern base of the Coteau des Prairies to Skunk Lake (recently called Lake Tewaukon), northeast over the smoothly undulating surface of till, very abundantly sprinkled with bowlders, about Forman and Lake Kandiota, to the Stormy Lakes and adjacent moraine near Milnor, and northward along the moraine and ice front into Ransom County. Its depth at Forman was 50 feet; at Perry, 6 miles east, nearly 100 feet; and farther east and northeast, beside the Dovre moraine, about 150 feet, if it continued tributary to the James River through the whole time of this glacial retreat.

It is more probable, however, that when the recession of the ice uncovered Lake Tewaukon and the country eastward, an outlet was found in that direction along the front of the ice-sheet and the Dovre moraine, flowing into Lake Agassiz in the northwest part of township 129, range 49. The belt of stratified gravel and sand, 1 to 2 miles wide, which there and for a distance of 15 miles southeastward constitutes the border of this lacustrine area,[1] seems to have been deposited by this great river, while the ice-sheet lay on its northeast side, terminating where the edge of this level or somewhat undulating tract descends like a terrace and is bordered by the slightly lower Herman and Norcross beaches. Since the deposition of these stratified beds, the River Warren, outflowing from Lake Agassiz, has eroded and carried away their continuation across an extent of several miles southeast to a remnant of the same gravel and sand which, with underlying till, forms the plateau cut by the Fargo and Southern (Chicago, Milwaukee and St. Paul) Railway in the southeast part of township 128, range 47, Traverse County, Minn., about half way between White Rock and Wheaton. The outline of the ice margin along the extreme southwestern edge of this glacial lake at the time of its accumulating the Dovre moraine and forming the northeast bank of the glacial Sheyenne River at its entrance to the area of Lake Agassiz may therefore be somewhat confidently traced around the little plateau between the Bois des Sioux and Mustinka rivers and southward by Wheaton to the rolling land about the Tokua Lakes at Graceville. The prominent morainic hills west of Taylor Lake, according to this interpretation of our observations, were massed in an angle of the ice margin, the usual place for plentiful drift accumulations.

Windy or Airy Mound, on the northern end or Head of the Coteau des Prairies, close south of the line between North and South Dakota, is a slight elevation above the general surface of this drift-covered Cretaceous ridge. Its height is about 1,950 feet above the sea, and by estimate 100 feet lower than the crest of this ridge a few miles farther south. Thence gentle slopes descend 750 feet to Sprague and Skunk lakes, near the northern base of this highland; and the whole view east, north, and west from Windy Mound sweeps over a broad, nearly flat expanse of till and lacustrine silt, ranging in altitude from 960 feet at Wahpeton to 1,250 feet at Forman and 1,300 feet on the area of Lake Dakota adjoining the James

[1] U. S. Geol. Survey, Bulletin No. 39, pp. 38–40.

River. After extending as a continuous massive ridge nearly 200 miles from south-southeast to north-northwest through southwestern Minnesota and the northeast corner of South Dakota, with an elevation increasing northward from 1,600 to 2,050 feet above the sea, the Coteau des Prairies is thus terminated, and along the next 175 miles northward to the south end of the Pembina Mountain escarpment no conspicuous rise of the surface is observable from a great distance on the west side of Lake Agassiz and the flat, low plain of the Red River Valley. There is, however, a slow ascent of several hundred feet from this lacustrine area west to the plain-like expanse of Cretaceous shales and overlying drift, which rises northward from 1,200 to 1,300 feet above the sea in Sargent County to about 1,500 feet in the region surrounding Devils Lake.

Into this plain the Sheyenne and James rivers have cut narrow and trough-like channels or valleys that vary from a third or a half of a mile to commonly 1 mile and rarely 2 miles in width. These channels, like the narrow morainic belts of knolls and low hills, are thus minor features of the general topography. The Sheyenne channel or valley is 100 to 200 feet deep, mainly cut in the Cretaceous shales for its lower half or more, though the faces of the bluffs are usually covered by a talus of drift, while the James Valley, ranging from 75 to 125 feet in depth, is mostly eroded in the drift sheet, there thicker than along the Sheyenne. From the vicinity of Valley City northward by Cooperstown to Devils Lake, Langdon, and a large part of southwestern Manitoba, stretching west from the crest of the Pembina Mountain, the depth of the drift is only from 10 to 50 feet. Over extensive tracts of Griggs and Cavalier counties it varies from 10 to 30 feet. Its average northward on this belt is small, not probably more than as 1 to 4 or 6 in comparison with its thickness in the Red River Valley, throughout western and southwestern Minnesota and on most parts of the great Cretaceous ridge of the Coteau des Prairies.

Between the Dovre moraine and the compound moraine next west the general level of the northwestern part of Sargent County and of southwestern Ransom County is diversified by three massive swells or hills, which, like the surrounding nearly flat country, have a smooth surface of till. One of these, rising 75 to 100 feet and extending 2 or 3 miles from south to north, is in the west part of township 131, range 57, close west of Harlem. Another, also trending with the meridian, lies 12 to 15 miles farther north, between Marshall and Elliott, above which railway stations it rises about 60 feet. The third is White Stone Hill, which extends about 4 miles from east to west in the north part of township 132, range 56, having a somewhat crescentric and oval form, convex to the south, with a height of about 150 feet. None of these elevations consists of morainic drift, but they seem to be due to the prominence of the underlying shale, which, however, has no outcrops, the thickness and character of the drift being nearly the same as on the surrounding intermorainic area.

Multitudes of bowlders, mostly Archean gneiss and granite, seldom exceeding 3 feet in diameter, are scattered on the gently undulating expanse of till north of the Head of the Coteau. The bowlder-strewn tract extends west to Belle Plaine and 2 or 3 miles west of Forman, and northward through townships 130 and 131, in ranges 54 and 55, occupying an area of about 150 square miles. The bowlders are fully fifty times more plentiful than their average numbers on similarly smooth areas of till in western Minnesota and North Dakota, their proportion being nearly the same as on the morainic belts of this region. They may belong to morainic drift which has been smoothed by a subsequent advance of the ice over it, having been, perhaps, deposited during the time of the Kiester or Elysian moraines, and covered by a glacial advance at the time of the Waconia moraine; or they may have been gathered in unusual numbers in the englacial drift of this part of the ice-sheet, because of convergent currents from the east and west, together with the influence of the highland so near on the south. Further observations seem needed for determining satisfactorily the reasons for their abundance. They lie upon the central and eastern part of the lacustrine area of Sargent County, unless that lake became almost wholly drained away eastward, as is probable, before this surface was uncovered from the ice.

The Dovre moraine extends north from its high hills in the Fort Ransom Reservation and forms a belt of lower rolling and knolly till, with plentiful bowlders, through sections 34, 27, and 22, township 136, range 58. On each side it is bounded by flat tracts, about 50 feet lower than the highest points of the moraine and 200 feet above the Sheyenne, that on the west being till and that on the east stratified gravel and sand 1 to 2 miles wide, dividing the moraine from the trough-like Sheyenne channel or valley. From near the center of this township the morainic belt, continuing with inconspicuous development, passes northeastward across the Sheyenne, and at the northeast corner of this township and in section 6 of that next east the drift, heaped in a reentrant angle of the ice border, forms Standing Rock Hill, rising 100 feet above the general level and about 300 feet above the river. Thence this moraine turns back by a right angle to the west and northwest, recrossing the Sheyenne and rising in hills 50 to 100 feet high, through sections 34, 27, 28, 21, 20, and 17, township 137, range 58, approaching within a mile of the equally prominent hills of the Waconia moraine at its reentrant angle in the next township on the west.

Continuing thence to the north, the Dovre moraine is represented by a narrow series of knolls, 20 to 30 or 40 feet above the general level, through township 138, range 58, veering slightly to the east, and closely skirting the west side of the Sheyenne Valley across the northern half of the township. Its drift covers the east slope and top, and its bowlders are strewn abundantly on the west slope of a hill of the Fort Pierre shale which rises nearly on the line between sections 32 and 33, township 139, range 58, to a height 50 feet above the average of the adjoining country, or about 225 feet above the river. Thence the moraine appears to turn northeastward and to lie concealed across a distance of about 4 miles beneath the high flood-plain of gravel and sand adjoining the Sheyenne, out of which the apex of a sharply reentrant angle projects in two typically morainic hills about 40 feet high in or near section 12 of this township, some 2 miles east of the river. Returning thence west-southwestward to the prominent and massive hill in the north part of section 19 of this township 139, range 58, 2 miles west of the river, abundant bowlders, apparently marking the course of the ice front at the time of the Dovre moraine, are strewn over the east, northeast, and southwest sides of this hill, which, however, is principally a rounded projection or boss of the Fort Pierre shale, seen in the slight ravines of its east side to 40 feet below its top. The higher part of its southwesterly sloping but somewhat plateau-like top, less encumbered with bowlders than its sides, is about 125 feet above the general level, or 300 feet above the Sheyenne. In the view from this hill I traced faint indications of the course of the Dovre moraine in a curve passing northwest, north, and northeast to the similarly prominent hill 2 miles west-northwest of Valley City. The highest hills of the moraine in this distance of 7 miles rise about 60 feet above the general level in sections 11 and 2, township 139, range 59. All the surface from this loop eastward 3 or 4 miles to the Sheyenne Valley is a very smooth, fertile tract, apparently the flood-plain of the river when it flowed about 175 feet above its present level, at the time of the retreat of the ice-sheet from this moraine.

In section 18, township 140, range 58, 1½ miles north of the Northern Pacific Railroad and slightly farther northwest of Valley City, a prominent tract of morainic drift, probably owing part of its height to an underlying hummock of the Cretaceous shale, rises 100 feet above the old gravel and sand flood-plain of the Sheyenne on the east or about 300 feet above the river. The surface of this elevation is abundantly strewn with bowlders and is very irregularly broken by ravines, hillocks, and small ridges, trending from south to north to its highest point and thence trending toward the west-northwest, indicating that there was here another reentrant angle of the ice margin. Looking across the country west-northwestward, I observed low knolls and ridges of this moraine, scarcely above the general level, extending at least 2 or 3 miles; but no prominent hills are visible in this direction. Two to 3 miles north of Hobart this moraine curves northward, and passes as a narrow belt of knolly drift north and northeast through the east half of township 141, range 59, and across the Sheyenne to the northeast part of township 142, range 58, where it becomes partially merged with the Fergus Falls moraine. Thence turning back by a right angle, it recrosses the Sheyenne about a mile above the mouth of Bald Hill Creek and extends northwestward along the east side of this creek. Its most prominent portion, called Bald Hill, lies 5 miles east of Dazey and extends along a distance of 2 miles or more from southeast to northwest, rising some 300 feet above the Sheyenne or fully 100 feet above the general level.

Through Griggs County the Dovre moraine is very well developed and forms especially conspicuous hills west and north of Cooperstown, rising 75 to 150 feet above the adjoining country. From Bald Hill it takes a very straight course a little west of north for 15 miles to the center of township 146, range 59, 2 to 3 miles west of Cooperstown, having through this distance an average width of a mile and consisting of many knolls and small hills of till, with abundant bowlders, rising 25 to 50 feet above the nearly level surface on each side. Toward the west this belt is bordered along much of its extent by an overwashed plain of gravel and sand, about a mile wide, descending by a very gentle slope away from the moraine, which thus has a very definite boundary; but on the east there is a gradual change through a decreasingly knolly and rolling contour to the slightly undulating expanse of intermorainic till, with only few bowlders, which stretches 4 to 6 miles east to the Sheyenne Valley and 20 miles north between the moraine and the Sheyenne, from Bald Hill to the scattered hills of a reentrant angle of this Dovre moraine 4 to 6 miles north of Cooperstown.

About 5 miles farther north another angle of the moraine is marked by the conspicuous hill called Butte Mashue, from the name of an Indian who was buried in a mound on its summit. This hill, situated in the east half of section 35, township 148, range 59, rises 150 or 175 feet above the general level east and north, or nearly 350 feet above the Sheyenne River, which is only 1 mile distant at the northeast. It is a typical morainic drift hill of small area, irregularly knolly contour, and very abundant bowlders. Its diameter of base is only a third to a half of a mile. On the township line south of this section 35 there is a hollow a quarter of a mile wide, through which a road runs from east to west, nearly 150 feet below the top of the Butte Mashue. Immediately to the south, in the north edge of section 2, a very rocky and typically morainic north-to-south ridge rises about 125 feet; and thence a series of hills and short morainic ridges, 75 to 125 feet high, extends south to the irregularly scattered hills of similar heights which occupy most of the area between Cooperstown and Clear Lake.

Unusual numbers of limestone bowlders were observed in this vicinity on the morainic hills and adjacent to them, including many 6 to 8 feet in diameter, one mass 10 by 15 feet in dimensions, and another, seen close east of the south-to-north road about a mile south of the Butte Mashue, measuring 20 by 30 feet and projecting 1 to 2 feet above the surface, and shown by digging to be more than 3 feet thick. All these are grayish-yellow, very compact magnesian limestone, similar to that which is found forming bowlders of equal abundance near Audubon and the White Earth Agency in Becker County, Minn., and again on the massive morainic hills near Fort Totten, on the south side of Devils Lake. In these localities the limestone bowlders sometimes occur in equal or even greater numbers than those of the Archean rocks; but generally throughout this region the proportion of such limestone masses in the drift is very small, averaging probably not more than a hundredth part of the large bowlders, though the portions of the gravel of the drift supplied respectively by the limestone and the Archean rocks are commonly about equal. They are like the outcrops of magnesian limestone in the neighborhood of Winnipeg, in Manitoba, 165 to 180 miles distant to the north, which are its nearest natural exposures.

West of Butte Mashue the Dovre moraine is represented by knolls and hills 25 to 75 feet high, which continue to the prominently rolling land surrounding Norway Lake, in the northeast corner of township 147, range 60. Next this moraine extends northward in an inconspicuous belt of knolly and rolling till to low hills in or near section 23, township 149, range 60; and thence, turning to the west-northwest, it holds this general course through a distance of 30 miles to the Devils Heart Hill. It crosses the Sheyenne River in the southeast part of township 150, range 61, and forms a conspicuous belt of hills, 100 to 150 feet high, along the south side of township 151, range 63, 4 to 5 miles south of Free Peoples Lake. A lower but well-marked series of morainic hills and knolls, mostly 40 to 60 feet high, with very abundant bowlders, curves thence northwest and north, passing through the center of township 151, range 64, to the Devils Heart. Again, only a few rods north of the base of that hill, a typically irregular belt of very rocky morainic knolls, 30 to 50 feet high, occupying a width of only 20 or 30 rods, trends from east-southeast to west-northwest, and forms the frontal line of the chief morainic tract bordering the south side of Devils Lake (Pl. XVIII). The Dovre moraine south of the Devils Heart Hill would thus join a larger morainic tract on the north, which appears referable to the Fergus Falls and Leaf Hills moraines. At this intersection there is heaped the largest and most remarkable kame that has ever come under my observation, known by its aboriginal appellation as the Devils Heart. This mound of gravel and sand appears to have been deposited where a glacial river descended from the convergent slopes of the ice-sheet to the open land contemporaneously with the accumulation of the Dovre moraine.

Devils Heart Hill rises in steep slopes of 20° to 30°, being thus steep on all sides excepting the south, where the otherwise nearly round-topped, conical hill is somewhat drawn out into a narrow, more slowly descending ridge. It consists of gravel and sand, mostly not showing pebbles on the surface larger than $1\frac{1}{2}$ inches in diameter. A few bowlders, however, a score or more in all, are seen on the sides of this hill to its top, and one a foot long (the only one seen at the crest) is embedded in the gravel a rod south of the highest point and less than 1 foot lower. The gravel is of threefold origin, being derived in about equal proportions from granitic and gneissic Archean rocks, from the Silurian limestones, and from the Cretaceous shales. Nearly all of the bowlders seen on the hill are granite or gneiss, but two or three on its west side are limestone. It is situated in section 4, township 151, range 64, about a mile southwest from the head of Donahues Bay of Devils Lake. Its height above its base is about 175 feet, and above Devils Lake, according to Nicollet's barometric determination, 290 feet, which appears to be about 15 feet higher than Sullys Hill, the culminating point of the very prominent hills of morainic till south of Devils Lake. From the altitude of the lake, 1,430 to 1,434 feet above the sea, as known by railway surveys, the top of the Devils Heart is approximately 1,722 feet, and of Sullys Hill, 1,707 feet, above the sea.

The Dovre moraine is blended with the later Fergus Falls and Leaf Hills moraines from the Devils Heart northwest and west by Fort Totten and the Crow Hills to the northwest part of township 151, range 66, in the west edge of the Indian reservation, where it again becomes a separate belt. Thence it passes in a general west-northwestward course along the north side of the Antelope Valley to the area of the glacial Lake Souris. Immediately north of Oberon its very irregular knolls, hills, and small short ridges border the Minnewaukan branch of the Northern Pacific Railroad along a distance of 3 miles. Next to the north there is a width of nearly 2 miles of moderately undulating, smooth till, in the central part of which is the disused Fort Totten station. Westward this smooth tract extends about 2 miles, dividing the Dovre moraine on the south from the compound Fergus Falls and Leaf Hills moraines on the north; but beyond this it is interrupted by morainic hills surrounding Long Lake, where the two belts seem to be once more united. The further course of the Dovre moraine and its relationship with these later moraines upon the very scantily settled country extending from Long Lake and Minnewaukan westward have not been definitely traced and are laid down on the map (Pl. XVII) only in a provisional manner. It is probable that the Dovre moraine is well developed 5 to 10 miles south of Rugby Junction, where the surface bears numerous small lakes, and that it is also represented on the southeast part of the Lake Souris area by swells about 60 feet above the general level, seen 1 to 3 miles southeast of Berwick. The continuation of the ice border thence northwest may have been approximately coincident with the sand hills lying on both sides of the Souris or Mouse River, in townships 157 and 158, ranges 75 and 76. Little Medicine Lodge, so named from its being formerly the scene of dances of the Indians, with incantations of their medicine men, is one of these dunes without vegetation, which rises about 75 feet in height on the west bank of the Souris River, 5 miles north of Towner.

EIGHTH OR FERGUS FALLS MORAINE.

The eighth and ninth or Fergus Falls and Leaf Hills moraines unite in the south part of Ottertail County, Minn., to form the Leaf Hills, 100 to 350 feet high, which reach from Fergus Falls in a semicircle 50 miles southeast, east, and northeast, to the Leaf Lakes. These are the most conspicuous morainic hills of this State; and on account of their prominence above all the adjoining country they have been commonly called the Leaf Mountains. Eastward from these hills the Fergus Falls moraine seems to be merged with the Dovre moraine through Miltona and Spruce Hill, in the northeast part of Douglas County, and through southwestern and southern Todd County. Next it runs northward in a well-marked belt of drift hills through the east edge of Todd County to the magnificent development of this moraine, apparently united again with the ninth or Leaf Hills moraine, about Fish Trap Lake and Lake Alexander, in northwestern Morrison County. Crossing to the east side of the Mississippi, the Fergus Falls moraine passes south along the east side of this river's Glacial flood-plain to Hole-in-the-Days Bluff and the massive hills east of Little Falls, where it is probably combined with a reentrant angle of the Dovre moraine. Thence it passes northeastward through the southeast part of Crow Wing County, skirting the northwest side of Mille Lacs; and curving next southeastward around this lake, it appears to be represented by morainic hills observed in the southeast part of Aitkin County and in northwestern Pine County. Northward from Fergus Falls, this moraine passes by Lakes Lida and Lizzie to Detroit, the White Earth Agency, and White Earth Lake; and thence it turns nearly by a right angle west-northwest to the Frenchmans Bluff, in township 143, range 43, Norman County, west of which it enters the area of Lake Agassiz, close south of the Wild Rice River.[1]

The course of the ice front where it formed the northern barrier of Lake Agassiz at the time of its accumulation of the eighth or Fergus Falls moraine is marked by hilly and knolly drift deposits, with plentiful bowlders, both east and west of the lake near the latitude of 47° 10′, which passes 20 miles north of Fargo; by an unusual abundance of bowlders near this latitude and farther north on portions of the slightly undulating or nearly level till forming each side of the lacustrine area; and by a tract of till several miles in width, probably representing both the eighth and ninth or Fergus Falls and Leaf Hills moraines combined, which stretches across the Red River Valley at Caledonia, from Ada, Rolette, and Beltrami west to Reynolds, Buxton, Cummings, and Blanchard, constituting the bed and banks of the river along the Goose Rapids. In Lake Agassiz the morainic till was spread with a generally even surface, but it has many small inequalities, the higher portions being 3 to 5 feet or rarely 10 feet above adjoining hollows. Bowlders and gravel are plentiful on its surface,

[1] Geology of Minnesota, Vol. II, pp. 630, 642; 625; 581–585, 605; 563, 564, 571; 475, 477, 478, 488; 544–549 [Fergus Falls and the Leaf Hills]; 647, 652. U. S. Geol. Survey, Bulletin No. 39, p. 33. (The references are in geographic order, from east to west.)

this being the only interruption of the lacustrine and alluvial clayey silt which elsewhere continuously occupies the central part of the Red River Valley plain from near Breckenridge to Winnipeg.

In North Dakota the Fergus Falls moraine passes southward in a loop outlining a lobe of the ice-sheet which lay between Lake Agassiz and the Sheyenne River. This lobe reached about 40 miles south from the latitude of Caledonia, which marks approximately the apex of a glacial reentrant angle in the Red River Valley, where the laving action of Lake Agassiz appears to have caused the melting of the ice border to progress faster than on the land surface at each side. Emerging from the lacustrine area, on which its drift was leveled by the waves, the Fergus Falls moraine presents a prominently rolling surface of till west-southwest of Galesburg, and forms typical morainic hills in the northwest part of township 142, range 53, 1 to 3 miles west of Erie, rising 50 to 75 feet above the intervening hollows and the adjoining surface of smoothly undulating till westward, and 100 feet or more above the highest shore of Lake Agassiz. Thence the east boundary of the ice-lobe is marked by rolling and knolly till, with plentiful bowlders, and by low kames of gravel and sand, occupying generally a belt about 1 mile wide, which runs south-southwestward close north and west of Ayr and southward across the Northern Pacific Railroad 1 to 2 miles east of Buffalo. In the northwest part of township 139, range 54, a few miles south of this railroad, this morainic belt, continuing with similar features, turns to the west-southwest, crosses the Maple River, and holds this course about a dozen miles, passing through sections 25 to 28 and 32 and 31, township 139, range 56. This portion defines the southern extremity of the ice-lobe, the distance of its retreat from the Dovre moraine at Taylor Lake and near Geneseo and Cayuga having been about 55 miles. In Minnesota the recession of the ice from Dovre to the Leaf Hills was 60 miles, and along the Red River Valley it was approximately 100 miles from the southeast corner of North Dakota to Caledonia.

Occasional kame knolls and small plateaus of gravel and sand, 15 to 25 feet high, were observed along a distance of a dozen miles south of the end of this morainic loop, in townships 138 and 137, range 57, showing where glacial streams had flowed down from the ice-sheet during its retreat between the Dovre and Fergus Falls moraines, and there are small areas of undulating or nearly level gravel and sand associated with these kames. With these exceptions, all the expanse there and southward between the Dovre moraine and the area of Lake Agassiz consists of smoothly undulating intermorainic till. A similar sheet of till also occupies the area 15 to 20 miles wide inclosed on the north between the sides of the morainic loop, from Tower City and Oriska to Page City, Hope, and Sherbrooke.

From sections 36, 25, and 26, township 139, range 57, the Fergus Falls moraine takes a north-northwest course through section 14 in this township, there and onward forming morainic hills 20 to 60 feet high, strewn with abundant bowlders, to the Northern Pacific Railroad. Alta station (having a side track for trains to pass each other, but no depot) is situated near the middle of the morainic belt, which there has a width of about 2 miles, consisting of very irregular drift hills 25 to 75 feet high, with many bowlders. Thence the moraine extends nearly due north about 40 miles, with a width that varies from 1 to 3 miles, lying 2 to 8 miles east of the Sheyenne River, and forming the watershed between the Sheyenne and the Maple, to Pickert post-office, in section 7, township 146, range 56, 6 miles west of Sherbrooke. It is especially well developed and incloses several lakelets in the west half of township 141, range 57. It also occupies almost the entire west half of the next township northward, and in its northwest corner is interlocked with a reentrant angle of the Dovre moraine. Beyond this it runs slightly to the east of north, passing with a width of about 3 miles through the middle of the north half of township 143, range 57, and onward through southwestern Steele County, where it lies 6 to 9 miles west of Hope and Sherbrooke. The morainic knolls and hills along this distance rise commonly 20 to 60 feet above the smoothly undulating till on each side.

Massive hills of Cretaceous shale, overspread with a smooth surface of till, are found in Barnes County, both west and east of the moraine, 5 to 10 miles north of Valley City and Alta. The largest of these hills or swells extends nearly 4 miles from south to north in sections 32, 29, 20, and 17, township 141, range 58, close east of the Sheyenne River, above which it rises about 275 feet. Its height above the Glacial flood-plain of the Sheyenne, a nearly level tract of gravel and sand on the east, about 3 miles wide, is by estimate 75 feet. Thence this plain of stratified drift extends south along the east side of the Sheyenne by Valley City and through township 139, range 58, varying from 2 to 4 miles in width. In the west half of section 25, township 142, range 58, a smaller swell or hill with such smooth surface rises to nearly the same height, being likewise about 75 feet above the plain of valley drift on the southeast and south. Against the northeast edge of this smooth hill, the nucleus of which is doubtless Cretaceous shale, there are piled typical morainic accumulations, 50 to 100 feet high, whose very uneven contour and plentiful bowlders afford a remarkable contrast. Another Cretaceous hill, called Pilot Mound, whose surface, smoothly oval like a drumlin, shows only the overlying till, rises in the southeast quarter of section 2, township 141, range 57, to a height of 75 or 100 feet above the surrounding smooth expanse of till on all sides. The base of this hill is about a third of a mile long from south to north, and its width is about a quarter of a mile. Its sides and top have somewhat more plentiful bowlders than the adjoining country, but no morainic accumulations were observed nearer than the Fergus Falls moraine, which lies 2 miles distant to the west.

In the northwest part of Steele County the Fergus Falls moraine turns to a north-northwest course, which it holds along an extent of about 25 miles to the southwest part of township 150, range 58, in Nelson County, where it unites with the ninth or Leaf Hills moraine. In the south edge of Nelson County the Fergus Falls moraine has a width of about 1½ miles, with its east boundary at the northeast corner of section 34, 3 miles east of Lee and the Sheyenne River. Its small knolls and hillocks of till, with abundant bowlders, there rise 20 to 40 feet above the intervening hollows and the adjoining surface, which is moderately undulating till, with few bowlders, having a height of 175 to 200 feet above the Sheyenne.

Beyond township 150, range 58, the Fergus Falls and Leaf Hills moraines are so indistinguishably combined in their prominent accumulations south of Stump and Devils lakes, on the Big Butte, and northwestward by Broken Bone Lake to the Turtle Mountain, that the two along this extent of about 140 miles will be best considered together under the next division of this subject.

NINTH OR LEAF HILLS MORAINE.

West of the Mississippi the Leaf Hills moraine passes through eastern Cass County in a belt of knolly and hilly till, with extensive kame deposits of gravel and sand, occupying together a width of 2 to 4 miles, extending southwesterly by Crooked, White Fish, Pelican, Gull, and Sylvan lakes, to the Crow Wing River about 10 miles west of Brainerd. Crossing to the south side of the Crow Wing, it is merged with the Fergus Falls moraine in the plexus of morainic accumulations surrounding Lake Alexander and Fish Trap Lake. Thence it passes west through the northern tier of townships in Todd County to the Leaf Lakes in Ottertail County.[1]

The Leaf Hills,[2] extending southward and then westward from the Leaf Lakes, through East Battle Lake, Folden, Effington, Leaf Mountain, and Eagle Lake townships, are the combined Fergus Falls and Leaf Hills moraines, like the great morainic belt south of Stump and Devils lakes, in North Dakota. Beyond Eagle Lake the Leaf Hills moraine is again separate, passing northwest and north in a well-marked belt, 1 to 3 miles wide, of knolls, short ridges, and low hills of till, with abundant bowlders, through Tordenskjold, Swerdrup, Maine, Star Lake, and Edna townships, amid multitudes of lakes, to the prominent group of kames about 5 miles northwest of Perham. A parallel belt of low morainic hills extends north-northwestward from East Leaf Lake, passing a few miles east of Rush Lake to the south end and east side of Pine Lake.[3]

In Becker County, according to my observations in 1889, these morainic belts become united and form conspicuous hills of till, with many bowlders, denominated the Toad Mountains, which rise 100 to 200 feet above the general level or 1,500 to 1,600 feet above the sea. Northward this moraine has a width of 4 to 6 miles in low hillocks, little ridges, and knolls, including much kame gravel and sand, in its course by Round, Many Point, and Elbow lakes, and the extreme source of the Red River. About Rock Island Lake and east of the Twin Lakes, in townships 143

[1] Geology of Minnesota, Vol. II, 1888, pp. 581–584, 606; 564, 571, 572.

[2] The name given by the Ojibways to this belt of hills signifies Rustling Leaf Mountain, and the same name is by them also extended to the Leaf Lakes and River (Rev. J. A. Gilfillan, in the Fifteenth Annual Report, Geol. and Nat. Hist. Survey of Minnesota, for 1886, p. 469).

[3] Geology of Minnesota, Vol. II, pp. 546–549.

and 144, range 39, on the road from White Earth to Red Lake, also south of Mountain Lake, and at the east side of the Lower Rice Lake, the Leaf Hills moraine is well developed, forming hills 50 to 75 feet and occasionally 150 to 200 feet or more in height, profusely strewn with bowlders. It continues north in a hilly belt several miles wide through range 39, by the sources of Poplar and Hill rivers, to the south side of Lost River, in the edge of the Red Lake Indian Reservation, where it turns sharply westward on the southeastern Herman shore of Lake Agassiz, in the south edge of township 150, range 40.

From this bend or angle of the moraine its belt of knolly and hilly or rolling drift, mainly till, with many bowlders, occupying a width of about 5 miles, stretches west-southwesterly 25 miles, crossing Hill and Poplar rivers, and passing by Badger Lake and other small lakes in the vicinity of Erskine, at the head of Badger Creek. It includes much of the large wooded tract, with very plentiful lakes, southeast and south of Maple Lake, and enters the area of Lake Agassiz, where it loses its unevenness of contour, between the west end of Maple Lake and the Sand Hill River. This morainic belt, lying just outside and southeast of Lake Agassiz, partially bordered its shore, and elsewhere was separated from it only by a long tamarack swamp, and farther west by Maple Lake, with an adjoining narrow strip of lowland.

Slopes of the ice surface descended toward the angle of its boundary from extensive areas on the east, northeast, and north; and their convergent drainage formed an exceptionally large glacial river which was laden with much gravel, sand, and fine silt, washed away from the englacial drift that had become exposed on the thinned outer portion of the ice-sheet. A well-defined watercourse, which carried this river from the glacial melting at the time of formation of the moraine, starts from three lakelets in the north half of section 34, township 150, range 40, near the apex of the morainic angle, and was traced southwestward and southward to the Sand Hill River, passing obliquely about 9 miles through the morainic belt and 7 miles beyond, across a moderately undulating expanse of till. In its first 3 miles, extending to the Hill River, in section 5, township 149, range 40, the channel is two-thirds of a mile to $1\frac{1}{2}$ miles wide, having a smooth and mostly flat bottom of stratified sand and gravel. Along its next 2 miles the Hill River occupies its east side, and close west of this stream the central part of the channel contains a kame or esker plateau of gravel and sand which extends 2 miles from north to south, with a width of a quarter of a mile or less, rising 40 to 50 feet above the bottom of the old watercourse, a half mile wide, west of the plateau. Continuing south-southwestward 4 miles farther within the moraine, by the west end of a lake in section 24, township 149, range 41, to the Poplar River, in the southwest quarter of section 3, township 148, range 41, this channel is a marshy hollow, from 1 mile to only a third of a mile wide. Beyond the morainic belt, its next 2 miles, reaching south to McIntosh, are now part of the valley of the Poplar River; and its remaining 5 miles also extend nearly due south, uniting with the Sand Hill River in section 10, township 147, range 41.

The glacial stream flowing through this channel undoubtedly contributed a large share of the delta, chiefly composed of sand and fine silt, which was accumulated where the Sand Hill River emptied into Lake Agassiz, at a distance of about 20 miles to the west. Other portions of this delta deposit, though probably far less in their aggregate amount, were also brought by many small streams and rivulets which flowed down from the melting ice-sheet along its edge lying near the Sand Hill River, between this old watercourse and the place of disappearance of the moraine in the lake.

On the area of Lake Agassiz the course of the ice front forming its northern border at the time of the Leaf Hills moraine probably extended westward from the vicinity of Maple Lake to Beltrami, the Goose Rapids of the Red River, Buxton and Reynolds, and thence curved northwestward, passing near Arvilla, Larimore, and McCanna, to the morainic islands in the west edge of Lake Agassiz, forming the east side of the Elk and Golden valleys. Abundant bowlders, many of them of large size, are strewn upon the till which was the bed of the lake in the part of this course lying south of the Sand Hill River for 6 miles east of Beltrami. Farther west, in crossing the central part of the Red River Valley, the surface is till, containing plentiful small bowlders and gravel, and having slight inequalities of contour, the small ridges and swells being 5 to 8 or

10 feet above adjoining depressions, remarkably in contrast with the very flat surface of lacustrine and chiefly alluvial clay and fine silt, containing no gravel or bowlders, which elsewhere is the axial lowest portion of this valley plain, continuous, excepting on this belt, from Breckenridge and McCauleyville to Winnipeg, with widths on each side of the river varying from a few miles to 15 or 20 miles.

The belt of till here stretching from east to west across the valley has a minimum breadth of about 10 miles, and probably comprises the marginal accumulations of the ice-sheet during its stages recorded by both the Fergus Falls and Leaf Hills moraines. In the massive Leaf Hills and again on the south side of Devils Lake these moraines are merged together; and such a compound moraine appears also to have been amassed by the ice-front in the deepest part of the bordering glacial lake. Upon this broad tract the till deposited in Lake Agassiz rises 50 to 75 feet above the top of the till along the center of the valley on the south and north, where it has been overlain by later stratified silt. The moraine was not covered by lacustrine silt, which is very scanty throughout the lake area, excepting where great rivers brought in gravel and sand deltas and more widely spread fine silt deposits of modified drift derived from the retreating ice-sheet. Neither, on account of its height, has it become covered, subsequent to the withdrawal of the lake, by the alluvium of the Red River and its tributaries, although this sedimentation has filled the valley both above and below almost to the height of the morainic belt.

Where the Red River cuts through this area of till its channel is obstructed by many bowlders, which form the Goose Rapids, 12 miles long in the winding course of the stream, next below the mouths of the Goose and Marsh rivers. The descent of the Red River along the rapids and onward to Belmont, a distance of 12 miles in due-north course, but about twice as far by the meanderings of the river, is 24 feet in its stage of lowest water, but only 14 feet in its highest floods. The plane of extreme high water rises 40 feet above the extreme low stage at the head of the rapids, and nearly as much all the way from Fargo and Moorhead to Winnipeg; but at Belmont, close below the foot of the rapids, the floods attain their greatest range in the entire valley, 50 feet.

In North Dakota the ice barrier of Lake Agassiz during the accumulation of the Leaf Hills moraine is believed to have curved to the northwest, extending upon the area of till along the eastern side of the sand and silt delta which reaches from McCanna 35 miles south to Portland. The existence of this large delta, evidently due to drainage from the melting ice-sheet without dependence on the aid of any of the present streams, having been deposited by a glacial river flowing southward from the Elk Valley, implies that north of it the ice front was deeply incised. The reentrant angle probably moved gradually toward the north from near Hatton to Larimore and McCanna and along the whole extent of the Elk and Golden valleys, and the ice-lobes stretched southward on each side of the delta, but were, like the angle, slowly undergoing change in their position by a steady or mostly intermittent recession from south to north.

The islands of morainic till which rose above the surface of Lake Agassiz at its highest stage along a distance of more than 30 miles east of the Elk and Golden valleys, between McCanna and Edinburg, were accumulated during this time on the west margin of the Minnesota ice-lobe. Their material and that of the beach ridges formed from their erosion were derived from the north and northeast, and contain scarcely any Cretaceous shale from the Pembina Mountain area. No glacial currents coming from even a few degrees west of north seem to have contributed immediately to the formation of this moraine, although during earlier stages of the glaciation currents from the north-northwest mingled their drift with that from the northeast upon this region. Numerous detailed notes of the Elk and Golden valleys and of the narrow series of morainic hills on their east side are given in Chapter VI, in connection with the description of the associated delta and beaches.

Rising from beneath the Elk Valley delta, which occupies the western margin of Lake Agassiz between the Turtle and Goose rivers, the Leaf Hills moraine seems to be represented by a succession of several more or less morainic belts, formed on the southeastern side of the Dakota ice-lobe. Subordinate stages of the glacial retreat are thus indicated, belonging to the time of progressive accumulation of the delta and of the moraine formed east of the Elk and Golden valleys, both of which, as well as the valley itself and the glacial river pouring southward in it, were gradually extended from south to north as the ice front with its deep indentation receded.

The most southeastern of these belts consists of somewhat rolling till west of Golden Lake, in township 147, range 55, and includes the area of very abundant bowlders which strew the bluffs of Fingals Creek or "Rocky Run," in township 148, range 56. Thence a belt of morainic knolls and hillocks, 10 to 40 feet high and occupying a width of half a mile, extends northwestward through sections 34 and 27, township 149, range 57, and rises in hills 50 to 75 feet above the general level in the southwest part of township 150, range 57, with numerous lakelets in the adjoining depressions. This moraine continues westward in knolls and hills 25 to 50 feet high to its junction with the Fergus Falls moraine, in the southern part of township 150, range 58, beyond which these two moraines seem to form a compound series, in many places very conspicuously developed, to the west part of the Turtle Mountain.

Other morainic tracts, probably all extending southward to join the preceding east of its union with the Fergus Falls moraine, were observed on the western shore of Lake Agassiz, as follows: First, somewhat rolling and hilly till 8 to 10 miles south of Larimore; second, knolls and swells of till, sprinkled with abundant bowlders, in the southwest part of Elm Grove township, crossed by the Great Northern Railway between the Herman beach and Shawnee station; and, third, moderately rolling and occasionally hilly till, with many bowlders, in the east part of Oakwood, forming a belt 2 to 3 miles wide, which lies about 3 miles west of the last and is crossed by the railway at and east of Niagara.

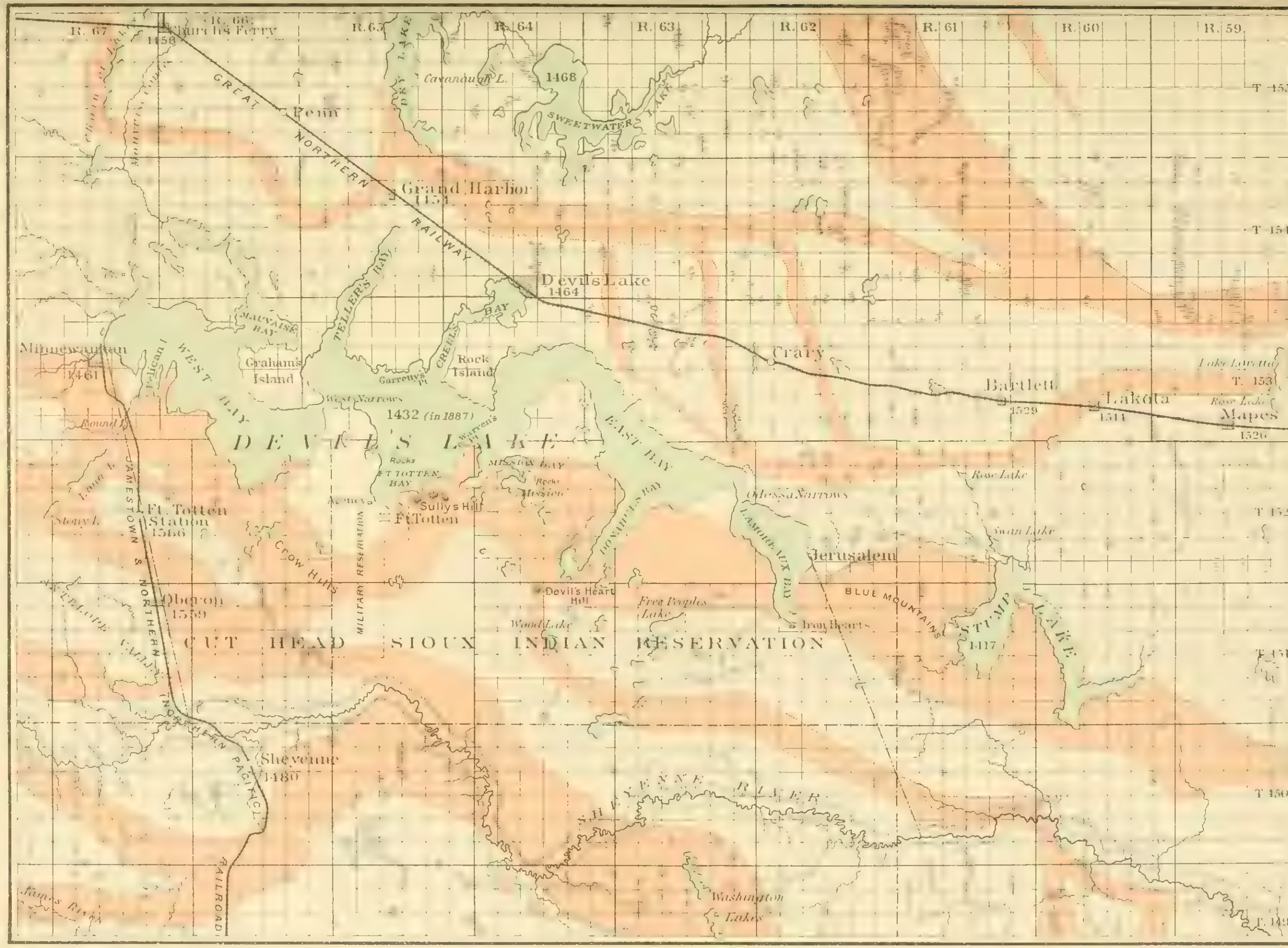
Similar recessional morainic accumulations of till and bowlders were also dropped on the western side of the Minnesota ice-lobe during its retreat across the Red River Valley, where it was rapidly melted back by the laving action of Lake Agassiz, between the chief stages of formation of the ninth and tenth or Leaf Hills and Itasca moraines. In this class may belong the remarkable profusion of bowlders found at a few points in Gilby (township 153, range 53), one of which is commonly called "The Island." Among other noteworthy localities of plentiful bowlders, the shores and bed of the Salt Lake of Park River, in section 36, Martin (township 158, range 52), should be mentioned, from which a belt of occasional bowlders in the lacustrine silt extends northward to the vicinity of Glasston. This belt is perhaps again recognizable in Minnesota, on the east side of the broad alluvial area adjoining the Red River, where many bowlders are spread on a flat or slightly undulating tract of till a few miles wide, extending from Euclid south to Shirley, succeeded on the northeast by silt and southward by till, with few bowlders.

Through the north half of township 150, range 59, the double Fergus Falls and Leaf Hills moraine consists of swells, knolls, and hills, 20 to 50 or 60 feet high above the smoothly undulating surface of till on each side. In the south half of this township the thickness of the sheet of till, extending as a plain toward the Sheyenne, is found to be only 10 to 20 feet, below which the wells enter the Cretaceous shale, obtaining slightly brackish and saline water. On the southern and western shores of Stump Lake, massive hills, called the Blue Mountains, consisting superficially of morainic drift, but probably having a nucleus of Cretaceous shale, rise 100 to 200 feet or more above this lake, their highest points being 100 to 150 feet above the plain on the south, which close to the hills is overwashed gravel and sand, descending 10 or 20 feet in its width of a half mile to 1½ miles. This is succeeded upon a width of 2 or 3 miles next to the south by a very flat expanse of till, the continuation of the same plain, profusely sprinkled with bowlders, continuing to the Sheyenne Valley, which here has a depth of about 150 feet below the plain and a width of a half mile to 1 mile.

Along the entire south side of Devils Lake (Pl. XVIII), extending more than 30 miles from Jerusalem to Minnewaukan, this compound morainic belt is magnificently developed, in many portions forming hills, knolls, and ridges of till, very rough in outline and bristling with multitudes of bowlders, of all sizes up to 10 feet in diameter, on a width that varies from 1 to 5 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; but Sullys Hill and others 2 to 6 miles east of Fort Totten constitute massive ridges 200 to 275 feet above the lake, and nearly equal heights are reached by the Crow Hills, 4 to 6 miles west of Fort Totten. As was stated of the similarly massive hills south of Stump Lake, these are probably in their central part the Fort Pierre shale, although no clear exposures of it were found, so completely are the slopes and summits mantled with their very rough morainic accumulations and innumerable bowlders. On the lake shore near the Fort Totten landing, and on the hills along the next 6 miles eastward, a large proportion of the bowlders consists of Silurian dolomitic limestone, like the strata which outcrop near Winnipeg in Manitoba. Limestone masses 5 to 10 feet in diameter are occasionally found in great numbers with the Archean granite and gneiss bowlders, which elsewhere form on an average fully 99 per cent of the large bowlders of North Dakota, so far as I have observed, excepting only in the vicinity of Butte Mashue (p. 155), where again these limestone bowlders are very abundant.

Perhaps the most striking feature of this morainic belt south of Devils Lake is its overwashed gravel and sand, which generally border the southern side of the hills, descending from them in graceful slopes. This deposit is most grandly exhibited between 3 and 4 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 accumulations of bowlders, which rise only from 5 or 10 to 40 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 watercourses which have become channeled to depths of 50 and even 100 feet without disclosing bowlders.

Devils Lake and Stump Lake were found by my leveling in August, 1887, respectively, 1,432 and 1,417 feet above the sea; but both were depressed about 2 feet lower by the drought of the following two years. These lakes, having very irregular outlines, with numerous windings and long bays or arms, probably lie in valleys of a preglacial river and its tributaries, elsewhere filled with drift. Devils Lake attains a maximum depth of 75 or 80 feet in the eastern portion of its broadest area, and the northeast arm of Stump Lake is said to be in some places 100 feet deep. The ancient watercourse appears to have flowed eastward directly to the Red River Valley. Its obstruction by drift during the Glacial period, and the



MAP OF DEVILS AND STUMP LAKES.

Scale, 6 miles to an inch.

Moraines

Altitudes of Railway stations and of lakes are noted in feet above the sea.

lobate outline of the ice-sheet in its retreat, with its morainic accumulations, have given to the postglacial Sheyenne River its circuitous course far to the south, over the Cretaceous plain, thinly covered by drift. The country adjoining these lakes generally consists of the Fort Pierre shale to a height 10 to 25 feet above their levels, as is ascertained by wells, while in the Big Butte, and probably also in the most massive of the hills on their southern shores, the shale rises much higher. Both lakes are now without outlets, but distinct beach lines, which are described in Chapter XI, in the discussion of past climatic changes in this district, show that during the recession of the ice they were raised nearly 25 feet above the present level of Devils Lake, being then confluent, with an outlet from the southwestern arm of Stump Lake southward to the Sheyenne.

West of Minnewaukan the compound Fergus Falls and Leaf Hills moraine forms a belt, 2 or 3 miles wide, of low hills, ridges, and swells of till, with plentiful bowlders, rising 25 to 50 or 75 feet, but inconspicuous in any distant view, through the central and northwest part of township 153, range 68; and thence curving northward it passes through township 154, range 69, to the west and highest portion of the Big Butte, or Mauvais Butte, as it is called by the French and Indians of Turtle Mountain. This prominent massive ridge of high land extends 10 miles from east to west and west-northwest, through the north edge of township 154, range 68, the northeast corner of the next township west, and the southern third of township 155, range 69. Its eastern 6 miles, to the west side of section 1, township 154, range 69, has a very smooth contour, and consists superficially of till, with the scanty proportion of bowlders generally observable on its lower areas. No morainic accumulations were seen on this part of the Big Butte, and the drift-sheet here is doubtless of similar depth (25 to 50 or 75 feet) as on the surrounding smoothly undulating country, above which this ridge rises 150 to 200 feet, to a height 1,650 to 1,700 feet above the sea. Its top along this distance is nearly level or only slightly undulating and rounded upon a width of 1 to $1\frac{1}{2}$ miles.

But the western 4 miles of the ridge is covered with irregular morainic deposits and a wonderful profusion of bowlders, giving to it a very rough contour, strongly in contrast with that on the east. A slight depression, sinking to about 1,600 feet above the sea, intervenes between the smooth and the morainic portions; and the latter, to which the name Big Butte is commonly limited, rises to 1,750 and 1,800 feet, or 250 to 300 feet above its base, the culminating point being near its west end. This Cretaceous highland, veneered with two diverse phases of the glacial drift, is situated 8 to 18 miles northwest of the west end of Devils Lake. It appears to be allied geographically and geologically with the highest of the hills south of Devils and Stump lakes; and the northwestward continuation of the old valley now filled by those lakes is probably represented along a distance of 30 miles north and north-northwest of the Big Butte by Ibsen, Hurricane, Grass, Island, and Long lakes.

Beyond the Big Butte this morainic belt is well developed in knolls and hills occupying a width of several miles, only moderately elevated above the general level, through township 155, range 70, and about Horse Shoe and Broken Bone lakes (the latter named from buffalo bones broken for extracting the marrow in making pemmican), in township 156, range 71. Next to the north of Limekiln and Broken Bone lakes and of Pleasant Lake station and Rugby Junction, on the Great Northern Railway, an extensive area is covered by morainic hills, with abundant bowlders, rising 50 to 100 feet or more above the intervening hollows and 100 to 150 feet above the smoothly undulating surface east, north, and west. This morainic area, probably representing the combined Fergus Falls, Leaf Hills, and Itasca moraines, extends about 15 miles north from the railway to Island Lake and Ox Creek, and an equal or somewhat greater distance from east to west across ranges 71, 72, and the east half of 73, pressing close to the Bottineau branch railway in the northeast part of township 157, range 73, and terminating thence along a south-to-north line which was also the east shore of the glacial Lake Souris, passing about 4 miles east of Round Lake and Barton. North of this remarkable development of the moraines a smoothly undulating or only moderately rolling surface of intermorainic till, with few bowlders, stretches from Island Lake and Ox Creek across the next 15 miles to the southern base of Turtle Mountain.

Gravel, sand, and silt, deposited in Lake Souris, extend from Dunseith southwest to Willow City and the Souris River, excepting a belt of moderately undulating till, about a mile wide, with frequent bowlders, rising 10 feet above the surface eastward, which crosses the central part of township 160, range 74, in a north-northwest course, having a descent of 40 feet within the first mile on its west side. The belt may represent the course of the combined Fergus Falls and Leaf Hills moraine, across the eastern margin of the area of Lake Souris, passing thence northward by Lords Lake to Butte St. Paul, Bur Oak, and Bear Buttes, on the west part of the Turtle Mountain area.

The highland of Turtle Mountain, extending about 40 miles on the international boundary, with two-thirds as great width, diversified by many subordinate hills and short ridges, 50 to 300 feet above adjoining depressions, rises with a massive general form, suggesting, as seen from some distant points of view, the rounded back of a turtle; but as seen from the south or north its many hills and buttes present a serrated outline. Its altitude above the surrounding country is 300 to 800 feet, the summits of its highest hills being about 2,500 feet above the sea. Beneath a veneering of glacial drift, which is in large part morainic and generally strewn with many bowlders, averaging perhaps 50 to 75 feet in thickness, Turtle Mountain consists of nearly horizontally bedded Laramie strata, chiefly shales, with very thin seams of lignite. At or below the base of this highland the fresh-water Laramie formation rests on the marine series, which comprises the Fox Hills sandstone and Fort Pierre shale, the two great shale formations being separated by a sandstone stratum which outcrops on Ox Creek and Willow River, and on the Souris River between Minot and its most southern bend.

TENTH OR ITASCA MORAINE.

On the south side of Pokegama and Leech lakes, and westward to Little Man Trap Lake and the southern arms of Lake Itasca,[1] the tenth

[1] This lake has been called by the Ojibways, from time immemorial, Omushkozo-Sagaiigun (Elk Lake), according to Rev. J. A. Gilfillan in Fifteenth Annual Report, Geol. and Nat. Hist. Survey of Minnesota, for 1886, p. 460. Its present name was given to it by Schoolcraft at the time of his exploration of the sources of the Mississippi in 1832. Rev. W. T. Boutwell, who was a member of that expedition, was asked by Schoolcraft to give the Latin words meaning "truth" and "head," and from these words, *veritas* and *caput*, the name was made by writing them together and cutting off, like Procrustes, the first and the last syllables. (Geol. and Nat. Hist. Survey of Minnesota, Final Report, Vol. I, p. 51. "A recent visit to Lake Itasca," by Warren Upham, Bulletin of the Minnesota Academy of Natural Sciences, Vol. III, pp. 284–292.)

or Itasca moraine occupies a width of 5 to 10 miles. Its hills of till, with abundant bowlders, rise 25 to 50 feet above the hollows and frequent lakes, and the elevation of the morainic belt averages 100 to 150 feet above the general level of the country. Following the main watershed onward, it bends to the northwest and north between Lake Itasca and the source of the Red River, and continues northward past the west side of the Upper Rice Lake to Clearwater Lake, about which it is well developed, and a few miles farther north it enters the area of Lake Agassiz, some 10 miles southwest of Red Lake.

The southern border of the Itasca moraine, where it is crossed by the road from Park Rapids to Lake Itasca, is called Stony Ridge. It consists of small ridges of till, trending from southeast to northwest, with very plentiful bowlders, all Archean from the northeast and north, chiefly granite and gneiss. No limestone bowlders were observed there; but in the vicinity of the White Earth Agency and about Red Lake they form a considerable proportion of the drift, having been brought by glacial currents from the region of Lakes Winnipeg and Manitoba. Very irregularly grouped morainic hills, 50 to 100 feet high, rise on each side of the road, which winds and climbs and descends over them, along a distance of about 8 miles from Stony Ridge to Mr. Peter Turnbull's claim cabin, on the southeast arm of Lake Itasca.

Many empty hollows 20 to 40 feet deep are seen beside this road, being kettle-holes, as they are called, well known as characteristic of morainic drift deposits. Several similar hollows, but of larger size and greater depth, contain a series of picturesque little lakes, lying east of the road, in descending order from south to north, the lowest having an outlet to Lake Itasca by Mary Creek. These small lakes fill depressions of the drift, and Lake Itasca doubtless owes its existence to greater thickness of the drift in the valley at the mouth of the lake and for several miles down the Mississippi, rather than to greater prominence of the underlying rock there. But the great valley, 150 to 200 feet deep and 2 to 4 miles wide, in which lie Lake Itasca and the Mississippi northward to Craig's crossing, and to its rapids over bowlders in section 8, township 145, range 35, and the similar but smaller valleys of the La Salle, Hennepin, and Schoolcraft rivers, successively tributary to the Mississippi from the south between Lakes Itasca and Pemidji, existed as grand topographic features of the country before the Glacial period, being then occupied by streams flowing in the same northward direction as now.

The ice front forming the northern boundary of Lake Agassiz at the time of accumulation of the Itasca moraine probably passed not far west of Red and Roseau lakes to the vicinity of Winnipeg. The remarkable group of eskers east of Birds Hill station of the Canadian Pacific Railway was perhaps deposited at the angle where the border of the ice-sheet turned back southwestward. In that course it seems to have reached across the lake area to the bowlder-strewn escarpment of the Pembina Mountain east of Thornhill, and beyond to have passed south along the west shore of Lake Agassiz into North Dakota.

Its terminal moraine, about 50 miles south of the international boundary, consists of two crescentic series of knolls and hills, with multitudes of bowlders, in townships 155 and 156, ranges 56 and 57, crossed by the head streams of Forest River and culminating in Pilot Knob.[1] Thence the front of this great ice-lobe appears to have extended westward to the north side of Devils Lake, and north-northwestward by the east part of Turtle Mountain, again entering Manitoba and passing along the moraine of the west part of the Tiger Hills and of the Brandon and Arrow hills.

Upon the country east and north of Devils Lake the Itasca moraine seems to be divided into several belts, which are marked by abundant bowlders and by knolls and hillocks of till and others of kame gravel and sand, sometimes occupying a width of a quarter of a mile, and rising only 10 to 25 feet above the adjoining surface of smoothly undulating till, such as are crossed by the railway within 2 miles west of Lakota and at two or three places in township 153, ranges 62 and 63, north of the east part of Devils Lake, and again forming tracts of notably rolling and hilly surface from 1 to 6 miles in width, such as are crossed to the number of two or three in a journey from Milton, Osnabrock, or Langdon southwest to Devils Lake, and likewise in traveling from Devils Lake due north to the

[1] U. S. Geol. Survey, Bulletin No. 39, pp. 61, 67–70. These very interesting morainic loops are described in Chapter VI, in connection with the Herman shore-line west of the Elk and Golden valleys.

international boundary. Both the narrow and the wide morainic belts mentioned trend mainly from southeast to northwest, and were apparently accumulated on the southwestern border of the ice-sheet during slight pauses of its retreat, perhaps being all contemporaneous with the single broad and massive Itasca moraine in northern Minnesota.

The outermost of these belts, varying from a half mile to 1 mile or more in width, here and there marked by hills 50 to 100 feet high, but more commonly by lower and often very scanty knolls and swells, passes from east to west about 3 miles north of the city of Devils Lake, by the south end of Dry Lake, through the northeast part of township 154, range 66, and thence by a somewhat devious course through the center of township 155, range 67 (there being on the west side of a chain of lakes which occupies unfilled portions of the preglacial or interglacial channel of the Mauvaise Coulée), and through the south half of township 156, range 68, to the southwest side of Hurricane Lake, from which it runs westward, becoming merged with the Leaf Hills moraine in the large morainic tract north of Broken Bone Lake. The farther course of this belt forms a south-to-north series of drift hills on the west shore of Long Lake, and it is doubtless traceable thence northward to the Turtle Mountain. Probably also one or more of the wide belts of rolling and hilly drift observed northeast and north of Devils Lake continue westerly to the east part of this massive highland, contributing to its morainic drift covering; but only scanty morainic hillocks were seen in the vicinity of Rolla and, indeed, along the whole eastern and southern base of the mountain area.

The continuation of the Itasca moraine in southwestern Manitoba extends northerly from the east end of Turtle Mountain, by Killarney, to the northern part of Pelican Lake, a distance of about 25 miles. Thence it extends west-northwest 20 miles, forming the west part of the Tiger Hills in their extent along the north side of Langs Valley and the Souris to township 7, range 19, where it again bends to the north and holds that course 10 or 12 miles to the prominent Brandon Hills. Here again it turns to the west, making a sharp angle, but within a few miles it sinks to the general level of the adjoining country and loses its distinctive character. Proceeding onward to the west about 20 miles, this moraine is next found on the north side of the Assiniboine a few miles northwest of Griswold, and thence it takes a northwest course, lying mostly from 5 to 8 or 10 miles northeast of the Assiniboine and approximately parallel with it to the Arrow River and Bird Tail Creek, beyond which I have no definite information of its farther course. On both sides of the Arrow River it rises in prominent elevations, with characteristically rough contour and plentiful bowlders, and this portion is called the Arrow Hills. The ascertained extent of this moraine in Manitoba, known in successive parts as the Tiger, Brandon, and Arrow hills, is about 125 miles. Its general course is northwest, but within the Souris basin and that of the head streams of the Pembina, on the north side of Turtle Mountain, it is deflected about 25 miles to the northeast. The ice-sheet was there indented by two reentrant angles, one having its apex in the range of the Tiger Hills, near Poors Lake, a few miles north of the north end of Pelican Lake, and the other in the Brandon Hills. The glacial Lake Souris, dammed by the ice-sheet and probably causing its indentations along the course of this moraine, then filled the Souris basin and outflowed around the south side of Turtle Mountain and Devils Lake, being tributary to Lake Agassiz by the Sheyenne.[1]

ELEVENTH OR MESABI MORAINE.

The development of the Mesabi[2] moraine, and of the foregoing moraines, in northeastern Minnesota eastward from the headwaters of the Mississippi River, and the still more northern twelfth or Vermilion moraine, I have described from exploration during the year 1893 for the Geological Survey of Minnesota.[3] The Embarras River, in its passage through the high granite belt of the Giants or Mesabi Range and the adjoining Mesabi

[1] Detailed descriptions of this moraine west of Pelican Lake, on the west part of the Tiger Hills (which the Souris River intersects in a gorge 350 feet deep), and in the Brandon Hills and Arrow Hills, are presented in the Annual Report of the Geol. and Nat. Hist. Survey of Canada, new series, Vol. IV, for 1888-89, pp. 33-36 E.

[2] This word, recently often spelled Mesaba, is stated by Rev. J. A. Gilfillan to be the Ojibway name of a giant of immense size who was a cannibal. The Ojibways at Grand Portage, according to Prof. N. H. Winchell, represent this giant as buried beneath the hills of the Mesabi Range, the various hills covering different members of his body. (Geol. and Nat. Hist. Survey of Minnesota, Fifteenth Annual Report, for 1886, p. 456.) The Giants Range and Mesabi Range, however, as these names are now applied by Professor Winchell (see the preceding Chapter II, p. 31), are distinctly separate but contiguous and parallel ranges of hills.

[3] Geol. and Nat. Hist. Survey of Minn., Twenty-second Annual Report, for 1893 (pub. 1894), pp. 45-52, with map.

moraine, forms a series of six or seven long and narrow lakes, indicating that a larger river flowed here during the recession of the ice-sheet, its deeply eroded channel having since been partially filled by alluvium from tributaries.

Continuing westward, the Mesabi moraine is apparently represented by hilly drift deposits north of Pokegama Falls of the Mississippi, about Bowstring Lake, the head of the Big Fork of Rainy River, and on the northeast side of Lake Winnebagoshish. Thence it passes west and northwest by the sources of Turtle River to the conspicuous morainic ridge of till with multitudes of bowlders which forms the tongue of land, 9 miles long and about 2 miles wide, between the south and north parts of Red Lake, extending westward to the Narrows, with a height of 100 to 200 feet above the lake. At the Narrows this moraine sinks beneath the highest level of the glacial Lake Agassiz, and it forms no noteworthy knolls or hills visible from Red Lake toward the west or northwest.

The ice barrier of Lake Agassiz at the time of the Mesabi moraine probably extended thence northwest and north across the area of Beltrami Island (described in Chapter VI), and thence farther northward and westward to the south ends of Lakes Winnipeg and Manitoba, giving to this glacial lake a length of more than 300 miles. Morainic drift deposits, with plentiful bowlders and typically rough contour, form the eastern end of the Tiger Hills, in township 7, ranges 9 and 10, crossed by the road running south from Treherne; and this tract, clearly distinct from the Itasca moraine, which forms the western end of this range of hills, appears to mark where the southern extremity of the ice-lobe west of Lake Agassiz still abutted on the north end of the Pembina Mountain escarpment and on the highland south of the Assiniboine delta during the accumulation of the eleventh or Mesabi moraine. The highest portion of this delta west of Brandon, the Big Slough, extending thence west from Alexander to Griswold, and the gap by which the Souris River flows through the Itasca moraine, forming the western part of the Tiger Hills, between its elbow and Gregory's mill, all bear testimony, as shown in the description of the Assiniboine Delta in Chapter VI, that for some time the embayed portion of this lake west of Treherne was held by this ice-lobe at a height considerably above that of the main body of the glacial lake with which it became united by the recession of the ice-sheet. Farther toward the northwest the glacial border, during the Mesabi stage, and probably during several later stages of pause or readvance interrupting its general retreat, rested on the highlands of the Riding and Duck mountains and the Porcupine and Pasquia hills, and held on its west side the glacial Lake Saskatchewan, which outflowed through the Qu'Appelle and Assiniboine rivers to Lake Agassiz.

MODIFIED OR ASSORTED DRIFT.

The modified drift comprises sediments of gravel, sand, clay, and silt that were derived directly from the ice-sheet, but were modified by currents of water, which assorted, transported, and deposited them. This class of drift occurs in many diverse forms. Some of its beds were subglacial and others were accumulated at the margin of the ice; but the writer believes that far the greater part of the modified drift was englacial at the time of the final melting, and was then washed away from the ice border by the streams of its ablation and by rains.

McGee[1] and Chamberlin[2] have judiciously proposed the restriction of the term *kames* to the knolls, hillocks, and short ridges of sand and gravel which were heaped at the mouths of brooks and rivers where they left their ice-walled channels and were spread out more widely, thereby losing their velocity and carrying power, on the adjoining land surface. These deposits are frequent on many portions of the general drift-sheet, but are most fully developed in connection with the terminal moraines.

Prolonged ridges of gravel and sand, or, in some tracts, of fine silt (as described by McGee in northeastern Iowa), narrow and bordered by steep slopes on each side, called *eskers* or *osars*, owe their form to deposition in the channels of glacial rivers walled by ice, but, the author thinks, commonly open above to the sky.[3] These peculiar ridges have a great development in Ireland and Sweden, whence their names come, and in Maine,

[1] Report of the International Geological Congress, second session, Boulogne, 1881, p. 621.

[2] U. S. Geol. Survey, Third Annual Report, for 1881–82, p. 299. Am. Jour. Sci. (3), Vol. XXVII, p. 389, May, 1884.

[3] Proceedings, Boston Society of Natural History, Vol. XXV, 1891, pp. 238–242.

where series extending 100 to 150 miles have been described by Prof. George H. Stone.[1] They are well exhibited also in the valleys of the Merrimac and Connecticut rivers and elsewhere in New England, but are less frequent on the nearly flat expanses which are drained to the Laurentian lakes, to the Upper Mississippi, and to the Red River of the North. Occasional plains or plateaus of gravel and sand, associated with the eskers, and, like them, terminating in steep escarpments which descend to adjacent lower land, were deposited in broad embayments of the waning ice border.

In the valleys of hilly and mountainous districts, and on certain belts and tracts of nearly flat areas, the departure of the ice-sheet supplied broad flood-plains of gravel, sand, and clay, brought by the waters of the glacial melting and of the accompanying abundant rains. These deposits, when inclosed in valleys, are named valley drift, and are seen to slope with the present streams, but often somewhat more rapidly; and they continue along the course of the larger rivers to the sea or to the areas of lakes that were pent up against the receding ice-sheet, and there form deltas and farther offshore sediments. Since the departure of the ice, river erosion has carved the valley drift into terraces, and the streams now flow far below their levels of the closing portion of the Ice age.

A very fine variety of the valley drift, especially where it contains some glacially comminuted rock flour from calcareous formations, is called loess. In the Mississippi and Missouri valleys and on the Rhine this deposit is clearly in large part of glacial origin, being directly supplied from the ice melting; but very similar fluvial beds are now being formed by the Nile and were formerly spread in great thickness by the rivers of China, where the origin of the silt is referable wholly or chiefly to subaerial denudation. The alluvium derived from erosion of the drift sheet and deposited by the Red River along its valley after Lake Agassiz was drained away resembles the loess in fineness, in its occasionally inclosing fresh-water and land shells, and in containing here and there small calcareous concretions.

[1] Proceedings, Boston Society of Natural History, Vol. XX, 1880, pp. 430–469, with map. Proc., Am. Assoc. for Adv. of Science, Vol. XXIX, for 1880, pp. 510–519, with map. Am. Jour. Sci. (3), Vol. XL, pp. 122–144, Aug., 1890.

BELT OF MODIFIED DRIFT BETWEEN ST. PAUL AND WINNIPEG.

Modified drift, consisting of stratified gravel and sand, with local deposits of clay, overlies the bed-rocks and the till, and generally forms the surface, on an extensive area about the southwest part of the Lake of the Woods and along the Rainy River. Southward similar deposits cover large tracts in Minnesota, reaching to the lakes at the sources of the Mississippi and to the Leaf Hills, and thence southeastward to Minneapolis and St. Paul. The contour of the greater part of these deposits is flat or moderately undulating, and their surface varies in height from a few feet to 50 feet or rarely more above the adjoining lakes and streams. In central Minnesota these tracts of gravel and sand have an elevation that increases from south to north, being 825 to 950 feet above sea-level in the vicinity of Minneapolis and St. Paul, rising gradually to 1,200 feet in the distance of about 100 miles northwest to Brainerd, and ranging from 1,350 to 1,500 feet between the Leaf Hills and Itasca Lake. Thence their surface sinks to 1,150 and 1,075 feet in the vicinity of Rainy River and the Lake of the Woods. West of this lake, gravel and sand cover most of the country for nearly 75 miles to the upper part of the Roseau, Rat, and Seine rivers, declining in this distance to about 900 feet above the sea. Northwestward these deposits continue to a remarkable group of eskers and small plateaus of gravel and sand, between 750 and 875 feet above the sea, 7 to 15 miles east-northeast of Winnipeg, of which Birds Hill, beside the Canadian Pacific Railway, is the most western and one of the most conspicuous.

This broad belt of country, characterized by extensive gravel and sand deposits overlying the till, reaches from south-southeast to north-northwest about 400 miles. From Red Lake, in Minnesota, north to the Rainy River, the Lake of the Woods, and the vicinity of Winnipeg, it lies within the area of Lake Agassiz. On each side this belt is bordered by areas of nearly the same general elevation, which have mostly a surface of till; and it is to be remarked that the heights of the tracts of modified drift and till are alike determined by that of the underlying rocks on which these superficial deposits are spread as a sheet of slight depth in comparison with the gradual change in their elevation. The drift sheet on this belt, including both the sand and gravel and the underlying deposits of till, probably varies in its average thickness from 50 to 150 feet, while its central portion rises 400 to 600 feet above its south and north ends. Though the greater part of both the modified drift and till have only slight undulations, the former being often nearly flat and the latter moderately uneven, other portions are crossed by moraines which have a prominently knolly and hilly contour, rising usually 25 to 75 feet, or occasionally 100 to 200 feet, and in the Leaf Hills 100 to 350 feet, above the adjoining country. In some places the belts of morainic hills, consisting chiefly of till, with abundant bowlders, are bordered on one side by tracts of stratified gravel and sand which slope slowly downward from them and are merged in the extensive plains or moderately undulating areas of this modified drift, showing that a part of the gravel and sand was brought by streams that descended from the ice-sheet during the time of accumulation of its moraines. Besides these overwash slopes of modified drift, the morainic belts often include kames, or knolls, hillocks, and short ridges of sand and gravel.

During the rapid melting of the ice in its times of retreat between successive moraines the glacial streams attained their greatest extent and volume, and brought proportionately extensive deposits of modified drift, spreading it mainly in plains or moderately undulating tracts beyond the ice margin, but here and there leaving long esker ridges of gravel and sand, which were formed in their channels between walls of ice. The distribution of the modified drift thus found upon large tracts along a broad belt from St. Paul to Winnipeg, while it is very scantily developed on a still wider region of Minnesota, North Dakota, and Manitoba southwest of this belt, and likewise is scanty or wanting on its northeast side in northern Minnesota and about Rainy Lake and the northeast and north portions of the Lake of the Woods, seems to be attributable to converging slopes of the surface of the ice-sheet and the consequent convergence of its currents, which brought an unusual amount of englacial drift into the ice along this belt, and by which also the streams produced in its melting were caused to flow thither from extensive areas of the ice on the east and west. The glacial striæ of these adjoining areas show that on the east the course of the motion and the descent of the surface of the ice-sheet were from northeast to southwest, but that on the west the glacial current moved and the ice surface sloped toward the southeast. On the east drift limestone is absent or very rare, because no limestone formations were crossed within several hundred miles by that part of the ice-sheet; but on the west the drift, consisting chiefly of a thick sheet of till, contains much fine limestone detritus, sand and gravel, and frequent bowlders of limestone, borne southeastward from Manitoba over the Archean area of the southwest part of the Lake of the Woods, of Rainy River, and of northern and central Minnesota. In the same directions with the slopes of the ice surface, which are known from the courses of the glacial striæ and the transportation of the drift, the streams of the glacial melting flowed convergently from the east and west, from the ice over northern Minnesota and eastern Manitoba on one side, and from that over the Red River Valley and western Manitoba on the other, toward this belt of plentiful superficial deposits of gravel and sand.

Dr. George M. Dawson[1] and Dr. A. C. Lawson[2] have referred these gravel and sand beds, observed by them only about the south part of the Lake of the Woods and along Rainy River to the mouth of Rainy Lake, within the area of Lake Agassiz, to lacustrine action. That explanation, however, is inconsistent with the restriction of the deposits to a small part of the area of this glacial lake, and with their continuation far to the south, beyond the limit of the lake and upon a district that rises in part considerably above it; while their distribution and character show that instead they were derived, as indicated, directly from the ice-sheet and its inclosed drift. They will be again noticed in connection with the history of the formation of Lake Agassiz, to be considered in the next chapter.

BIRDS HILL AND OTHER ESKERS IN MANITOBA.

Prominent eskers begin at Birds Hill, the first station of the Canadian Pacific Railway northeast of Winnipeg, from which it is 7 miles distant, and extend thence 7 or 8 miles east-northeast and an equal distance southeast, as shown in the sketch map forming fig. 9. The southern and southeastern portion of this group comprises many low ridges of gravel and sand 5

[1] Report on the Geology and Resources of the Region in the Vicinity of the Forty-ninth Parallel, pp. 203–218.

[2] Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. I, for 1885, pp. 131 and 139 CC; Vol. III, for 1887, pp. 174–176 F.

to 15 feet high, trending from northwest to southeast; also somewhat rounded mounds, as Oak Hummock, in the southeast quarter of section 12, township 11, range 4 east, which rises about 30 feet above the adjoining country, with its top approximately 810 feet above the sea; and occasionally a massive and conspicuous hill, as Moose Nose, in sections 29 and 30, township 11, range 5 east, which projects 60 feet above the average of the nearly flat country around it, rising to about 840 feet above the sea.

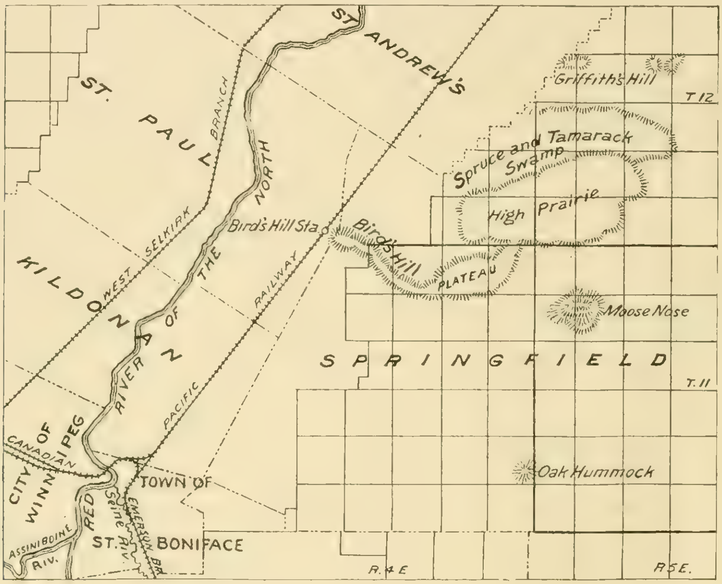


FIG. 9.—Map of Birds Hill and its vicinity. Scale, 3 miles to an inch.

Toward the north, in sections 35 and 36, township 11, range 4 east, and again from section 2, township 12, range 4 east, through a distance of 4 miles east-southeast to section 9, township 12, range 5 east, these deposits of gravel and sand form plateaus a half mile to 1 mile wide, trending from west to east, elevated 820 to 850 feet above the sea and 40 to 60 or 75 feet above the adjoining low land, which on the north is a spruce and tamarack swamp about 1 mile wide and 4 miles long from east to west. Next to the north, these eskers again rise in plateaus, ridges, and hills in sections 19 to 22, township 12, range 5 east, culminating in Griffiths Hill, in the northeast quarter of section 19, about 875 feet above the sea, or a little more than 100 feet above the railway, 2 miles distant on the west. This whole group of elevations is composed of gravel and sand, irregularly bedded, which appear to be deposits formed near the mouths of glacial rivers where they flowed between walls of ice, and were here and there divided by ice islands, whose melting left these hills, ridges, and plateaus bounded by moderately steep slopes and separated by intervening depressions. With the completion of the melting of the ice about and beneath these deposits they sank to the bottom of Lake Agassiz, here about 500 feet deep; and the infrequent bowlders that are found scattered upon their surface were dropped from floating ice. Toward the north, west, and southwest they are bounded by the flat plain of the Red River Valley, 750 to 760 feet above

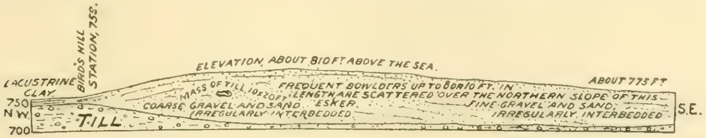


FIG. 10.—Section of Birds Hill. Horizontal scale, one-fourth mile to an inch.

the sea, while toward the east and southeast they are connected with plains and undulating tracts of gravel and sand which reach with slow and gradual ascent to the Lake of the Woods and into Minnesota.

An instructive section of Birds Hill (fig. 10) has been made in the excavation of its gravel and sand for railway ballast. This massive esker extends from the railway station about 1 mile east-southeast and thence a half mile southeast, beyond which it is connected by a low ridge with the plateau of sections 35 and 36, township 11, range 4 east. Its width is a quarter to a half of a mile; and its maximum height, one-third to two-thirds of a mile from the station, is 45 to 50 feet above the railway and the flat plain that extends thence west. The elevation of Birds Hill station is 759 feet, and of the crest of this hill 805 to 810 feet, above the sea. It has a broadly rounded top, with gentle slopes on all sides. Along its northern slope an excavation reaches three-fourths of a mile, varying in width from

10 to 25 rods and in depth from 10 to 30 feet. The top of the excavation is about 20 feet below the crest of the hill. As thus exposed to view, the greater part of this deposit is seen to be gravel, much of which is very coarse, containing pebbles and rock fragments of all sizes up to $1\frac{1}{2}$ feet in diameter, many of the smaller being well rounded, but the larger mostly angular, with only slight marks of water wearing. In some portions near the west end of this section no interbedding of coarser and finer layers of the torrential esker gravel is noticeable for 10 feet or more vertically, the spaces between the larger stones and cobbles being filled with finer gravel and sand. Embedded in this coarse gravel on the south side of the excavation I noted a mass of ordinary till, unstratified bowlder-clay, inclosing gravel and bowlders in a solid matrix of somewhat sandy clay, wholly bounded by definite but irregular outlines, its dimension vertically being about 10 feet and its length 20 feet. No other mass of till, of either small or large size, was observed in this entire section. It probably was derived from the drift that was contained within the ice-sheet and finally overspread its surface when the greater part of the thickness of the ice was melted. From a sheet of drift thus deposited on the ice that formed the bank of the glacial river this mass may have fallen into its channel. The eastern half of the section includes much fine gravel and sand irregularly interbedded, and along a considerable extent there the south side of the excavation, from 10 to 20 feet below its top, is clear sand. Paleozoic limestones make up about three-fourths of the gravel, the remainder being Archean granites, gneiss, and schists. Some two hundred bowlders were found scattered upon the area of the excavation; and they occur with nearly the same frequency on other portions of this northern slope of the hill, but are rarely found on its top and southern slope. They vary in size from 2 to 8 or 10 feet in length; nearly all are Archean, but a few of Paleozoic limestone, up to 5 feet in length, were observed. None was seen inclosed within the gravel and sand of the esker, and the workmen informed me that they occur only on or near the surface. This hill was covered by Lake Agassiz, and its bowlders were doubtless dropped or stranded from bergs and floes on this lake before the border of the ice-sheet had retreated from the vicinity. Indeed, the occurrence of the bowlders chiefly on the northern

slope seems to indicate that they were mostly stranded there while ice yet remained beneath this deposit and prevented its entire submergence in the lake. The thickness of this esker is at least nearly 100 feet; for a well 45 feet deep, dug at the bottom of the excavation, was wholly in the same formation of gravel and sand. It is thus known to extend considerably below the level of the Red River Valley plain, which consists of fluvial and lacustrine clay underlain at a slight depth by till. A section across the esker and plain (fig. 10) would show till abutting upon the edge of the gravel and sand, indicating that both the stratified esker and the upper part of the till were formed from englacial drift.

Smaller esker deposits were observed in townships 12 and 13, range 1 east, 10 to 20 miles northwest of Winnipeg. Beginning about 3 miles east of Rosser, a narrow and occasionally interrupted belt of esker gravel and sand, with frequent bowlders scattered on the surface, extends northwest diagonally across sections 10, 16, and 20, the northeast corner of section 19, and the southwest part of section 30, township 12, and thence westward through section 25 of the next township. Its highest portions rise 10 to 25 feet above the depressions of the moderately undulating surface of till on each side and are 800 to 810 feet above the sea. Along a distance of about a third of a mile in section 30 it has the form and character of an ordinary beach ridge and is destitute of bowlders. A similar low esker crosses sections 12 and 14, township 13, trending from southeast to northwest; and others occur in the vicinity of the Grosse Isle, a name applied to poplar groves in sections 17 and 18 of this township and in sections 12 and 13 of the next west.

From the east part of the Grosse Isle a notable esker, known as Burns Ridge, runs north-northwestward across sections 30 and 31, township 13, range 1 east. Five miles west of Stonewall a section of this little beach-like ridge was made in section 30 by the original line of the Canadian Pacific Railway, which was abandoned for the more southern route by way of Winnipeg. The esker is cut to a depth of 8 feet by the railway and to 12 feet in an excavation on the south side of the railway grade. A well in the lowest part of this excavation goes 4 feet deeper, to a total of 16 feet below the crest of the ridge. The entire section consists of stratified gravel and sand, extending 8 feet above and at least as far below the general level of the adjoining surface, and the visible width of the deposit is about 30 rods. How much deeper it may extend, perhaps with increasing width, is undetermined. Its gravel, which is nearly all limestone, contains pebbles up to 6 inches in diameter. No bowlders occur in this excavation, and they are rare upon the surface of this and other such comparatively broad and high portions of this esker, none being sometimes seen along a distance of several rods; but in its narrower and slightly lower portions, as traced in its somewhat crooked course northward through the next $1\frac{1}{2}$ miles, it often is found to be sprinkled with frequent bowlders up to 3 or 4 feet in diameter, mostly Archean. They appear to have been stranded, as at Birds Hill, immediately after the ice walls inclosing the esker were melted, or even during that process, and before the melting of the ice under this gravel and sand allowed the water of Lake Agassiz to submerge the more massive portions of the ridge. Only a small depth of water, probably not more than 30 or 50 feet at the most, would be required for this; and afterward the melting of the underlying ice gave to the lake here a depth of fully 500 feet. Farther to the north the esker sinks or is merged in the moderately undulating till which there forms the surface. The crest of this peculiar ridge, approximately 800 to 805 feet above the sea, undulates 3 to 5 feet within short distances, not showing so much uniformity in elevation and directness in its course as are characteristic of beach ridges; and it is the only instance observed in all my exploration of Lake Agassiz where a gravel formation nearly resembling a beach bears bowlders on its surface. Not a single bowlder has been anywhere found on or within the beaches of this lake; nor have eskers like the Birds Hill group or like these of smaller size and more stream-like courses been observed by me in any other part of this lacustrine area, excepting the vicinity of Red Lake, in Minnesota. But eskers doubtless exist here and there throughout the belt of modified drift that extends upon this area from Red Lake by the Lake of the Woods to Birds Hill and Burns Ridge, and probably they continue north-northwesterly upon the country between Lake Winnipeg and Shoal Lake.

PROPORTION OF MODIFIED DRIFT SUPPLIED TO THE DELTAS OF LAKE AGASSIZ.

Extensive contributions of fluvial silt were received in Lake Agassiz from the englacial drift of the retreating ice both on the east and west; and these deposits agree with the terminal moraines of that region in indicating that against this great glacial lake the ice was melted back faster than on the adjoining land areas. On the eastern side of Lake Agassiz only the Buffalo and Sand Hill rivers brought in noteworthy deltas, but several other tributaries from the east are at the present time larger than these. No topographic or other now existing causes for this difference are discoverable, and we are left to the inference that during the vicissitudes of the glacial recession exceptionally large streams poured down from the ice surface, laden with its drift, to these deltas. Similar conditions seem also to have been largely efficient in producing the four great deltas which I have examined on the western side of Lake Agassiz, namely, the Sheyenne, Elk Valley, and Pembina deltas in North Dakota, and that of the Assiniboine in Manitoba. Each of these demonstrably contains much tribute of modified drift; that is, of drift brought directly from the ice by the rivulets, brooks, and rivers formed in its melting.

It will be especially instructive to notice the Assiniboine delta of Lake Agassiz and attempt to estimate its proportion of modified drift as distinguished from the alluvium of ordinary river erosion. This remarkable delta of gravel and sand covers an area of about 2,000 square miles and has an estimated average depth of at least 50 feet. Its volume is about 20 cubic miles, so that it exceeds the combined capacity of the Qu'Appelle Valley, which was the outlet of the glacial Lake Saskatchewan, and of the Assiniboine Valley from the mouth of the Qu'Appelle to this delta. Each of these valleys has an average width of about 1 mile, and their depth probably averages 250 feet along their extent of about 350 miles, being eroded in drift and the underlying soft Fort Pierre shales. This was doubtless a preglacial watercourse, which, like the Pembina and Minnesota valleys, became only partly filled with drift. Much of the erosion of the upper Qu'Appelle Valley during the departure of the ice-sheet was effected by its glacial river while it emptied into the Lake Souris, and probably the lower valley and that of the Assiniboine were filled on the average only to the extent of a third or half of their depth by the glacial drift. The erosion of the valley, therefore, must have fallen far short of supplying the material of the Assiniboine delta, not to mention the fine silt and clay which were carried into the lake beyond the gravel and sand delta and may be of equal volume. Probably at least half of these lacustrine deposits were modified drift brought down by streams from the melting ice-sheet on the upper Assiniboine basin, north of the mouth of the Qu'Appelle, and swept forward by the strong current of the river until it reached Lake Agassiz.

INFLUENCE OF ADJOINING LAKES OR THE SEA ON THE DEPOSITION OF THE DRIFT.

From Nantucket and Cape Cod northeastward the ice-sheet, at its greatest extent and during a considerable part of its time of recession, terminated in the ocean. In the interior of the continent, too, it was bounded during its recession by vast lakes filling the basins that are now partly occupied by the great lakes of the St. Lawrence, Nelson, and Mackenzie rivers. During all my examination of the shore-lines, deltas, and bed of Lake Agassiz I have carefully studied the effects attributable to the influence of this lake on the deposition of the drift, comparing its area, the valley of the Red River of the North, with other portions of Minnesota, South and North Dakota, and Manitoba, which had a land surface during the departure of the ice. Other glacial lakes of smaller size in these States and this Canadian province have also come under my observation, besides portions of the drift deposited in the glacial precursors of the Laurentian lakes; and on the Atlantic Coast I have made a detailed examination of the marine drift of southeastern New Hampshire. The more southern parts of the New England seaboard which I have similarly examined, including the coast from Boston to Plymouth, Cape Cod, Nantucket, Marthas Vineyard, the Elizabeth Islands, Block Island, and Long Island, appear to me to have stood at their present height or somewhat higher during the maximum extension and the recession of their broad eastern lobe of the ice-sheet.

Upon all the areas thus studied by me where the ice-sheet was bordered by great lakes or the sea, tracts of stratified sediments, as deltas of gravel, sand, and silt, and somewhat more extensive deposits of finer silt and clay, are found, and their distribution shows them to have been brought into these bodies of water chiefly by rivers flowing from the melting ice. But a large portion of the englacial and superglacial drift, corresponding to that which fell as wholly unstratified till on land areas, was received from the receding ice into these lakes or the sea with little change, being allowed to fall to their bottom only very slightly modified by water action. Within the area of Lake Agassiz and the other associated glacial lakes, very extensive tracts, probably half or a larger part of their whole extent, have a surface of till, which differs from its characters on the adjoining tracts that were land during the ice retreat in having usually slight traces of stratification within the 5 to 15 feet of the upper and englacial till, and in having a more smooth and even contour.

Bowlders, gravel, sand, and clay are mingled in this englacial till in the same proportion as on the country outside these glacial lakes. There was generally no noteworthy transportation of bowlders or other drift by ice floes or bergs on these lakes; nor was the fine clayey part of the englacial drift washed away in any noteworthy amount from the submerged and melting and receding ice margin by wave action, which would have covered the till in front of the ice-sheet with beds of silt. Instead, the englacial and finally superglacial drift that escaped the stream erosion of the drainage from the glacial melting sank through the water to the bottom as the ice gradually withdrew, and exhibits essentially the same characters as on areas that were land, excepting its usually obscure traces of stratification and its smoother surface.

CHAPTER V.

HISTORY OF LAKE AGASSIZ.

TWO CLASSES OF PLEISTOCENE LAKES.

Among the most important geologic records of the Pleistocene period in America are the sediments and shore-lines of former lakes of great extent which are now represented by lakes that occupy, excepting within the basin of the St. Lawrence, only a small part of their ancient area. Lake Bonneville, in the basin of Great Salt Lake, Utah, and Lake Lahontan, in the basin of the Humboldt River and Pyramid Lake, Nevada, are conspicuous examples of one class of these Pleistocene lakes, formed by increased rainfall, where now an arid climate limits the lakes to small areas, with their surface far below the watersheds across which they would outflow to the sea. These are south of the glaciated area of the continent, but they appear to have owed their existence to the changes of climate by which the ice-sheet of the Glacial period was formed. Lake Agassiz belongs to another class of these lakes, caused directly by the barrier of the ice-sheet where this was accumulated on a northwardly sloping land surface. Such glacial lakes were developed on a vast scale in the basins of Lake Winnipeg and the Laurentian lakes during the recession of the ice border, when it was being gradually melted away by a warmer climate; and it is also evident that many small lakes of the same kind then flowed southward over the lowest points of the present watersheds. Examples of this class now existing are the little Merjelen See, pent up in a tributary valley on the east side of the Great Aletsch glacier in the Alps, and similar ice-dammed lakelets in Greenland.

LAKES BONNEVILLE, LAHONTAN, AND OTHERS IN THE GREAT BASIN.

Twice during the climatic changes of the Glacial and post-Glacial periods, Lake Bonneville, described by Gilbert,[1] and Lakes Lahontan and

[1] Lake Bonneville. By G. K. Gilbert. Monographs of the U. S. Geol. Survey, Vol. I.

Mono, described by Russell,[1] have risen nearly or quite to overflowing. The climate of the Great Basin of interior drainage, which comprises the areas of these lakes, was marked at these times by considerably greater humidity than now, though to less degree than the present climate of the eastern half of the United States. The humid epochs were divided by a long interval of aridity, in which, as Gilbert and Russell have shown, the lakes were perhaps wholly evaporated, their soluble salt and alkaline mineral matter becoming intermingled and covered with playa silts, so that it could not be redissolved by the water of the lakes during their second rise, which therefore may have been nearly fresh.

Lake Bonneville, the largest one of the many lakes which were formed during the Pleistocene period in the Great Basin, covered at its maximum stage an area of 19,750 square miles, lying mostly in northwestern Utah, but extending also into the borders of Nevada and Idaho. It was about ten times as large as its present representative, Great Salt Lake, which, having a mean height of 4,208 feet above the sea, lies 1,000 feet below the highest of the ancient shore-lines. The maximum depth of the Pleistocene lake was about 1,050 feet, while that of Great Salt Lake, in its range from the lowest to the highest stage within the past forty years, is from 36 to 49 feet. The hydrographic basin of Lake Bonneville comprised a fourth part of the Great Basin, whose total area is estimated to be 210,000 square miles; almost another quarter was tributary to the companion Lake Lahontan, which attained an extent of 8,422 square miles, occupying a very irregular tract of interlocking valleys among mountain ranges in western Nevada; and the remaining half of this arid region held some twenty-five smaller lakes, much exceeding, however, the saline lakes and playas to which they are now reduced.

The first great rise of Lake Bonneville, lifting its level to within 90 feet of the lowest point of the inclosing watershed, is recorded by numerous beaches, marking the oscillations of the lake level under the varying influence of secular climatic changes, and by a thick deposit of yellow

[1] Geological History of Lake Lahontan. By I. C. Russell. Monographs of the U. S. Geol. Survey, Vol. XI. Quaternary History of Mono Valley, California. By I. C. Russell. Eighth Annual Report of the U. S. Geol. Survey.

clay. A long interlacustrine epoch is known by overlying alluvial gravel and sand. The second rise of the lake reached the level of overflow apparently after the water surface had been long held within 5 to 20 feet below that level, forming a widely spread deposit of white marl and the well-defined highest beach ridges and eroded cliffs, which Gilbert names the Bonneville shore-line. The time required for the great amount of wave work at this level would be made possible by long-continued underground drainage from the lake through the alluvial deposit of Cache Valley, over which a slightly higher rise of the lake finally gained a superficial outflow to the Columbia River, and then rapidly cut a channel 375 feet deep in the alluvium to a sill of limestone. At this lower level, marked by the Provo shore-line and deltas, the lake was held for a long time, perhaps occasionally interrupted by dry climate and fall of the water too low to maintain its outlet.

Glaciers descending the canyons on the west front of the Wasatch Range attained their maximum extent, pushing their moraines into Lake Bonneville, during the time of formation of the Provo shore-line. From these moraines, and from those of the Sierra Nevada extending into the Pleistocene area of Lake Mono, the glaciation of the Cordilleran region is known to have been contemporaneous with the epochs of humid climate and extension of lakes in the Great Basin, the interlacustrine epoch being attended probably with a nearly or quite complete departure of the glaciers and ice-fields on the mountains.

LAKE AGASSIZ AND OTHER GLACIAL LAKES.[1]

A glacial lake, according to my use of the term in this volume and elsewhere, is a body of water bounded in part by a barrier of land ice. The lake may be hemmed in by a glacier, as the Merjelen See, or by a continental ice-sheet, as Lake Agassiz. And the same name is also applicable to the lakelets, wholly bounded by ice, which are occasionally formed, attaining a considerable depth and extent and appearing in the same places during the summers of successive years, on the surface of

[1] The following descriptions and discussion of this class of Pleistocene lakes were originally presented in a paper before the Geological Society of America ("Glacial Lakes in Canada," Bulletin, G. S. A., Vol. II, pp. 243–276).

glaciers, as in the Himalayan Range, or on an ice-sheet, as observed by Nordenskjöld in Greenland.

Very abundant and extensive development of glacial lakes attended the recession of the ice-sheet in the northern United States and in Canada, being due to the temporary damming of the waters of glacial melting and of rains on areas where the land has a northward descent. While the ice-sheet was melting away from south to north on such a slope, free drainage was prevented, and a lake was formed, overflowing across the lowest point of what is now the southern watershed of the basin. Many of these lakes were of small extent and short duration, being soon, by the continued retreat of the ice, merged into larger glacial lakes, or permitted to flow away where basins sloping northward are tributary to main river courses draining southward. Professor Chamberlin has well written of these lakes fringing the ice-sheet:

> They vary in areal extent from trivial valleys blocked by ice to the broad expanses of the great basins. If an attempt were made to enumerate all instances, great and small, and all stages, earlier and later, the list of localities and deposits would swell, not by scores and hundreds, but by thousands.[1]

EVIDENCES OF GLACIAL LAKES.

Five principal evidences of the former existence of glacial lakes are found, namely: (1) Their channels of outlet over the present watersheds; (2) cliffs eroded along some portions of the shores by the lake waves; (3) beach ridges of gravel and sand, often on the larger glacial lakes extending continuously through long distances; (4) delta deposits, mostly gravel and sand, formed by inflowing streams; and (5) fine sediments spread widely over the lacustrine area. A few words of general description may be given to each of these before proceeding to notice the areas of some of the more important glacial lakes formed by the waning North American ice-sheet, and to trace in detail the stages of the growth of Lake Agassiz and its final reduction to the present Lake Winnipeg.

Outlets.—Among the evidences of glacial lakes, the one most invariably recognizable and most definite in its testimony is the outlet showing

[1] Proc. A. A. A. S., Vol. XXXV, for 1886, p. 208.

distinct stream erosion across the rim dividing adjacent river basins, which now in many instances send their waters respectively to the Gulf of Mexico and to Hudson Bay or the Gulf of St. Lawrence. Obviously, water-courses could exist in these positions only as the outlets of lakes which were pent up by some barrier that is now removed. Shore-lines traceable northward from these deserted channels must therefore belong to a lake, and can not be regarded as the record of any marine submergence.

Closely associated with such channels crossing watersheds, and at the same level, are the three following classes of proof cited, namely, eroded cliffs, beach ridges, and deltas; and below these shore records are the fine lacustrine sediments. These are found in hydrographic basins which are now drained by a continuous descent northward, presenting no indication that any land barrier ever existed across their lower portions to form these lakes, being afterward removed by erosion or by depression. The shore-lines, as shown thus by wave-cut cliffs, wave-built beaches, and deltas brought by inflowing rivers, extend far along both sides of the present hydrographic basin, often rising slightly and regularly northward, instead of sinking in that direction, as they would do if there had been a depression of the land at the north. When traced carefully with leveling, they are found, sometimes after an extent of hundreds of miles, as on the glacial Lake Agassiz and about the great lakes tributary to the St. Lawrence, to terminate abruptly where the basin attains its greatest width. Hence it is manifest that the barrier of these lakes could not have been land formerly raised higher than now, but was the receding ice-sheet, against which the land shores terminated.

On slopes descending in parallelism with the retiring ice border, drainage from it in many places flowed in channels from which the streams became turned into new and more northerly courses as the ice retreated. Several glacial river courses of this kind I have observed between the Coteau des Prairies and the Minnesota River.[1] Others have been noted by G. M. Dawson,[2] McConnell,[3] and Tyrrell,[4] in various parts of Alberta

[1] Geol. and Nat. Hist. Survey of Minnesota, Final Report, Vol. I, 1884, pp. 508, 509, 606.

[2] Report on the Geology and Resources of the Region in the Vicinity of the Forty-ninth Parallel, 1875, pp. 263–265; Geol. Survey of Canada, Report of Progress, for 1882–83–84, p. 150 C.

[3] Geol. Survey of Canada, Annual Report, new series, Vol. I, for 1885, pp. 21 C and 74 C.

[4] Ibid., Annual Report, new series, Vol. II, for 1886, pp. 43 E, 45 E, and 145, 146 E.

and Assiniboia. But these seldom were outlets of glacial lakes of large size. It was only when extensive hydrographic basins were inclined toward the ice-sheet that broad glacial lakes, as those named Lake Agassiz, Lake Souris, Lake Saskatchewan, and the greatly enlarged Laurentian lakes from Superior to Ontario, were held between the northwardly sloping land and the waning ice-sheet, with long-continued outflow across the present main watersheds of the continent.

The depth of erosion of these outlets varies from 50 feet or less to 150 feet or more. So far as known to me, they are cut through the easily eroded drift deposits, and sometimes beneath these, on the extension of the great plains in the Canadian Northwest, through Cretaceous shales or clays and soft, unconsolidated sandstones, which could be easily worn away. Nowhere is it found that a glacial river has channeled deeply into the harder rock formations. The time required for the work observed was brief.

A noteworthy feature of many of the old watercourses which were outlets of glacial lakes, then carrying a much greater volume of water than now, is the occurrence of long and narrow lakes in such valleys, of which Long Lake, in Assiniboia, lying on the west side of a high remnant of the eroded Cretaceous strata called Last Mountain, is a conspicuous example. This lake, occupying one of the channels of outflow from the glacial Lake Saskatchewan, which thence continued down the Qu'Appelle Valley, is about 50 miles long from south to north and 1 to 2 miles wide. Its southern end is separated from the Qu'Appelle River by alluvial deposits only a few feet above Long Lake, which have been brought into the valley since its great glacial river ceased. Similarly the Qu'Appelle Valley has been partly refilled by the postglacial deposits of its tributaries, and the present stream in its course through the Fishing Lakes flows at a level about 60 feet above the ancient river bed. Other rivers which thus flow through lakes produced by postglacial alluvium in the beds of the outlets of glacial lakes are the James River, formerly the outlet of Lake Souris; the Pembina River, which, with Langs Valley, afforded a later outlet from Lake Souris, now marked by Pelican, Rock, and Swan lakes, besides several other lakes of small size; the Minnesota River, with Browns Valley, by which Lake Agassiz outflowed, where now are Lakes Traverse, Big Stone, and Lac qui Parle; the St. Croix River and Lake St. Croix, formerly the course of drainage from the west part of Lake Superior when that lake was held 500 feet higher than now by the barrier of the receding ice-sheet; and the Illinois River, the outlet of the glacial Lake Michigan, flowing through Lake Peoria.

Eroded cliffs.—This type of shore-lines, denominated sea cliffs by Gilbert, is developed where a glacial lake has formed a terrace, usually in the unmodified glacial drift or till (see fig. 7, p. 26). Waves at these places have been efficient to erode, by undercutting at the base of the terrace; and shore currents have borne away the eroded material, excepting usually a considerable number of large bowlders. Only a small portion of the shores of Lake Agassiz examined by me consists of these wave-cut slopes of till; and they nowhere form conspicuous topographic features, their range in height being from 5 or 10 to 30 feet. Much higher cliffs of till of similar origin exist on some parts of the shores of the present great lakes of the St. Lawrence and Nelson rivers, where erosion has been in progress ever since the time of the glacial recession. Scarboro Heights, on Lake Ontario, near Toronto, extending 9 miles, with a height of 170 to 290 feet, consisting of till and interglacial beds, are cliffs thus produced by postglacial lake erosion. The duration of the glacial lakes appears to have been much shorter than the postglacial epoch.

It is important, however, to note here that cliffs of preglacial erosion, which remained as prominent escarpments through the vicissitudes of the Ice age, became in some places the shores of glacial lakes. Of this class are the bold highlands of Pembina, Riding, and Duck mountains, which rise steeply 100 to 1,000 feet from the highest western shore-line of Lake Agassiz to form the margin of a plateau that stretches with a moderately undulating surface westward. Even where this lake washed the bases of the cliffs, it doubtless eroded them only to a slight extent. The horizontal Cretaceous beds of this great escarpment originally extended eastward a considerable distance, as believed by Hind and Dawson, probably so far as to cover the areas now occupied by Lake Winnipeg and the Lake of the Woods; and we must attribute the erosion of their eastern portion, leaving this steep line of highlands, to river action during the time of epeirogenic elevation which closed the Tertiary and introduced the Quaternary era, not in any important degree to glaciation, and least of all to shore-cutting by the glacial lake.

Beaches.—The course of the shore of a large glacial lake is usually marked by a smoothly rounded beach ridge of gravel and sand (see Pl. VI and fig. 6, p. 26) wherever the land is a slope of till sinking slowly beneath the ancient water-level. Like the shore accumulations of present lakes and of the seacoast, the glacial lake beaches vary considerably in size, having in any distance of 5 miles some portions 5 or 10 feet higher than others, due to the unequal power of waves and currents at these parts of the shore. Moderate slopes bordering the greater glacial lakes were favorable for the formation of beach ridges, and such ground frequently displays many beaches at successive levels which marked pauses in the gradual elevation of the land when it was relieved of its ice burden, and in the subsidence of the lake as its outlet became eroded deeper or as the glacial retreat uncovered new and lower avenues of discharge.

Waves driven toward the shore by storms gathered the beach gravel and sand from the deposit of till or other drift which was the lake bed, and corresponding deposits of stratified clay, derived from the same erosion of the till, sank in the deeper part of the lake. But these sediments were evidently of small amount and are not commonly noticeable on the sheet of till which forms the greater part of the lacustrine areas. Where the beaches cross delta deposits, especially the fine silt and clay that lie in front of the delta gravel and sand, they are indistinctly developed or fail entirely. On the other hand, the most massive and typical beach ridges, often continuous several miles with remarkable uniformity of size, having a central thickness of 10 to 15 feet and a total width of 20 to 30 rods, are found on areas of till that rise with a gentle slope of 10 or 15 feet per mile. Under the influence of irregular contours of the shore, however, the beach deposits assume the form of bars, spits, hooks, loops, and terraces, of which Gilbert has given a careful classification, with analysis of the interactions of waves and currents by which they were made.[1]

[1] "The topographic features of lake shores:" Fifth Annual Report of the U. S. Geol. Survey, 1885, pp. 75–123; "Lake Bonneville:" Monographs of the U. S. Geol. Survey, Vol. I, 1890, Chapter II.

Deltas.—A broad expanse of water exposed along a distance of many miles to strong winds is required for the formation of sufficiently large and powerful waves to erode cliffs or accumulate well-defined beach ridges; but the area of any glacial lake, small or large, may be partly occupied by deltas brought into its margin by tributary streams. These deposits at the mouths of small brooks are often only a few rods wide, while the deltas of rivers, especially those supplied with much englacial drift from the melting ice-sheet, sometimes extend many miles in a flat or moderately undulating plain of gravel and sand, lying at the level which the surface of the lake held during the accumulation of the delta, or within a few feet above or below that level. But at the mouth of the river forming the delta it was frequently built up in a fan-shaped mass to a considerable height, the head of the alluvial slope being in some instances 50 feet or more above the lake. The delta plain is generally bounded on its lakeward side by a somewhat steep descent, partly due to the ordinary conditions of delta formation, but often made more conspicuous by erosion of the outer portion of its original area by waves and shore currents when the lake fell to lower levels.

Winds in many places have channeled and heaped the surface of the more extensive deltas, acting most efficiently as soon as they became uncovered from the lake and before they could be overspread by vegetation; and many of the resulting sand dunes (see Pl. VII, p. 28), which frequently range from 25 to 100 feet in height, though mainly covered by grass, bushes, and trees, are still undergoing slight changes of their form by wind erosion. All the dunes on the areas of the glacial lakes Agassiz, Dakota, Souris, and Saskatchewan, occur on delta deposits; but the great tracts of dunes about the south end of Lake Michigan belong wholly to beach accumulations, being sand derived from erosion of the eastern and western shores of the lake, whence it has been borne southward by shore currents, especially during northern gales. None of the beaches of our glacial lakes are large enough to make dunes like those on Lake Michigan, though the size and depth of Lake Agassiz, its great extent from south to north, and the character of its shores, seem equally favorable for their accumulation. It is thus again indicated that the time occupied by the recession of the ice-sheet was comparatively brief.

Lacustrine sediments.—In front of the delta plains of gravel and sand, the finer silt and clay brought into the glacial lake by the same tributaries were spread over the lake bottom, covering the till on large tracts adjacent to the great deltas. Only small contributions of fine sediment, usually inappreciable, as before stated, on the greater part of the lake basin, were supplied from the shore and sublittoral erosion of till, which yielded the gravel and sand of the beaches; but some of these areas of wave erosion, reaching a quarter of a mile off shore, are plentifully strewn with the residual bowlders.

Because of their relation to the receding ice-sheet, the glacial lakes might be expected to receive noticeable deposits, including bowlders, from floating bergs and from floes of the ice foot which would be formed in winter along their northern barrier. It is certain, however, that no deposits which can be referred to such origin are spread generally over the lake basins. Bowlders are absent or exceedingly rare in the beaches, deltas, and finer lacustrine sediments. In a few places, however, I have observed bowlders in considerable numbers on esker ridges of gravel and sand (pp. 186, 188), where they were evidently brought and stranded by floating ice masses from the melting ice border, whose distance could not have exceeded a few miles at the farthest, and, indeed, probably was not so much as 1 mile while the bowlders were being stranded.

Where terminal moraines cross a glacial lake, their knolly and hilly contour, as deposited on land, is changed to a smoothed, slightly undulating surface, and their proportion of bowlders exposed to view is diminished. The lake leveled the till that would otherwise have formed knobs and hills, in which process many of its bowlders were covered.

After the drainage of the glacial lakes by the complete departure of the ice-sheet, the lower portions of their basins, in depressions and along the present river courses, have become filled to a considerable extent by fluvial beds of fine silt. These are similar in material with the lacustrine sediments bordering the deltas, from which they are distinguishable by their containing in some places shells like those now living in the shallow lakes and streams of the region, remains of rushes and sedges and peaty deposits, and occasionally branches and logs of wood, such as are floated down by streams in their stages of flood. In the valley of the Red River of the North these recent fluvial deposits have commonly greater thickness and extent than the underlying silt of the glacial Lake Agassiz, which, however, in some portions, as near the deltas of the Sheyenne and the Assiniboine, occupies large areas.

PRINCIPAL GLACIAL LAKES OF THE NORTHERN UNITED STATES AND OF CANADA.

New England, Quebec, the eastern provinces, the Northeast Territory, and Labrador.—Attending the retreat of the ice-sheet from New England, Quebec, and the eastern provinces, many glacial lakes of small size and short duration were formed on areas declining toward the north or northwest, as in the valley of the Contoocook River, in New Hampshire;[1] on the western flanks of the Green Mountain range, in Vermont, where Mr. C. L. Whittle informs me that delta deposits of such origin occur up to heights of fully 2,000 feet; on head streams of the River St. John, in northern Maine; and in southern Quebec, between the Atlantic-St. Lawrence watershed and the receding ice front. Fewer and still smaller glacial lakes, usually leaving no well-marked records of their existence, doubtless also attended the glacial retreat in New Brunswick, Nova Scotia, Newfoundland, and Labrador. But soon the ocean-washed ice border was melted back from the Gulf of St. Lawrence and along the broad St. Lawrence Valley perhaps to Quebec, admitting the sea to the area of Lake Champlain, which, with the Hudson Valley, had been occupied during the recession of the ice by a long and narrow glacial lake, extending from near New York City to near Montreal, caused by the southward elevation and northward depression of the land.[2]

North of the St. Lawrence the receding ice opposed no barrier to drainage from large areas until it withdrew across the height of land dividing the St. Lawrence waters from those tributary to James and Hudson

[1] Geology of New Hampshire, Vol. III, 1878, pp. 103–120.
[2] Bulletin, G. S. A., Vol. I, p. 566; Vol. III, pp. 484–487.

bays, when upon the country around Lake Mistassini and upon many other tracts glacial lakes of considerable size must have been formed. In the exploration of that region traces of these former lakes, especially of their channels crossing the watershed, should be carefully looked for, as not the least important of our records of the Ice age.

Basins of the Laurentian lakes and of Hudson Bay.—As soon as the border of the retreating ice-sheet was withdrawn across the various parts of the watershed south of the Laurentian lakes, each considerable stream valley and embayment between the height of land and the ice front held a glacial lake. Doubtless hundreds of channels may be traced where these lakes outflowed. But the continuing glacial retreat merged these minor lakes into a few of large size, overflowing at the lowest passes. In the States adjoining on the south, and in portions of Canada on the north, the shores of these glacial representatives of the present Laurentian lakes are recorded by eroded cliffs, beach ridges, deltas, and lacustrine sediments; but along other portions of their Canadian boundaries, where they were held in by the receding ice barrier on the northeast and north, the land shows no shore erosion nor beach deposits.

The west part of Lake Superior stood about 500 feet higher than now, and outflowed by the St. Croix River. Lake Michigan outflowed by the low divide at Chicago to the Des Plaines and Illinois rivers. The glacial Lake Erie was at first some 200 feet above the present level of this lake, with overflow to the Wabash; but later it obtained lower outlets, the last being by Chicago, after the glacial lakes Erie, Huron, Michigan, and Superior had been merged into one expanse, which Spencer has named Lake Warren. Lake Ontario, or rather its glacial forerunner, named by Spencer Lake Iroquois, becoming by the retreat of the ice separated and distinct from the upper lakes, extended far to the north and northeast of its present limits and poured its waters into the Hudson, at first by the Mohawk and afterward by the way of Lake Champlain, while the continuing glacial recession uncovered the country north of the Adirondacks and along the great valley where it now outflows by the St. Lawrence.

The watershed which divides the upper St. Lawrence basin from the basin of James Bay is crossed by many channels of outflow from glacial lakes pent up between that watershed and the departing ice-sheet on the north. Kenogami or Long Lake, north of Lake Superior, having a length of about 54 miles from northeast to southwest and a width mostly between a half mile and 2 miles, forming the head of Kenogami River, tributary to the Albany, occupies the channel of outlet from a glacial lake in the Albany basin, passing southward by Trout Lake and Black River to Lake Superior.[1] The elevation of Kenogami Lake, according to the survey of the Canadian Pacific Railway, is 1,032 feet above the sea. Dr. Robert Bell states in a letter that the summit crossed by the Height of Land portage close south of this lake, and leading from it to Black River, is about 70 feet higher, being therefore approximately 1,100 feet above the sea. This portage "is about a half mile long, and is over an accumulation of well-rounded bowlders, with gravel and earth filling the interspaces in part; at other parts the bowlders are piled on each other quite naked. The valley between the rocky walls is about half a mile wide. The surface is somewhat level, and there is a subordinate valley or depression sweeping around on the west side between the bulk of the accumulation of bowlders and the rocky bluff on that side." The ancient watercourse thus described west of the portage is probably only a few feet above Kenogami Lake, having very nearly the same elevation as the divide between the Missinaibi and Michipicoten rivers, some 150 miles distant to the east. Both these low points of the watershed were doubtless occupied by rivers outflowing from glacial lakes on the north during the recession of the ice-sheet.

Missinaibi Lake, near the head of Missinaibi River, the western branch of the Moose River system, is about 1,020 feet above the sea. This lake "bears south 48° west, is 24 miles long, nearly straight, and varies from a half mile to 1½ miles in width."[2] Close southwest of Missinaibi Lake, in the continuation of this glacial river course, is Crooked Lake, at an elevation of about 1,038 feet. "It is 8½ miles long, and averages less than a quarter of a mile in width." Near the head of Crooked Lake, and only a few feet above it, is the Height of Land portage, approximately 1,042

[1] Geol. Survey of Canada, Report of Progress, 1871–72, p. 336.

[2] Ibid., Report of Progress, 1875–76, p. 330.

feet above the sea, and thence descending toward Lake Superior the old channel contains Dog Lake, having a height of about 1,026 feet, and Mattagaming or Mattawagaming Lake, which, according to the Canadian Pacific Railway survey, is 1,025 feet above sea-level.

When the Kenogami, Missinaibi, and other glacial lakes of the James Bay region became merged in one of great extent, rivaling Lake Agassiz, the outlet of this confluent lake probably crossed the low watershed south of the eastern end of Lake Abittibi, passing to Lac des Quinze and the Ottawa River. The elevation of Lake Abittibi, according to observations of the Canadian Geological Survey, is about 857 feet above the sea, and the portage over the watershed rises only about 100 feet higher. Its present altitude is thus nearly a hundred feet less than that of the Kenogami and Missinaibi outlets, and it is probable that when the land was first uncovered from the ice-sheet the Abittibi outlet was relatively lower than the others by a much greater difference, and that with reference to the sea-level it was much less elevated than now.

Basins of the Saskatchewan and the Red River of the North.—During the recession of the ice-sheet from Alberta small glacial lakes doubtless existed in the basins of the Bow and Belly rivers, outflowing from the former successively by the Little Bow River and the Snake Valley, and from the latter successively by the Verdigris, Etsi-kom, and Chin coulées, which Dr. Dawson describes as remarkable abandoned river courses now carrying little or no water. The glacial drainage from the present sources of the South Saskatchewan, and probably also of the North Saskatchewan and Athabasca, was thus carried southeastward, in parallelism both with the main Rocky Mountain range and with the retiring ice border, to the Milk River, west and south of the Cypress Hills. The whole area of Alberta, partly land sloping northeastward and partly ice sloping southwestward, with glacial lakes here and there along the ice margin, seems then to have been tributary to the Missouri and the Gulf of Mexico.[1]

From Lake Pakowki, through which this glacial drainage for a long time flowed southward to the Milk River, the ice front must have been

[1] G. M. Dawson, Report on the Geology and Resources of the Region in the vicinity of the Forty-ninth Parallel, 1875; Geol. Survey of Canada, Report of Progress for 1882-83-84, Part C. Compare with Mr. J. B. Tyrrell's paper in Bulletin G. S. A., Vol. I, pp. 401, 403.

withdrawn more than 200 miles to the east, past the Cypress Hills and Wood Mountain, before a lower outlet from the Saskatchewan country north of these highlands would be obtained by Twelve Mile Lake and over the present continental watershed to Big Muddy Creek, which flows through the northeastern corner of Montana to the Missouri. But only a slight further retreat of the ice was sufficient to give still lower avenues of drainage. As soon as the Missouri Coteau was uncovered a glacial lake occupying the valley of the South Saskatchewan, in the vicinity of its elbow, outflowed by the way of Moose Jaw Creek, and through a glacial lake in the upper Souris or Mouse River basin, to the Missouri near Fort Stevenson. Later the outflow from the Lake Saskatchewan may have passed to the Lake Souris by way of the Wascana River, after flowing through a glacial lake which probably extended from Regina 60 miles to the westward in the upper Qu'Appelle basin.

Through the whole period of the existence of the Lake Souris, which at first outflowed to the Missouri and afterward to Lake Agassiz, the glacial lake in the basin of the South Saskatchewan, doubtless also at last including the North Saskatchewan, was tributary to it, and the outlet of this Lake Saskatchewan was transferred to lower courses as the border of the ice-sheet receded from southwest to northeast. In the concluding part of this chapter detailed descriptions of these glacial lakes, and of their successive channels of outflow to Lake Agassiz, will be presented.

Lake Agassiz, the largest of all the glacial lakes of North America, occupying the basin of the Red River of the North and Lake Winnipeg, covered extensive tracts of Minnesota and North Dakota, the greater part of Manitoba, and a considerable area of eastern Saskatchewan and southwestern Keewatin. The history of this lake, which increased in area as the ice-sheet decreased, forms the central theme of this chapter, succeeded by reviews of the associated glacial lakes of large size, two of which, lying in southern Minnesota and in South Dakota, had their brief existence before Lake Agassiz, the others being contemporaneous with this lake and several of them tributary to it.

British Columbia, Athabasca, and the Northwest Territory.—Light-colored silt deposits, distinctly stratified and of considerable thickness, which seem to me referable in some districts to glacial lakes and in others to river floods supplied from the melting ice-sheet, are reported by Dr. G. M. Dawson in many basins of the British Cordilleran region. His interpretation of their origin, however, is by a marine submergence since the latest glaciation of the region. No fossils, either of the sea or of fresh water, are found, though they are abundant in postglacial marine beds of the St. Lawrence Valley, on the southwestern side of Hudson Bay, and in Greenland and Grinnell Land; but lakes of only moderate size temporarily bordering the ice-sheet during its departure would probably be destitute of life, and this would certainly be true of rivers produced by the glacial melting. These deposits occur, up to heights 2,300 to 2,700 feet above the sea, in the basin of the Kootanie and upper Columbia, on the interior plateau of British Columbia, on the northward extension of the great plains crossed by the Peace River, and in the upper valleys of the Stikine, Liard, and Yukon rivers.[1]

On the last-named river and the Lewes, tributary to it, Russell refers the formation of silt beds, fully 200 feet thick, and of higher terraces, to a glacial lake, named by him Lake Yukon, 150 miles long from north to south, with a maximum width of about 10 miles and depth of between 500 and 600 feet; and he suggests that this lake was probably caused by a depression of the upper part of the Yukon basin by the weight of the ice-sheet. The mouth of Lake Yukon, at its northern end, was near the northwestern boundary of the ice-sheet at its maximum extension, the whole lake being within the area that was ice-covered, as is known by the limits of glacial drift and striæ, which a e first found in ascending the Yukon near the Rink Rapids, approximately in latitude 62° 20′ north and longitude 136° 15′ west, about 160 miles east of the line between British America and Alaska.[2]

No other portion of the glaciated area of this continent presents a more interesting or more difficult problem in Pleistocene geology than these "white silts," as they are denominated by Dawson; and much further field work and study will be needed to demonstrate the conditions of

[1] Reports of the Geol. and Nat. Hist. Survey of Canada; Trans. Royal Society of Canada, Vol. VIII, sec. 4, 1890, pp. 3–74, with five maps; Am. Geologist, Vol. VI, Sept., 1890, pp. 153–162; Nature, Vol. XLII, Oct. 30, 1890, pp. 650–653.

[2] Bulletin G. S. A., Vol. 1, pp. 140, 146–148, 514.

their deposition in each of the numerous basins in which they are found. But I believe that ultimately they will be shown to be everywhere attributable either to fluvial deposition attendant on the recession of the ice-sheet or to deposition as deltas in glacial lakes which owed their existence to ice dams or to depressions where the land had sunk beneath the ice weight and has since been reelevated. For example, the Kootanie basin may well have been filled by a glacial lake obstructed in the present course of drainage by the retreating ice-sheet and outflowing by the way of Pack River and Lake Pend d'Oreille, which Professor Chamberlin finds to have been covered by the maximum advance of the ice, while gravel-bearing floods from the glacial melting poured thence to the south and west.[1] Again, the silts on the Peace River east of the Rocky Mountains seem referable, as will be stated more fully on a later page, to a glacial lake held by the barrier of the departing ice-sheet on the north and northeast, with outflow southeastward into Lake Agassiz.

EXTENSION OF LAKE AGASSIZ WITH THE DEPARTURE OF THE ICE-SHEET.

On the west side of Lake Agassiz the Dakota lobe of the ice-sheet, from its junction with the Minnesota lobe near the Head of the Coteau des Prairies, 25 miles west of Lake Traverse and Browns Valley, at the beginning of the moraine-forming or Wisconsin division of the Glacial period, reached about 200 miles south along the valley of the James or Dakota River to Yankton and the Missouri; but it was gradually diminished in its extent until, at the time of formation of the Kiester, Elysian, Waconia, and Dovre moraines, it no longer retained its lobate outline. While these moraines were being formed in Minnesota the southwestern boundary of the ice-sheet in South and North Dakota passed from the vicinity of Big Stone Lake and Lake Traverse northwesterly along morainic belts which have been traced through Sargent, Ransom, Barnes, and Griggs counties, N. Dak., and by the sources of the James and Sheyenne rivers. During the later stages, represented by the Fergus Falls and Leaf Hills moraines, the Dakota ice front appears to have become

[1] U. S. Geol. Survey, Bulletin No. 40, p. 8.

again lobate, extending from the west shore of Lake Agassiz southward and then westward and northward, between the lake area and the Sheyenne River, to the prominent and typical moraines that are found south of Stump and Devils lakes, on the Big Butte, about Broken Bone Lake and northward, and on Turtle Mountain. In their remarkable development these moraines are similar to the massive Leaf Hills, with which they seem to have been contemporaneous. The laving action of Lake Agassiz caused the thick portion of the ice-sheet filling the Red River Valley to melt back somewhat faster than its thinner portions on the higher land areas at each side.

The highest of the Herman beaches of Lake Agassiz extends in Minnesota, as traced in this survey, to the north side of Maple Lake, 20 miles east-southeast of Crookston, and probably it continues thence into the forest region on the east, where it is impracticable to follow its course, to the vicinity of Red Lake; and on the west it reaches through North Dakota and at least 14 miles into Manitoba, terminating on the northern part of the Pembina escarpment somewhere between Thornhill and its northern end, that is, between 14 and 40 miles north of the international boundary. Before the formation of this beach was completed the ice-sheet had retired from the lake area as far north as the beach extends. During pauses of this glacial recession the Dovre, Fergus Falls, Leaf Hills, and Itasca moraines were formed, showing a northward retreat of the ice border from the Dovre moraine across a distance of about 150 miles in central Minnesota and 150 to 200 miles in North Dakota and southern Manitoba, with a maximum of probably not less than 300 miles in the Red River Valley, where Lake Agassiz produced a more rapid melting of the ice margin. Through this time the River Warren, outflowing from this glacial lake, fed by abundant ice-melting and rains, eroded a channel about 50 feet deep, approximately from 1,100 to 1,050 feet above the sea, or perhaps it eroded only the lower half of that depth, in the moderately undulating sheet of till which reached across the present valley of Lakes Traverse and Big Stone. The shortness of the time thus indicated as probably occupied in the formation of a single one of the beaches of Lake Agassiz, reaffirmed as it is by the small amount of the littoral erosion and resulting beach deposits, may well astonish us in what it implies concerning the rapidity of the recession of the ice-sheet, and the brevity, geologically speaking, of the stages of pause or readvance when its moraines were accumulated.

Between the times of accumulation of the successive terminal moraines, the ablation of the ice surface and the retreat of its border caused the portion of the drift which had been inclosed within the ice-sheet to be rapidly deposited on the land, partly as till and partly as stratified gravel, sand, and clay, brought by the streams that were produced by the glacial melting. Thus while the series of Herman beaches was being formed not only were several large moraines amassed, but also much englacial till was spread over the country between the moraines, and glacial rivers deposited a broad belt of modified drift that stretches from central Minnesota to Red Lake and the Lake of the Woods, and continues northward in Manitoba, as described in pages 181–183. The most southeastern part of this prolonged tract of plentiful modified drift, in the vicinity of St. Paul and Minneapolis and northwestward to St. Cloud, belongs to a time previous to Lake Agassiz; the portion of these stratified beds between St. Cloud and Lake Itasca represents the time of formation of the highest Herman beach; and the deposition of their northern half, continuing from the headwaters of the Mississippi to the southwest part of the Lake of the Woods and to the Birds Hill group of eskers, was contemporaneous with the lower Herman shores of Lake Agassiz. Toward this belt great areas of the ice-sheet sloped convergingly during its maximum extension, and in the early part of its time of recession rivers flowed thither from the ice-lobes on the northeast and northwest until this glacial lake began to exist and to grow northward, occupying the Red River Valley.

STAGES OF GROWTH SHOWN BY MORAINES.

The retreat of the ice between the Waconia and Dovre moraines (pp. 142, 147) began to uncover the southern end of the bed of Lake Agassiz, into which the inflowing glacial Sheyenne River, even at that early stage, brought much gravel and sand. This first delta deposit of the glacial lake is spread along its southwestern margin from near Taylor Lake to the bluff, in the northeast corner of South Dakota, that overlooks the valley of

Lake Traverse and the Bois des Sioux River, about 4 miles southwest of White Rock, lying 100 feet below this gravel and sand bluff. The same high tract was at that time continuous also southeastward across the present valley, which is 4 miles wide, to the plateau in Traverse County, Minn., between the Bois des Sioux and Mustinka rivers, which is crossed and cut into by the railway in section 26, township 128, range 47. A thickness of 12 feet of this delta of gravel and sand, having a surface 75 feet above Lake Traverse, is shown by the railway excavation, without exposing its plane of contact with the underlying till, which forms the basal part of the plateau and extended, before its erosion by the outflow from Lake Agassiz, in an inclined plane gradually rising to the bluff of till, 100 to 110 feet high, east of the northern end of Lake Traverse. In this incipient stage, contemporaneous with the accumulation of the Dovre moraine, Lake Agassiz stretched nearly 30 miles from northwest to southeast, with a width varying from 1 to 2 or 3 miles, being probably widest in the vicinity of Wheaton, Minn., at its southern end, where the River Warren flowed away southwestward. The lake in this stage was little more than a broad expansion of the glacial representative of the Sheyenne River, which deposited its delta sediments along the edge of the lacustrine area, being walled in by the front of the ice-sheet.

With the glacial recession thence to the Fergus Falls moraine (p. 158) Lake Agassiz attained a length of about 120 miles from Lake Traverse north to Ada, Caledonia, and Hillsboro, with a width of 40 to 50 miles, occupying thus an area of about 5,000 square miles (Pl. XIX). Its depth at Breckenridge and Wahpeton was approximately 100 feet; at Moorhead and Fargo, 200 feet; and at Caledonia, 275 feet.

In the earliest part of this extension of the lake its outlet by the River Warren seems to have been for a short time about 25 feet higher than during the later and much longer part of this stage of recession of the ice and growth of the lake, as is shown by the Milnor beach, a less distinct shore deposit than the Herman beach and 20 to 25 feet above it, which was observed near Milnor, N. Dak., and along a distance of about 10 miles thence northwest to the Sheyenne, but was not recognized farther north nor in Minnesota. The Sheyenne at the time of formation of the Milnor beach had become established in the course which it now has to its debouchure into Lake Agassiz at the present most southern bend of the river. Its large delta there brought into the lake was already in progress of deposition during the accumulation of the Milnor beach-ridges and partly supplied the gravel and sand of which they are formed.

But the River Warren quickly cut down its channel to the base of the earlier Sheyenne deposit of gravel and sand before described, lying above the present valley of the Bois des Sioux, until it reached the harder till, and there was stayed during the numerous stages of lacustrine extension and glacial retreat which are represented by the single Herman beach of this southern portion of the lake. The growth of the great Sheyenne delta continued, and the Buffalo delta was probably mostly completed, during the withdrawal of the ice-sheet to the Fergus Falls moraine and its pause or readvance by which that moraine was made. Through the same stage, excepting its very short early portion, represented by the Milnor beach, and for a long time afterward, Lake Agassiz held its Herman level, changing only very slightly in this southern area by slow erosion of the outlet, but experiencing northward a gradual uplifting of its basin, whereby its Herman beach, single at the south, becomes double and multiple in proceeding to the north.

The next stage in the departure of the ice withdrew portions of its border to the ninth or Leaf Hills moraine (p. 163), which is closely associated with the Fergus Falls moraine, the two being merged together through much of their course. Lake Agassiz, therefore, gained only a small extension of its length and area (Pl. XIX). The most notable change was the formation of a northwestern bay of the lake, reaching in a reentrant angle of the ice-sheet to Larimore and McCanna, which received the Elk Valley delta, deposited by a large glacial river flowing from the depression on the ice surface where the descending slopes of its Minnesota and Dakota lobes met.

After these contiguous and partly combined moraines were formed, the increasing warmth of the climate again pushed back the ice border a long distance, until its retreat was temporarily interrupted at the line marked by the tenth or Itasca moraine (p. 173). Advancing northward,

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MAP SHOWING THE EXTENT OF LAKE AGASSIZ AT THE TIMES OF FORMATION OF THE FERGUS FALLS AND LEAF HILLS MORAINES.

Scale, about 42 miles to an inch.

Area of Lake Agassiz contemporaneous with the Fergus Falls Moraine

Area added at the time of the Leaf Hills Moraine

Fergus Falls (eighth) and Leaf Hills (ninth) Moraines

Lake Agassiz then expanded beyond the limit of the international boundary, reaching probably to Winnipeg and Birds Hill (Pl. XX). The entire area of this lake in North Dakota had become uncovered from the ice, a lobe of which, however, remaining on the Pembina Mountain plateau, closely bordered the shore along a distance of 50 miles south from the Manitoba line. In northwestern Minnesota the lake washed the base of ice cliffs that formed its eastern shore, beginning about 40 miles north of Lake Itasca and running north-northwesterly, as I have supposed, to an angle of the ice front at Birds Hill, from which a similar long, high coast of ice appears to have stretched southwestward to the Pembina Mountain in the vicinity of Thornhill, being the northwestern barrier of the widening and deepening lake. The water surface was about 290 miles in length, 110 miles in maximum width, and approximately 16,000 square miles in area; and the depth of water above St. Vincent, Pembina, and Emerson was about 450 feet, while its maximum above the site of the city of Winnipeg was not less than 550 feet. The extent of the portion of the lake in Manitoba at this time was probably about 3,500 square miles.

Once more the margin of the ice-sheet recedes, and next halts at the eleventh or Mesabi moraine (p. 177), having relinquished the whole of its area in North Dakota, but still lingering on a large tract of northern Minnesota, from Red Lake and Lake Winnebagoshish eastward to Lake Superior near the international boundary. The great glacial lake has now extended north to the south end of Lakes Winnipeg and Manitoba, attaining a length of about 325 miles, a maximum width of 130 miles from the east end of the south half of Red Lake to Larimore, and an area not far from 26,000 square miles, of which fully one-third was comprised in Manitoba (Pl. XX). Its maximum depth, lying over the present mouth of the Red River, was about 650 feet, and its depth above the south end of Lake Manitoba was 525 feet, very nearly.

These estimates of depths, it is to be noted, are derived from the determinations of the height of the shore-lines formed during the highest Herman stage, with allowance for the known north-northeastward differential elevation of the basin since the old plane of the lake surface was marked by the waves of storms. This earliest and highest level of Lake

Agassiz (excepting only the unimportant stage recorded by the Milnor beach) extended north along the Pembina Mountain into Manitoba and northeast to the south side of Red Lake, being contemporaneous with the accumulation of the Fergus Falls, Leaf Hills, Itasca, and Mesabi moraines, so that the single lacustrine plane of the uppermost in the series of the Herman beaches covered, at its final stage of greatest extent, all of the lake area to the latest of these moraines, which is the most northern one that has been definitely traced and mapped across this area.

Yet again, and doubtless many times again, the ice-sheet was compelled to retreat across spaces of varying widths, sturdily resisting the encroachments of the warmer climate and of its product, the glacially dammed lake, pausing here and there long enough to heap up moraines, then shrinking and dissolving away from new tracts strewn with its drift deposits. When future researches shall enroll the numbers and delineate the courses of the probably many morainic belts lying still farther north, it will be possible to show the later stages of the gradual extension of this lake along the great Cretaceous escarpment and over the great lakes of Manitoba, across Rainy Lake, the Lake of the Woods, and the Winnipeg River, over a large region east of Lake Winnipeg, and to some now unknown distance down the Nelson River.

Step by step, as fast as the ice-sheet waned, Lake Agassiz grew. The whole lacustrine area, as mapped provisionally for its northern and northeastern boundaries on Pl. III, was about 110,000 square miles or more, considerably exceeding the combined areas of the great Laurentian lakes. Although it was not entirely occupied by Lake Agassiz at any one stage of its existence, the beaches and terminal moraines indicate that the lake, during both its earlier and later stages, covered the greater part, probably three-fourths, of this area.

The chief evidence of such great extension of the lake during the first half of its history is the observed extent of the higher and earlier Herman and Norcross beaches, which have been mapped from near Red Lake, Minnesota, southward to Lake Traverse, and thence northward through North Dakota to Riding and Duck mountains in Manitoba, a distance of about

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MAP SHOWING THE EXTENT OF LAKE AGASSIZ AT THE TIMES OF FORMATION OF THE ITASCA AND MESABI MORAINES.

Scale, about 42 miles to an inch.

Area of Lake Agassiz contemporaneous with the Itasca Moraine   Area added at the time of the Mesabi Moraine

Itasca (tenth) and Mesabi (eleventh) Moraines

700 miles. Delta sand deposits, brought into Lake Agassiz by the Saskatchewan and referable to the Herman, Norcross, and later stages, reach from near Prince Albert, on the North Saskatchewan, about 40 miles west of the fork of the North and South branches, through a distance of more than 100 miles eastward to the head of the Seepanock Channel and the one hundred and third meridian.[1] The descent of the river in this distance is approximately from 1,275 or 1,300 feet to 950 feet, and the elevation of the west part of the delta is about 1,350 to 1,400 feet above the sea. As early as the time of the lower beaches of the Herman series, therefore, the recession of the ice-sheet had permitted the lake to extend along the whole front of the Manitoba escarpment to the latitude of the north end of Lake Winnipeg. The length of Lake Agassiz at that time was 550 miles or more, and I believe that its average width was not less than 150 miles, reaching east to the moraine which Mr. J. B. Tyrrell describes as forming the eastern shores and islands of Lake Winnipeg, with a height of 100 feet on Black Island.[2] This moraine would then have been deposited in water 600 to 700 feet deep, bordering the ice margin; its knolly and irregular accumulations of drift would not have been subjected to the leveling action of the lake waves until the further melting of the ice opened avenues of outflow to Hudson Bay and reduced the glacial lake nearly to the level of Lake Winnipeg; and the latest change of the northward outlets may have lowered the water surface so rapidly and to such vertical amount that it left no distinct marks of erosion or shore-lines on the upper portion of the moraine.

Before the successive northeastward outlets began to drain Lake Agassiz below its channel of southward discharge at Lakes Traverse and Big Stone, the border of the ice-sheet had been gradually melted back from Lake Winnipeg doubtless far toward Hudson Bay, and perhaps even its thick central part, which occupied the basin of Hudson and James bays, had so far disappeared as to admit the sea there. At a time of halt or readvance, interrupting this recession, another terminal moraine appears to have been accumulated, crossing the Churchill and Nelson rivers, as observed

[1] Canadian Pacific Railway Report, 1880, pp. 14, 19.
[2] "Pleistocene of the Winnipeg Basin," Am. Geologist, Vol. VIII, pp. 19-28, July, 1891.

by Dr. Robert Bell.[1] If this belonged to the time of the Campbell or McCauleyville beaches, as seems most probable, the extent of the lake during these later stages of southward outflow was even greater than I have supposed it to be at the time of the Herman and Norcross beaches, and the area occupied by Lake Agassiz in its numerous stages much exceeded that of my map and estimate.

Measured on the maps of this report, the portion of Lake Agassiz comprised within the limits of Minnesota has an area of approximately 15,000 square miles, and its portion in North Dakota is 6,800 square miles, very nearly, making together a tract of about 21,800 square miles in the United States, probably all uncovered from the ice and occupied by the lake during the time of formation of the Herman series of beaches. Within the limits of Manitoba and adjacent parts of Saskatchewan and Keewatin the extent attained by Lake Agassiz during its Herman and Norcross stages was probably at least 65,000 square miles. Somewhat more than three-quarters of its expanse then was north of the international boundary, for while the lake expanded northward with the recession of the ice-sheet, the southern part of the basin was being uplifted and the lake was slowly cutting down its outlet, so that it had already relinquished the margins of its earliest area in Minnesota and North Dakota.

During the stages of the lake represented by the Tintah, Campbell, and McCauleyville beaches, probably its area occupied by water at one time grew to exceed 100,000 square miles. Its southern portion, however, was meanwhile diminishing, until at that late time of maximum size of Lake Agassiz not more than a tenth or perhaps a fifteenth part of its water surface was in the United States. The decrease was in width, not in length, for at its maximum stage the outflow was doubtless still to the south by the River Warren.

REDUCTION TO THE PRESENT GREAT LAKES OF MANITOBA.

By the melting away of the ice-sheet from the country northeast of Lake Agassiz this glacial lake at length obtained successive outlets lower than that through Lakes Traverse and Big Stone and the Minnesota River. Owing to the northeastward depression of the ice-laden area, the earliest of

[1] Bulletin, G. S. A., Vol. I, pp. 303, 306.

these outlets may have flowed to the east and south, passing along the margin of the receding ice into Lake Superior, and thence into the Mississippi by the way of the Chicago outlet of the glacial Lake Warren, as Prof. J. W. Spencer has named the confluent glacial lake which is now reduced and separated into parts as the five great lakes of the St. Lawrence. After the glacial melting had proceeded so far as to open the great area of Hudson and James bays to the entrance of the ocean, Lake Agassiz was tributary for some time to this inland sea by outlets higher than the Nelson River, while the ice-sheet west of Hudson Bay was withdrawing northward.

Some of the lowest and latest stages of Lake Agassiz during its decrease as it was drained away by its northeastern outlets, each in succession lower than the preceding, are shown by Mr. J. B. Tyrrell's observations of beaches on Kettle Hill close south of Swan Lake, on the portage between Lake Winnipegosis and Cedar Lake, and in the vicinity of the Grand Rapids of the Saskatchewan.[1] Between the time of formation of the Stonewall beach and that of the Niverville beach the surface of Lake Agassiz was lowered 45 or 50 feet, from a level slightly higher than Lake Winnipegosis to one slightly lower than Lake Manitoba. The former of these levels seems to be represented near the mouth of the Saskatchewan by a beach 140 feet above Lake Winnipeg, or 850 feet above the sea; and the latter becomes apparently double or triple, being represented by three beach ridges, 95, 90, and 80 feet above Lake Winnipeg. These beaches, if my correlation as thus stated is correct, are nearly horizontal throughout their observed extent of nearly 300 miles from south to north, and show that the differential northward uplift of the basin of Lake Agassiz was almost completed before the ice barrier was melted back from the area crossed by the Nelson River.

According to my correlation of the five shore-lines noted by Mr. Tyrrell on Kettle Hill, successively, in descending order, 1,070, 1,015, 995, 955, and 920 feet above the sea, the highest belongs to the Hillsboro stage of Lake Agassiz; the next two to the Emerado stage, there divided because of northward uplifting of the land; while the lower two are, respectively,

[1] "Pleistocene of the Winnipeg Basin," Am. Geologist, Vol. VIII, pp. 19–28, July, 1891.

the second of the Ojata beaches and the Gladstone beach. This locality is about 235 miles north of the international boundary, being 150 miles north from the latitude of Gladstone, Arden, and Neepawa, the most northern line upon which my own explorations supply a comparison of the beaches and determination of their northward ascent.

At the time of formation of the Hillsboro beach, which had been already preceded by the three higher Blanchard levels of Lake Agassiz since it first began to outflow northeastward, the lake surface thus appears to have been about 140 and 240 feet, respectively, above the southern portions of the present Lakes Manitoba and Winnipeg, and approximately 240 and 360 feet above the northern portions of Lakes Winnipegosis and Winnipeg, the northward ascent of the Hillsboro beach being nearly 120 feet in the 150 miles between Gladstone and Kettle Hill. Lake Agassiz during this stage stretched south in the Red River Valley about 15 miles beyond Fargo and Moorhead; and its total length was probably not less than 650 miles, with a maximum width of about 200 miles.

During the formation of the two Emerado beaches the lake on the latitude of Kettle Hill was about 185 and 165 feet, respectively, above the northern part of Lake Winnipegosis, to which 118 feet should be added for its depth above Lake Winnipeg, besides some undetermined amount of present northeastward ascent of the plane of that lake surface in the distance of more than a hundred miles to the north end of Lake Winnipeg. The Emerado level of Lake Agassiz began at the south about 5 miles north of Moorhead and Fargo, and stretched probably 600 miles to the north. Its width was little less than that of the Hillsboro stage; but the northward uplifting of the lower Emerado beach between Gladstone and Kettle Hill has been only 85 feet.

When the lake held its two Ojata stages and Gladstone stage, the depth of water above Lake Winnipegosis was, successively, about 140, 125, and 90 feet; and its extension southward in the Red River Valley was for the lower Ojata beach to Caledonia, near the mouth of the Goose River, and for the Gladstone beach to the vicinity of Belmont, N. Dak., about 20 miles south of Grand Forks. The portion of Lake Agassiz extending into the United States at the Gladstone stage had a length of almost 100 miles;

and the total length of the glacial lake, then near the middle of its entire time of northeastward outflow, was more than 500 miles, with probably one-third as great width in its northern part. The amount of upward tilting toward the north upon the area extending 150 miles from Gladstone to Kettle Hill since the Gladstone beach was formed has been 40 or 45 feet. About twice as much tilting had occurred there between the times of formation of the Hillsboro and Gladstone beaches as since the date of the later one of these shore-lines. Lake Agassiz in its Gladstone stage had become reduced probably to half of its earlier maximum extent.

Mossy portage, between Lake Winnipegosis and Cedar Lake, is about 60 miles northeast of Kettle Hill; and the Grand Rapids of the Saskatchewan, near its mouth, are about 25 miles farther east. Both these localities are nearly on latitude 53° 10′ north, being some 50 miles north of the latitude of Kettle Hill and 285 miles north of the international boundary. The summit of the eastern Mossy portage is described by Mr. Tyrrell as a gravel ridge with crest 93 feet above Lake Winnipegosis or 921 feet above the sea. It is doubtless a beach formed by Lake Agassiz when it stood here at the level of about 910 feet. Descending southward to Lake Winnipegosis, the portage crosses another beach ridge with its crest 27 feet and its base about 15 feet above this lake, and it is therefore clearly referable to a level of Lake Agassiz about 845 feet above the sea. These stages of the glacial lake are quite surely the same which made the Burnside and Stonewall beaches near the south end of Lake Manitoba and the city of Winnipeg. An escarpment crossed by the portage midway between these beach ridges appears to mark the position of the intermediate Ossowa shore.

The Burnside lake level reached south in the Red River Valley to Grand Forks, and had an entire length of nearly 500 miles thence to the latitude of 55° north, with a width from 150 to 175 miles in its northern half. Above the southern end of Lake Winnipeg the depth of Lake Agassiz at this stage was 150 feet, and above its northern end about 200 feet.

The next lower level of Lake Agassiz, which is recorded by the Ossowa shore-line, lacked only 15 miles of reaching to Grand Forks, and had almost as great total length and width as the preceding. Its height above the south ends of Lakes Manitoba and Winnipeg was about 30 and 130 feet, respectively.

At the time represented by the Stonewall beach, lying next in descending order, the surface of Lake Agassiz was 10 to 20 or 25 feet above Lake Manitoba, 5 to 15 or 20 feet above Lake Winnipegosis, and about 110 and 140 feet, respectively, above the southern and northern ends of Lake Winnipeg. It yet extended nearly 40 miles south of the international boundary, to the vicinity of the mouth of Park River.

In receding from the Stonewall to the Niverville stage Lake Agassiz sank below Lakes Winnipegosis and Manitoba, which remain as two of the three large remnants of this vast body of water. On the line of the tramway at the Grand Rapids of the Saskatchewan Mr. Tyrrell reports four beach ridges of gravel and sand, as already noted, at the heights of 850, 805, 800, and 790 feet above the sea. The first is referable to the Stonewall stage, and the three others to the Niverville stage, which is here compound, apparently on account of intermittent northward uplifting of the country. Mr. Tyrrell informs me that the Niverville beach on Black Island, in the southern part of Lake Winnipeg, is about 60 feet above the lake. At the Grand Rapids, 175 miles northwest from Black Island, its three ridges, in descending order, are 95, 90, and 80 feet above the lake, showing that there was a northward uplift of 15 feet along this distance during the Niverville stage, and that since then a further differential tilting of about 20 feet has taken place. The southern end of the Niverville level of Lake Agassiz was near Morris, Manitoba. It failed to reach into the United States by a distance of about 25 miles, being the first stage of this glacial lake that lay wholly in British America, and it was the latest stage held by the ice barrier and recorded by a well-marked shore-line. Lake Agassiz at this time, as during several preceding stages, reached far north and northeast of Lake Winnipeg, and up to its latest year it may have had an area of 20,000 or 30,000 square miles.

Finally the retreat of the ice-sheet uncovered the land across which the Nelson outflows from Lake Winnipeg to Hudson Bay. The existence of the glacial lake was ended, and this largest of the great lakes of Manitoba was added to the number of its present representatives or descendants. Dr. Bell's descriptions of the outlet of Lake Winnipeg and the topography of the adjoining country[1] show that no barrier of land so high as the Niverville beach can have been removed there by erosion. The original level of Lake Winnipeg, due to the height of the land upon which the Nelson River began to cut its channel in its present course, is doubtless that of the well-defined beach observed by Hind between the mouths of the Winnipeg and Red rivers, having "an elevation of 21 feet above the present level of Lake Winnipeg."[2] Traces of this shore-line will probably be found at nearly the same height around the whole lake.

SUCCESSIVE SHORE-LINES OF LAKE AGASSIZ.

In the southern part of the area of this glacial lake, within 75 miles northward from its mouth at Lake Traverse, five principal beaches have been observed, and in their descending order have been named, from towns in Minnesota near which they are well exhibited, the Herman, Norcross, Tintah, Campbell, and McCauleyville beaches. These shore-lines, however, when traced farther north, are found to become double or multiple. The Herman beach in the vicinity of Maple Lake, Minnesota, is divided into five beaches, four besides the highest having been formed when the rise of the land, with the slight fall in the level of Lake Agassiz, amounted, successively, to 8, 15, 30, and 45 feet on the east side of the lake in that latitude. Still farther to the north, in Manitoba, we find seven beaches corresponding to the single Herman beach at the southern outlet. In like manner, the Norcross and Tintah beaches are each represented at the north by two, and the Campbell and McCauleyville beaches each by three distinct shore-lines, separated by slight vertical intervals. The northern part of the lake has thus no less than seventeen shore-lines, which were successively formed from the highest to the lowest during the time of the southward outflow through Lakes Traverse and Big Stone and the Minnesota River to the Mississippi.

After the lake obtained its earliest outlet to the northeast, sinking below Lake Traverse, it formed fourteen shore-lines. The first three of

[1] Chapter II, pp. 29 and 62.

[2] Narrative of the Canadian Red River Exploring Expedition of 1857, and of the Assiniboine and Saskatchewan Exploring Expedition of 1858, Vol. 1, p. 122.

these pass near Blanchard, N. Dak., and thence are denominated the Blanchard beaches. The next in descending order is the Hillsboro beach, the succeeding two are the Emerado beaches, and the two next lower the Ojata beaches, named similarly from other towns of this State. The remaining six lower beaches are named from localities in Manitoba. In the same descending order, they comprise the Gladstone, Burnside, Ossowa, Stonewall, and Niverville beaches, the last being double. There are thus in total thirty-one separate shore-lines of this lake in the northern portion of its area explored by me; and all of them, excepting the lowest, extend south of the international boundary.

DEPENDENCE OF THE LAKE LEVELS ON THE EROSION AND CHANGES OF OUTLETS.

PROGRESS OF EROSION BY THE RIVER WARREN

Through the greater part of the duration of Lake Agassiz its outlet remained constantly in one position, and the stream of its overflow, named the River Warren, eroded during that time the remarkable valley, rather to be described as a trough-like channel, mostly 1 to 2 miles wide and 150 to 230 feet deep, which is now occupied by Lakes Traverse and Big Stone and the Minnesota River. There is evidence, however, in the terraces of modified drift along the Minnesota Valley, that in large part its erosion was effected in preglacial time and during stages of retreat and readvance of the ice-sheet previous to its final departure, when it was the barrier of this glacial lake.[1] The general surface of the moderately undulating drift sheet, having swells 10 to 25 feet above its hollows, which stretches away on each side from the top of the bluffs inclosing this valley at Lakes Traverse and Big Stone, is about 1,100 feet above the sea, and the heights of these lakes at their low stage of water are, respectively, 970 and 962 feet. Before the retreat of the ice uncovered this tract, a channel 40 or 50 feet deep probably existed here, nearly or quite continuous, along the course that was taken by the River Warren in its first discharge from the incipient Lake Agassiz; for this level, much below the even expanse

[1] "The Minnesota Valley in the Ice age," Proc., A. A. A. S., Vol. XXXII, for 1883, pp. 213-231. Geology of Minnesota, Vols. I and II.

of drift through which the river flowed, is the height of the Herman beach, which was the shore of the glacial lake at an early stage and through a long time ensuing. The somewhat higher Milnor beach appears to have been due to the temporary barrier interposed at first by the delta gravel and sand of the glacial Sheyenne River, spread wholly across the southern end of the lake at its beginning. Over this barrier, to the west of the line between White Rock and Wheaton, the River Warren flowed for a short time with rapids, speedily cutting it down 20 or 25 feet to the bed of the previously existing channel along the distance of 50 miles above the present sites of Lakes Traverse and Big Stone. This channel, whose depth determined the level of the Herman beach while the lake expanded with the recession of the ice-sheet even to southern Manitoba, was, as I believe, a vestige of a preglacial and possibly interglacial river course not wholly filled by the drift deposits. Reasons for this belief are sufficiently stated in the memoir on the Minnesota Valley before referred to, and in the description of certain remarkable chains of lakes in Martin County, Minn.[1]

Nearly all the changes in the relative heights of Lake Agassiz and the basin that held it, by which the Herman beach became fourfold and even sevenfold in proceeding northward, must be ascribed to epeirogenic uplifting of the land, with only a very small element of change in the lowering of the lake level by erosion of its outlet. The southern portion of this shore-line, as far to the north as the latitude of Moorhead and Fargo, is marked by a single beach ridge, very definite in form and course, but not massive in comparison with the present beaches of the ocean or of the great lakes tributary to the St. Lawrence, the Nelson, and the Mackenzie. While Lake Agassiz was forming the Herman beach, erosion probably lowered the channel of the River Warren and the level of the lake 5 or 10 feet. During the same time a much greater differential northward uplift, presently to be considered, was in progress.

From the level of the Herman beach to that of the Norcross beach Lake Agassiz fell somewhat suddenly 15 or 20 feet. As this change of level affected the southern part of the lake, adjoining its mouth, it is evident that between the dates of these shore-lines the River Warren eroded

[1] Geology of Minnesota, Vol. I, 1884, pp. 479–485.

its bed to this additional depth. Through a comparatively long time, represented by the Herman beach, this large outflowing river, bearing the waters supplied by the progressive glacial melting upon a vast area, had only deepened its channel slightly; but at the close of this stage the division between it and the next following Norcross stage, though doubtless only a short interval of time, was marked by a considerable increase of depth of the channel. Why was the river able to erode so much faster then than during the time of formation of the Herman beach, or of the Norcross beach afterward, which likewise represents a nearly stationary period in the progress of erosion of the Lake Traverse Valley? The answer which seems best was suggested to me by Mr. G. K. Gilbert in a letter dated February 3, 1888, as follows:

> * * * Retreat of the ice modified the geoid, and perhaps produced also a crustal change, and in consequence the baselevel assumed a new attitude to the land. The river adjusted its grade to the new conditions, and then remained stationary during the formation of the Norcross beach.

The portion of Mr. Gilbert's explanation which we must appeal to is that attributing the temporarily rapid erosion to a crustal change, that is, to an uplifting of the region about the mouth of Lake Agassiz; and this meets the case fully. There was, however, no apparent reason why the region of Lake Traverse or the Minnesota Valley should be thus intermittently elevated, so far as we can directly compare the change with the process of the glacial retreat; and to what extent this movement affected the northern portions of the lake area can only be ascertained by very exact comparison of the altitudes of the lowest Herman and the highest Norcross beaches.

Rhythmic stages of elevation of the country across which the River Warren flowed, intervening with pauses in the action of the uplifting forces, are shown in succession by the Norcross beach, to which the erosion from the level of the lake at the later part of its formation of the Herman beach was about 20 feet; by the two Tintah beaches, to the first of which there was further erosion of about 15 feet, and a similar amount more to the second; by the Campbell beach, to which again the river still further cut down its channel 15 or 20 feet; and by the McCauleyville beach, formed by the lake when its channel of outlet was the bed of Lake Traverse, once more

15 to 20 feet below its preceding level. Each of these beaches records a comparatively long pause in an uplifting of the land adjoining the mouth and outlet of Lake Agassiz, which was periodically renewed during brief stages of somewhat rapid increase of elevation at no less than five times while Lake Agassiz outflowed southward. The regularity or rhythm in the sequence of these beaches, and their division by nearly equal vertical intervals, were doubtless produced by rhythmic uplifts, alternating with longer stages of nearly complete rest.

In total the rise of the country about Lake Traverse appears not to have exceeded 90 feet during the time of existence of the River Warren, and probably it was less. This river is not known to have formed alluvial deposits along its course, building up its bed, but instead was apparently cutting down its channel throughout the whole extent of the valley now occupied by Lakes Traverse and Big Stone and the Minnesota River, finally flowing at Belle Plaine, in the lower part of the Minnesota Valley, probably 150 feet below the present river and 140 feet below low water in the Mississippi at St. Paul.[1] A considerable share of the total erosion of 90 feet from the Herman to the McCauleyville beach is therefore probably attributable to the descending slope and ordinary downward cutting of the River Warren, independent of its stages of faster rate when the southern part of the basin was being elevated. While these five slight uplifts, probably together not exceeding 90 feet and perhaps no more than 75 or 50 feet, took place at the south, a much larger number of elevatory movements, mostly of similarly small amount, to be presently discussed, raised the northern part of the lake basin 200 to 300 feet or more, their amount becoming greater from south to north. The little depths that the River Warren eroded during the several stationary stages of the southern end of the lake basin harmonize well with the small volume of the beach deposits and with the scanty amount of cliff-cutting and other wave action on the shores, all attesting the brevity of the time required for the work done.

[1] "The Minnesota Valley in the Ice age," Proc., A. A. A. S., Vol. XXXII, for 1883, pp. 227-231.

LATER OUTLETS NORTHEASTWARD.

When the outlet of Lake Agassiz was changed and an avenue of discharge toward the northeast was obtained, the south end of the lake at first fell only 15 feet below the McCauleyville beach and the bed of Lake Traverse. Its numerous stages, recorded by the shore-lines of the whole time of northeastward outflow, until the retreat of the ice-sheet uncovered the present course of the Nelson, were in succession each lower than the preceding by the following amounts, as determined mostly by leveling on the latitude of Gladstone, Manitoba, 308 miles north of Lake Traverse and 84 miles north of the international boundary: The first, second, and third Blanchard beaches, respectively, about 20, 15, and 15 feet; the Hillsboro beach, 12 or 15 feet; the Emerado beach, about 30 feet; the Ojata beach, 25 feet; the Gladstone beach, 20 feet; the Burnside beach, again 20 feet; the Ossowa beach, 15 feet; the Stonewall beach, 20 feet; and the Niverville beach, 45 feet. Thence to the earliest level of Lake Winnipeg there was again a fall of about 45 feet, and erosion by the Nelson River has since lowered this lake about 20 feet.

As soon as the ice upon Hudson and James bays and the adjoining country had so receded as to give to Lake Agassiz an outlet lower than the River Warren, it began to be drained in that direction, perhaps flowing at first across the watershed between the Poplar and Severn, and later along lower courses, including the canoe route by the Hill and Hayes rivers. Each of its successive outlets was probably eroded to a considerable depth, being occupied by the outflowing river during the time of formation of two or more beaches, until the retreat of the southeastern border of the portion of the ice-sheet remaining west of Hudson Bay finally permitted drainage to take the course of the Nelson, the ice-dammed Lake Agassiz being thus changed to Lake Winnipeg. The northeastern outflow commenced when the lake at the latitude of the south end of Lake Winnipeg stood about 1,000 feet above the present sea-level, and it was gradually lowered to 730 feet, when the Nelson, between its successive lakes, began to erode the shallow channel of the upper part of its course.

Inspection of the series of vertical intervals between the successive levels of the lake during its northeastern drainage suggests that probably the earliest outlet in that direction was occupied during the time of the three Blanchard beaches and the Hillsboro beach, the channel being cut down about 45 feet. The comparatively large interval above the Emerado beach may be supposed to imply the transfer of the discharge to a new outlet; and the series of smaller intervals separating the next five beaches may indicate that they all were formed while this channel was being cut down about 100 feet. Another large fall of the lake, to the Niverville beach, which is compound in its northern part, would again mark the occupation of a new outlet. This, however, was soon abandoned for the still lower course of the Nelson. Exact heights of these old river courses, crossing present lines of watershed, and the depths of their erosion, will doubtless be determined at some future time by exploration and leveling, though probably not until after many years, on account of the difficulty of carrying instrumental surveys through that wooded and uninhabited region.

DEPENDENCE OF LAKE LEVELS ON EPEIROGENIC ELEVATION.[1]

The five or six distinct beaches that were formed by the southern part of Lake Agassiz during its outflow southward are represented in the northern part of its basin by seventeen separate shore-lines, which are marked by definite beach ridges. The individual beaches at the south, being traced northward, become double or triple, and the highest or Herman beach expands into seven successive shore-lines. During the earlier years of my exploration of this glacial lake I believed that this duplication and multiplication of the beaches observed in advancing from south to north was referable to the diminution of the attraction of the ice-sheet as its final melting progressed. Gravitation of the lake toward the vast mass of the ice, and its decrease with the glacial recession, I then supposed to be adequate to explain the observed northward ascent of the beaches, amounting for the highest Herman beach to 5 or 6 inches per mile for its first 50 miles at the south, but thence increasing northward to 1 foot and 1½ feet per mile; for the succeeding beaches, of gradually diminishing amount; and for the McCauleyville beach, the latest formed during the southward outflow,

[1] For the definition of this term, proposed by Gilbert, see page 103.

ranging from 1 inch per mile at the south to about $2\frac{1}{2}$ inches per mile from the international boundary to the latitude of Gladstone.

With further exploration and study, including the portion of the lake area examined by me in Manitoba, I became convinced that this explanation is inapplicable to the problem, because the highest beach of the Herman series (formed contemporaneously with the six large deltas which were dependent for their formation on the accompanying retreat of the ice-sheet supplying their sand and gravel) is found to be continuous along an extent of nearly 250 miles from south to north, reaching from Lake Traverse at least to Thornhill, in Manitoba, across an area which has several prominent moraines of recession, denoting important stages of decrease of the ice-sheet. These moraines extend to the borders of Lake Agassiz, and the ice front at the time of their formation traversed the lake basin. Therefore, if diminution of the ice-attraction were the principal cause of the changes of the levels of the lake, we should expect the highest beach to cease at the successive morainic belts, and another somewhat lower to take its place thence northward.

For aid in the investigation of this and other movements of elevation of the land following the departure of ice-sheets and the evaporation of Lake Bonneville, Mr. R. S. Woodward, of the United States Geological Survey, made a careful mathematical computation of the effects of such masses of matter formerly existing upon portions of the earth's surface to deform the geoid or level of the water of lakes or the sea.[1] His result, agreeing approximately with conclusions from similar computations by European mathematicians and physicists, shows that the North American ice-sheet, with its known area and its maximum probable thickness, would be capable of drawing the level of Lake Agassiz upward to the north not more than a quarter, or perhaps no more than an eighth or tenth, as much as the ascent of the Herman beach. It is thus evident that we must look to some other cause for explanation of these changes of level, and this is found in a differential uplifting of the lake basin, increasing in amount from south to north upon all the area where we have determined the heights of the beaches.

[1] U. S. Geol. Survey, Sixth Annual Report, pp. 291–300; and Bulletin No. 48, "On the form and position of the sea-level."

The departure of the sheets of land ice which spread drift formations over the northern part of North America, northwestern Europe, and Patagonia, was in each of these great and widely separated areas attended by a depression of the land. While each of these ice-sheets was melting away, the land on which it had lain was somewhat lower than now, and its coasts were partially submerged by the sea. These are the only extensive regions of the earth which have lately borne ice-sheets that have now melted, and it seems to be a most reasonable inference that the vast weight of their burdens of ice was an important element in the causes of their subsidence. Since the disappearance of their ice-sheets, each of these continental areas has been uplifted, probably in large measure because of the withdrawal of the ice-load. In Europe these epeirogenic movements of depression and reelevation seem to have been more nearly proportionate to the volume and extent of the ice-sheet than on our continent. Both in North and South America, other great epeirogenic movements, affecting large areas which were never glaciated, have been in progress, apparently during the same time and in close association with the oscillations of the glaciated regions. In another chapter, treating more fully of the causes of the changes in level of the beaches of Lake Agassiz, these complex movements of our continent and other parts of the world during the Quaternary era will be reviewed for the purpose of learning, if possible, how and why such subsidences and uplifts of great areas take place.

At present we need only to inquire what were the amounts of depression of the basin of Lake Agassiz and of contiguous parts of this continent, since these would affect the history of this lake in its reduction from its highest level to its lower shore-lines and to Lake Winnipeg; and what was the manner of the reelevation, whether by regular and continued movement, or by intermittent uplifting and stages of repose, and whether the basin was uplifted differentially as a whole or in successive portions.

Depression of the continent shown by coastal submergence.—Answering the first part of these inquiries so far as we may by the known extent of oceanic submergence of the land when it became uncovered from the ice, we have the testimony of marine fossils in beds overlying the glacial drift, which show that the country southwest of Hudson and James bays then stood

300 to 500 feet below its present level; that the Ottawa basin was depressed 400 to 500 feet; the St. Lawrence Valley, about 250 feet at the mouth of Lake Ontario, at least 560 feet at Montreal, and 375 feet opposite the Saguenay; and the country bordering the Gulf of St. Lawrence, about 200 feet at the Bay of Chaleurs, with diminishing amount thence to the east and south, ceasing in Nova Scotia and southeastern Massachusetts. In the Mackenzie basin, evidences of marine submergence since the Glacial period have not been found; but they are discovered, up to heights of 100 to 300 feet, on the Pacific coast of the drift-bearing area. It is probable, however, that these elevations of marine deposits are not full measurements of the depression under the ice-load. The nearly complete uplifting of the basin of Lake Agassiz while the ice-sheet was retreating from it and was still the barrier of the waning glacial lake proves that the reelevation closely followed the departure of the ice, and suggests that in the districts of these marine beds some uplifting may have been done while the ice above was becoming thin, but had not wholly disappeared, or at least before its retreat had opened ways of ingress for the sea.

Depression and reelevation of the basin of Lake Agassiz shown by differentially uplifted beaches.—If we next seek a measure of the subsidence of the basin of Lake Agassiz while it was ice-burdened, no marine beds above the drift in this district can aid in giving an answer, but we must look to the known amount of northward uplifting of the once level beaches, and from this differential elevation it seems well-nigh sure that the maximum depression which this basin underwent failed to sink its lowest part, the shallow bed of Lake Winnipeg, to the sea-level. The central and northern portion of the area of Lake Agassiz, where the great lakes of Manitoba are now outspread, was depressed apparently 400 or 500 feet, carrying the present shores of Lake Winnipeg down to an altitude of only 300 or 200 feet above the sea; but the bed of this lake, which is less than 100 feet deep, was still above the ocean. The amount of subsidence here is thus found to be harmonious with that of other parts of our glaciated area which bordered the oceans and Hudson Bay. As a whole, the ice-enveloped portion of the continent is seen to have sunk slightly more in its central region than on its boundaries. The vertical extent of the maximum known depression, determined by marine fossils of the Champlain epoch and by the inclined beaches of this glacial lake, ranged from no subsidence in the greater part of Nova Scotia to probably 600 feet at Montreal, nearly the same at Ottawa and about James Bay, approximately 500 feet in Manitoba, none or little on the Mackenzie, and from 300 to 100 feet, probably decreasing from north to south, on the shores of the Queen Charlotte Islands and British Columbia.

Some addition to these figures, but probably nowhere exceeding a quarter or third more, is required to give the earlier extreme extent of the subsidence of the ice-weighted land, thus including its rise before the ice above had wholly melted, or before the sea was admitted to Hudson and James bays, and to the St. Lawrence, Lake Champlain, and Ottawa valleys. But this small added amount was offset in part or entirely by the effect of gravitation, which raised the levels of the ocean and lakes toward the ice-sheet. These two causes of changing levels acted in conjunction in their relationship to the series of shore-lines of Lake Agassiz, and to the position and course of its outlets after it fell below the channel at Lake Traverse; but the effect of ice attraction must be deducted from the total, if we ask the extent of epeirogenic subsidence and reelevation, which therefore are probably closely expressed in the figures before stated, having a maximum of 500 to 600 feet.

Improbable hypothesis of an outlet from Lake Agassiz to the Mackenzie River.—We may therefore dismiss as untenable the supposition that the outflow of Lake Agassiz, after falling below Lake Traverse and the McCauleyville beach, and being still obstructed from going to Hudson Bay by the presence of a large remnant of the ice-sheet there, could have passed for a time across the divide between the Churchill and Athabasca rivers, thus being discharged into the Mackenzie and the Arctic Ocean. Such northwestward outflow would have crossed the present watershed near the Methy portage, or by way of Wollaston or Hatchet Lake, which has two outlets, one to the Churchill and the other to the Athabasca. The altitude of the summit of the Methy portage, according to Richardson's observations, with correction for the now better-known heights of Lake Winnipeg and the Saskatchewan, appears to be about 1,750 feet above the sea; and Methy Lake, at the head of a series of lakes and connecting streams tributary to the Churchill, is about 50 feet lower. According to Dr. Robert Bell, "there is said to be a continuous watercourse" near this portage, passing from the Clearwater, a branch of the Athabasca, into the Churchill basin;[1] but its height forbids the inference that the waters of Lake Agassiz ever outflowed there, for a subsidence of more than 700 feet would be required to reduce Methy Lake and the divide in its vicinity to the level of Lake Traverse. Instead, as was stated on page 64, it is my belief that this channel was the outlet of a lake in the Athabasca basin, dammed by the barrier of the receding ice-sheet on the north and thus made tributary to Lake Agassiz. The other pass over the watershed, by the way of Hatchet and Jackfish lakes, situated 300 to 375 miles northeast of the Methy portage, is probably 1,300 or 1,400 feet above the sea, and presents nearly equal difficulty to the hypothesis of an outlet from the Winnipeg basin to the Mackenzie; but again there is much likelihood that this course also served, at a later date, as an important avenue of inflow to Lake Agassiz from the Athabasca glacial lake.

Probable hypothesis of the discharge from the northeastward outlet being tributary successively to the Mississippi and Hudson rivers.—When the discharge by the River Warren ceased, the new outlet flowed northeastward. Perhaps, as before stated, it turned back for some time to the south along the border of the waning ice-sheet, and thus still passed into the Mississippi by the way of Lakes Superior and Michigan. Stranger yet, through the effect of subsidence, which greatly modified the conditions of drainage in the Champlain epoch, as pointed out by Mr. Gilbert,[2] this overflow, prevented by the ice-barrier from going in the direction of the land slope to Hudson Bay, may have been later carried into the Atlantic by the Mohawk and Hudson rivers; or, at a still later stage, it may have taken its course past the mouth of Lake Ontario to the sea near the head of the greatly enlarged Gulf of St. Lawrence, which then filled the St. Lawrence Valley, the basin of Lake Champlain, and the Ottawa Valley to Allumette Island

[1] Bulletin, G. S. A., Vol. I, 1890, p. 291.

[2] "The History of the Niagara River," Sixth Annual Report of the Commissioners of the State Reservation at Niagara, for the year 1889, pp. 61–84, with maps (also in the Annual Report of the Smithsonian Institution, 1890, pp. 231–257).

or higher.[1] Perhaps, last of all, before the glacial recession admitted the sea to Hudson Bay, this discharge from Lake Agassiz, flowing through a great glacial lake in the southwestern part of the basin of Hudson and James bays, would find its lowest and final outlet to the south by the way of Lakes Abittibi, des Quinze, and Temiscaming, then entering the Ottawa arm of the Gulf of St. Lawrence. It seems even possible that the vicissitudes of the changing courses of drainage produced by the gradual retreat of the ice may have included for the outflow from Lake Agassiz, after it began to pass first northeastward, all of these four ultimate routes; first, by Chicago to the Mississippi; second, by the glacial Lakes Algonquin, Lundy, and Iroquois, and the Mohawk and Hudson rivers, to the Atlantic; third, by the lake portion of this route, and perhaps for some short time by Lake Nipissing and the Mattawa River, to the head of the Gulf of St. Lawrence, then filling the St. Lawrence Valley and a part of the Ottawa basin; and fourth, by Lake Abittibi, crossing the lowest point of the watershed between James Bay and the St. Lawrence. The known epeirogenic subsidence of the Champlain epoch and the probable manner of recession of the ice border from south to north make each and all of these courses, diverting the northeastward outflow to the south, far more probable than either of the courses before considered by which this glacial lake might be supposed to send its overflow to the Mackenzie.

Division of the ice-sheet into parts east and west of Hudson Bay.—It seems to me most probable, however, that long before the complete departure of the ice-sheet it became melted in twain by the laving action of Lake Agassiz and of a great glacial lake in the southwestern and southern part of the basin of Hudson Bay, and on its other side by the sea washing its ice-cliffs in Hudson Strait and the northern part of Hudson Bay, so that the latest general glaciation of our continent was confined to two areas, one east and the other west of this vast mediterranean sea. Several of the lower shorelines of Lake Agassiz, formed during its northeastward drainage, if not all of them, doubtless mark levels of outlets which flowed into this inland sea, until the northward recession of the remnant of the ice-sheet on its west side laid bare the course of the Nelson. Careful collection and study

[1] Am. Jour. Sci. (3), Vol. XLIX, pp. 1-18, with map, Jan., 1895.

of observations of the bearings of glacial striæ on all portions of Canada to the far north, and examination of the lowest points of watersheds as to their glacial river courses, will be the means of displacing these speculations by definite knowledge and proofs of what were the fortunes of the departing ice-sheet and of the late outlets of this lake.[1]

Amount of differential elevation between Lake Traverse and Gladstone.—How the Red River Valley and the lake country of Manitoba were uplifted from the late glacial or Champlain depression is told by the inclination of the Lake Agassiz shore-lines. So far as exploration and determination of the heights of the beaches have extended, including both my own and Mr. Tyrrell's work, there is found to be a northward ascent of the old lake levels, greatest in amount along the earlier and higher beaches, and diminishing almost to horizontality in the latest and lowest. Comparing the heights of the beaches at or near the mouth of the lake with their heights about 300 miles to the north, on the latitude of Gladstone, which is near the northern limit of my observations, it is seen that the epeirogenic uplifting of this part of the lake basin, increasing gradually from south to north, and the fall of the lake surface, also greatest at the north on account of the decreasing effect of gravitation toward the diminishing and receding ice-sheet, were together approximately 265 feet in this distance, averaging nearly 1 foot per mile, after the formation of the second Herman beach, which is the highest found on that latitude. Of this combined uplift of the land and fall of the lake, about 80 feet had taken place before the formation of the Norcross beach; 50 feet more before the upper Tintah beach; about 45 feet more before the Campbell beach; and again some 25 feet more before the McCauleyville beach; leaving only 65 feet of the whole 265 feet of changed level to take place after the lake began to outflow northeastward, and it appears that all but about 20 feet of this remaining change had been accomplished before the formation of the lowest or Niverville beach. While the ice was departing from the country and still was the barrier of the lake, this part of its basin was uplifted nearly to its

[1] Since this paragraph was written the explorations of Mr. J. B. Tyrrell in the region from Lake Athabasca northeast to the Chesterfield Inlet of Hudson Bay (Geol. Magazine, IV, Vol. I, pp. 394–399, Sept., 1894) have given much support to this opinion. See also Professor Chamberlin's map of the North American ice-sheet, with indications of its centers and currents of outflow, in J. Geikie's Great Ice Age, third ed., 1894, Pl. XIV.

present altitude, and the total amount of the differential elevation in this extent of 300 miles, after subtracting a quarter part for the probable or possible effect of ice attraction, was about 200 feet.

Alternate stages of elevation and rest.—The considerable number of definite additional shore-lines observed in proceeding to the north indicates, like the stages of erosion by the River Warren between the times of formation of the beaches near Lake Traverse, that there were periods of comparatively rapid uplifting which alternated with others of repose or of very slow progress of the general epeirogenic movement. Vertical uplifts of 10 to 20 or 25 feet were many times repeated, and were separated by longer intervals of rest. But the initiation of these stages of uplift was delayed until long after Lake Agassiz began to exist. The ice-sheet had retreated from Lake Traverse to Manitoba, and three or four conspicuous moraines of recession had been formed, while the lake level reposed undisturbed during the formation of the first and highest beach of the Herman series and the accumulation of the contemporaneous deltas. Such tardiness in the beginning of the elevation of this area, as it is recorded by the inclined shore-lines, implies, and, indeed, makes it almost certain, that very little uplifting, if any, had taken place during the time of melting away of the ice above. If the restoration of the land to its wonted height had already begun under the thinned edge of the ice, it would probably have gone forward more promptly, while the Red River Valley was being gradually occupied by Lake Agassiz, following upon the retreat of the ice-front.

Later and greater inclination of beaches along the base of Riding and Duck mountains.—On the area of 300 miles extent from south to north between the mouth of the lake and Gladstone, the epeirogenic differential uplift was mostly done before the times of formation of the Campbell and McCauleyville beaches, the last two belonging to the southward outlet; but farther to the north, within the area at the base of the escarpment of Riding and Duck mountains, where Mr. Tyrrell has mapped the beaches of this lake and determined their heights, a very important differential elevation, amounting to about 3 feet per mile along a distance of 50 miles between Valley and Duck rivers—that is, between latitudes 51° 15′ and 52° north—took place after the Campbell and McCauleyville beaches were formed, since they are thus remarkably changed from their original horizontality. It is clearly shown here that the uplifting was not uniformly proportionate and regular for the whole area of Lake Agassiz. The chief movements of elevation of its southern and central part, as far to the north as Gladstone, seem not to have extended farther, at least in their full proportion. The district next to the north along an extent of 120 miles to Pine, Duck, and Swan rivers, at the north end of Duck Mountain, was perhaps only so far disturbed by these movements as was necessitated to connect the rise of the country on the latitude of Gladstone with the continuing condition of maximum subsidence on the latitude of the lower part of the Saskatchewan and the north end of Lake Winnipeg. But there ensued in this district, after the date of the Campbell beach, a great differential elevation, giving to these late shore-lines two to three times more northward ascent than that of the Herman beach from Lake Traverse to Gladstone; and the total change in level of the highest observed beach, probably representing the upper Norcross stage, situated at Pine River, on latitude 51° 50′ to 52° north, is approximately 400 feet as compared with this shore-line at Lake Traverse, about 420 miles distant to the south. Nearly the whole uplift of the northern part of the basin was accomplished, however, while the ice-sheet was still a barrier of the lake, for the Niverville beach at the Grand Rapids of the Saskatchewan is only slightly higher than on the Red River, 250 miles to the south.

Review of the epeirogenic uplifting.—After the recession of the ice from its vicinity, the mouth of Lake Agassiz by the River Warren was uplifted apparently at least 50 or 75 feet, and perhaps as much as 90 feet, by several small stages of elevation, separated by comparatively long pauses. Thence to the latitude of Gladstone, in a distance of 300 miles northward, such small uplifts, increasing in number and in aggregate vertical amount from south to north, raised the lake basin in southern Manitoba not less than 200 feet; and, in combination with the fall of the lake level northward, due to decreasing ice attraction, the change in level was 265 feet. To these figures we must add the uplift of the Lake Traverse region, which was probably between 50 and 100 feet, to obtain the total epeirogenic elevation at Gladstone. Later epeirogenic movements of the same kind raised a more northern part of the basin, on the latitude of 52° north, about 400 feet, if we neglect the fall of the lake level, in comparison with Lake Traverse. At the same time, or possibly still later, the northern end of the area of Lake Agassiz and the adjoining portion of the Churchill basin were uplifted a similar amount. Last of all, when Lake Winnipeg and the Nelson River had come into existence, the shores of Hudson and James bays were raised 300 to 500 feet from their temporary postglacial marine submergence.

The elevation of the eastern shore-lines of Lake Agassiz, in Minnesota, exceeded that of the western shores, in North Dakota; and the ratio of this eastward ascent of the old lake levels to their doubly greater northward ascent implies that the tilting of this area was from south-southwest to north-northeast. Again, at the north end of Duck Mountain, the west-to-east portions of beaches observed by Mr. Tyrrell, between the Swan and Duck rivers, show a similar eastward ascent, about half as much as the northward rise along the eastern base of this highland. It thus appears true of the greater tilting of that northern district also, after the formation of the Campbell beach, that its maximum ascent was toward the north-northeast; but, like the elevation between Lake Traverse and Gladstone, this movement was doubtless of limited extent, so that the country adjoining Hudson Bay retained nearly or quite its maximum depression until the somewhat later time when the sea was admitted to that basin.

MOLLUSCAN FAUNA OF LAKE AGASSIZ.

Fossils have been found in the deposits of Lake Agassiz at two localities. They are all fresh-water shells of species now living in this district, occurring in beach ridges where excavations have been made to obtain sand for masons' use. The Campbell beach, about 6 miles southwest of Campbell, Minn., at an elevation approximately 985 feet above the sea, has thus yielded shells of *Unio ellipsis* Lea, a common species of the Upper Mississippi region. In the Gladstone beach, a half mile northeast of Gladstone, Manitoba, about 875 feet above the sea and 165 feet above Lake Winnipeg, four species occur in considerable abundance from 2 to 4 feet below the surface, namely, *Unio luteolus* Lamarck, *Sphærium striatinum*

Lam., *Sphærium sulcatum* Lam., and *Gyraulus parvus* Say. These species from both localities were kindly determined by Prof. R. Ellsworth Call, who states that *Unio luteolus* is one of the most widely distributed representatives of the genus, its range being from Lake Winnipeg to Texas, east to New York, and west to Montana. It is generally abundant in Minnesota. Both these species of *Sphærium* are reported by Dr. Dawson from the Lake of the Woods and Pembina River; and the first is the most common species of its genus in Minnesota, while its range northward extends at least to Great Playgreen Lake and York Factory, where it has been collected by Dr. Bell. The Campbell beach was formed in the later part of the time of the lake's southward outflow; and the Gladstone beach belongs to the middle portion of the time of its outflow toward the northeast, its south end being then about 90 miles south of the international boundary.

MEASUREMENTS OF TIME SINCE THE GLACIAL PERIOD.

If the question be asked, How many thousand years ago did the recession of the ice-sheet take place, causing Lake Agassiz to fill the Red River Valley and the basin of Lake Winnipeg? a reply is furnished by the computations of Prof. N. H. Winchell,[1] that approximately eight thousand years have elapsed during the erosion of the postglacial gorge of the Mississippi from Fort Snelling to the Falls of St. Anthony; of Dr. Edmund Andrews,[2] that the erosion of the shores of Lake Michigan, and the resulting accumulation of dune sand drifted to the southern end of that lake, can not have occupied more than seven thousand five hundred years; of Prof. G. Frederick Wright,[3] that streams tributary to Lake Erie have taken a similar length of time to cut their valleys and the gorges below their waterfalls; of Mr. G. K. Gilbert,[4] that the gorge below Niagara Falls has required only seven thousand years or less; and of Prof. B. K. Emerson,[5] on the rate of

[1] Geology of Minnesota, Fifth Annual Report, for 1876; and Final Report, Vol. II, pp. 313–341. Quart. Jour. Geol. Soc., Vol. XXXIV, 1878, pp. 886–801.

[2] Transactions of the Chicago Academy of Sciences, Vol. II. James C. Southall's Epoch of the Mammoth and the Apparition of Man upon the Earth, 1878, Chapters XXII and XXIII.

[3] Am. Jour. Sci. (3), Vol. XXI, pp. 120–123, Feb., 1881; The Ice Age in North America, 1889, Chapter XX.

[4] Proc. A. A. A. S., Vol. XXXV, for 1886, p. 222. "The History of the Niagara River," Sixth An. Rep. of Commissioners of the State Reservation at Niagara, for 1889, pp. 61–84.

[5] Am. Jour. Sci. (3), Vol. XXXIV, pp. 404, 405, Nov., 1887.

deposition of modified drift in the Connecticut Valley at Northampton. Mass., from which he believes that not more than ten thousand years have elapsed since the Ice age.

Making such inquiry also concerning the glaciation of Europe, we find that in Wales and in Yorkshire, England, the amount of denudation of limestone rocks on which bowlders lie has been regarded by Mr. D. Mackintosh as proof that a period of not more than six thousand years has elapsed since the bowlders were left in their positions.[1] The vertical extent of this denudation, averaging about 6 inches, is nearly the same with that observed in the southwest part of the Province of Quebec by Sir William Logan and Dr. Robert Bell, where veins of quartz marked with glacial striæ stand out to various heights not exceeding 1 foot above the weathered surface of the inclosing limestone.[2]

Another indication that the final melting of the ice-sheet upon British America was separated by only a very short interval, geologically speaking, from the present time is seen in the wonderfully perfect preservation of the glacial striation and polishing on the surfaces of the more enduring rocks. Of their character in one noteworthy district Dr. Bell writes as follows: "On Portland promontory, on the east coast of Hudson's Bay, in latitude 58°, and southward, the high, rocky hills are completely glaciated and bare. The striæ are as fresh-looking as if the ice had left them only yesterday. When the sun bursts upon these hills after they have been wet by the rain, they glitter and shine like the tinned roofs of the city of Montreal."[3] Again, Professor Macoun writes of the red Laurentian gneiss in the vicinity of Fort Chipewyan, at the west end of Lake Athabasca: "The rocks around the fort are all smoothed and polished by ice action. When the sun shines they glisten like so much glass, and a person walking upon them is in constant danger of falling."[4] It seems impossible that these rock exposures can have so well withstood weathering in the severe climate of those northern regions longer than a few thousand years at the

[1] Quart. Jour. Geol. Soc., Vol. XXXIX, 1883, in Proceedings, pp. 67–69. Compare id., Vol. XLII, 1886, pp. 527–539.

[2] Bulletin, G. S. A., Vol. I, 1889, p. 306.

[3] Bulletin, G. S. A., Vol. I, p. 308.

[4] Geol. Survey of Canada, Report of Progress, 1875–76, p. 90.

most; and they even suggest that remnants of the continental ice-sheet may have lingered there considerably later than the time, computed to be six to eight thousand years ago, when its southern portion retreated.

SHORT DURATION OF LAKE AGASSIZ.

The foregoing measures of time, surprisingly short, whether we compare them on the one hand with the period of authentic human history or on the other with the long record of geology, carry us back to the date when the ice-sheet was melting away from the basins of the Upper Mississippi, of the Red River of the North, and of the Laurentian lakes. If the postglacial epoch has been so short, we must infer that the final recession of the ice was very rapid and that its barrier between the Red River Valley and Hudson Bay was soon melted away. Though Lake Agassiz attained vast areal extent, its duration or extent in time was geologically brief, as is shown by the small volume of its beach deposits and lacustrine sediments in comparison with the Pleistocene lakes of the Great Basin and with the amount of postglacial erosion and deposition on the shores of the great lakes tributary to the St. Lawrence and Nelson rivers. The geologic suddenness of the final melting of the ice-sheet, proved by the brevity of existence of its attendant glacial lakes, presents scarcely less difficulty for explanation of its causes and climatic conditions than the earlier changes from mild or warm preglacial conditions to prolonged cold and ice accumulation.

Comparison with postglacial lakes.—The disappearance of the greater part of the vast North American ice-sheet probably occupied not more than two or three thousand years; and half of this time may measure the duration of Lake Agassiz, with the formation of its beaches marking more than thirty successive stages in the concurrent subsidence of its surface and rise of the earth's crust. But even these short estimates may be too long. The shores of Lake Michigan, similar with those of Lake Agassiz, in the drift of which they are formed, in their north and south trends, and in the adjoining depths of water, have suffered an amount of erosion by the lake waves during postglacial time which very far exceeds the total erosion that was effected upon the shores of Lake Agassiz during all its stages, the proportion between them being surely not less than ten to one; and Lake Michigan has a similarly greater amount of beach deposits, which upon a large area about its south end are raised by the wind in conspicuous dunes. This contrast, indeed, suggests that the duration of Lake Agassiz and the recession of the ice-sheet from Lake Traverse to the lower part of the Nelson River may have been included within less than one thousand years.

Likewise, as Mr. Tyrrell remarks, beach ridges of larger size tnan those of Lake Agassiz, and composed of coarser shingle, occur on each of the three great lakes of Manitoba, although these lakes are far smaller than their glacial predecessor and therefore surely have less powerful waves.

Comparison with Lakes Bonneville and Lahontan.—During the first high stage of Lake Bonneville, a fine, laminated, olive-gray clay, which weathers to a pale-yellow color, was spread throughout all the lower parts of its basin, ascending also in the shallower bays toward the upper shore-lines. In two typical deep sections this member of the lacustrine sediments has an exposed thickness, respectively, of 90 and 100 feet, but its base is not seen. Again, during the second rise of this lake it deposited a similarly widespread stratum of light-gray or cream-colored marl or calcareous clay, weathering nearly white, and passing upward into a fine sand; and typical sections show that this marl and associated sand range from 20 to 50 feet or more in thickness. In like manner, Lake Lahontan during its two high-water periods deposited over all its bed fine marly clays, which in the earlier flood stage attained a thickness of more than 100 feet, their base not being exposed by the deepest sections, and in the later stage an average of 50 to 75 feet. These thick sediments occupying the basins of the Pleistocene lakes of Utah and Nevada indicate, like their great amount of shore erosion and correspondingly massive beach deposits, that the term of existence of these lakes during each of their high stages, and especially the first, far exceeded that of Lake Agassiz. No such lacustrine beds are generally spread over the basin of this glacial lake, which upon large tracts, even of its lower portion, as on and near the Red River, near the lower Assiniboine between Poplar Point and Winnipeg, and adjacent to Lake Manitoba, Shoal Lake, and Lake Winnipeg, consists of till, with frequent bowlders, the direct product of the ice-sheet, very slightly changed by its deposition in the lake, and not covered by any aqueous sediments.

Only where tributaries entered this lake and brought, besides the ordinary alluvium of their erosion, a much larger volume of modified drift from the melting ice-sheet, were any important lacustrine sediments laid down; and these appear in the form of extensive deltas of gravel and sand, with fine silt spread over adjoining parts of the lake bottom. Other inflowing streams, though in several instances important rivers, as the Red River itself above Fergus Falls, the Wild Rice River of Minnesota, and the Red Lake River, formed no noteworthy delta accumulations, which, however, could not have failed to be conspicuously developed if the lake had long remained at any of the levels of its many successive shore-lines. The sediments in Lakes Bonneville and Lahontan were evidently derived in large part from wave erosion of their shores; but in the case of Lake Agassiz, though its shores are the easily eroded drift, no appreciable lacustrine beds were supplied from this source. The duration of Lake Agassiz was very short in comparison with either of the Pleistocene humid epochs of the Great Basin and Cordilleran mountain belt.

Brevity of time required for the formation of terminal moraines.—The shortness of the existence of Lake Agassiz seems, at first thought, to present a difficulty in the brevity of the time which would be allowed, if the glacial lake endured only a thousand years or less, for the accumulation of the moraines described in the preceding chapter. By the probable ratios of time deduced from the extent of the upper Herman beach and the sequence of all the lower and later beaches, we see that the formation of even the great moraines of the Leaf Hills and of the south side of Devils Lake could have occupied only a small fraction of the whole duration of Lake Agassiz, perhaps not more than fifty or even twenty-five years for amassing these morainic hills 100 to 350 feet high on a belt 3 to 5 miles wide! For the Dovre, Fergus Falls, Leaf Hills, and Itasca moraines were apparently formed before the completion of the highest one in the series of four principal beaches which unite in the Herman beach along the southern 75 miles of Lake Agassiz. But this may be easily accepted when we recall the rapidity of motion of the thick and wide glaciers of Greenland and

Alaska, 30 to 100 feet per day.[1] Doubtless the continental ice-sheet moved faster than the glaciers of the Alps, but the waste from its border by melting must evidently have been less than the discharge of ice from these Arctic glaciers where they terminate in the sea and are broken into bergs and floated away.

The two factors on which the accumulation of the terminal moraines depends are the rate of motion of the ice-sheet and the amount of the englacial drift which was thus brought forward to its margin. In the region of Lakes Benton, Shaokatan, and Hendricks, in southwestern Minnesota, we have evidence that the drift contained within the ice amounted to a sheet at least 40 feet thick.[2] As great volume of englacial drift is also indicated in Manitoba by the relation of the Birds Hill esker to the adjoining sheet of till.[3] The inequalities in the aggregate mass of the drift forming different portions of the morainic belts, causing these to rise in great prominence upon some areas, while in other places they are low and scanty, seem due to unequal distribution of this drift within the basal part of the ice-sheet.[4] It was most abundant in those portions where glacial currents had converged between the great lobes of the ice border during the time of maximum area of this ice-sheet, as from the vicinity of Minneapolis and Lake Minnetonka northwestward to the Leaf Hills, to Lake Itasca, and to Birds Hill, and in the country west and northwest of Cooperstown, N. Dak., to the Washington Lakes, Devils Lake, the Big Butte, Broken Bone Lake, and to Turtle Mountain. Upon these areas the morainic belts show a close relationship, not only by their parallelism and the similar positions of

[1] Helland, in Quart. Jour. Geol. Soc., Vol. XXXIII, 1877, p. 149. Nature, Dec. 29, 1887. Prestwich's Geology, Vol. II, 1888, pp. 530–533. Prof. G. F. Wright, on the Muir Glacier, Am. Jour. Sci. (3), Vol. XXXIII, pp. 1–18, Jan., 1887, and Ice Age in North America, Chapter III. The daily motion of the central portion of the Muir glacier in 1886 was reported by Professor Wright, according to a series of measurements, to be from 40 to 70 feet; but in 1890, when the front of this glacier had fallen back a half mile to two-thirds of a mile from its place four years earlier, more reliable measurements of its motion by H. F. Reid (National Geographic Magazine, Vol. IV, pp. 19–84) and H. P. Cushing (Am. Geologist, Vol. VIII, pp. 207–230) show a maximum of only about 7 feet per day. In 1886 the ice front projected into the Muir Inlet as a promontory, but in 1890 it was nearly straight. At each date the length of the ice front was almost 2 miles and its height about 250 feet above the water of the inlet, which is 600 feet deep. See a discussion of "Recent changes in the Muir glacier," by S. Prentiss Baldwin, Am. Geologist, Vol. XI, pp. 366–375, June, 1893.

[2] Geology of Minnesota, Ninth Annual Report, for 1880, pp. 322–326; Final Report, Vol. I, 1884, pp. 603, 604.

[3] Chapter IV, pp. 183–187.

[4] Bulletin, G. S. A., Vol. III, 1892, pp. 134–148; id., Vol. V, 1894, pp. 71–86. Am. Geologist, Vol. VIII, pp. 376–385, Dec., 1891; id., Vol. XII, pp. 36–43, July, 1893.

reentrant angles of the ice border through several stages in its retreat, but also by remarkably massive accumulations of drift in corresponding portions of the successive moraines. If the average amount of englacial drift thus supplied by the ice-sheet where its moraines are largest was equal to a thickness of 40 feet, or even 20 or 10 feet, it will be seen that these moraines would require, with a steep frontal gradient of the ice due to the marginal melting and a consequent rate of glacial motion probably several times faster than that of the Alpine glaciers, only a few decades of years for their formation.

ALTERNATIVE INTERPRETATIONS.

By T. C. Chamberlin.

It would be remarkable indeed if in a discussion touching so many vital phases of glacial history there should not arise some points on which coworkers entertain different interpretations, even though their fundamental views be in close harmony. In consideration of the partial responsibility for this report resting upon the writer of this note, by reason of his official relations to the investigation upon which it is based, Mr. Upham has generously urged that a statement of such of our differences of interpretation as may be thought worthy of note be inserted in the text. The suggestions here offered in response to this are made with the full recognition of the fact that the investigator who has made a special study of the region is far more likely to have reached the correct interpretation than one less intimately familiar with all the facts. Nevertheless, alternative hypotheses may be worthy of statement.

Mr. Upham's interpretation of the history of Lake Agassiz is based upon the belief that all its deposits fall within that epoch near the close of the Glacial period during which the earth's crust was either stationary or differentially rising at the north. In harmony with this belief, the uppermost or Herman beach is thought to represent the outline of the lake during the entire period occupied by the ice in its retreat from the Dovre moraine, lying close north of Lake Traverse, to the line of the Mesabi moraine, which crosses northern Minnesota and Manitoba. This retreat of the ice involved, as is fully stated, the formation of a series of three prominent terminal moraines, which represent either halts or readvances of the ice front. The Herman beach overrides these moraines as they come down into the borders of the lake basin. This clearly indicates that the completion of the beach formation was subsequent to that of the moraines. But Mr. Upham thinks that the beach was in process of formation throughout the whole period occupied by the successive formation of the several moraines and the intervening retreats of the ice. The descriptions of the beach, however, clearly indicate that it is not very massive and is unaccompanied by any very considerable erosion. It furthermore appears that the southern portion is not very notably stronger than the northern portion, and there is little inherent evidence that it is notably older. The natural, if not necessary, inference from these facts, under the hypothesis of Mr. Upham, is that the period occupied by the retreat of the ice and the formation of the moraines was short, and his inferences with reference to the mode of the formation of the moraines take forms in harmony with this conviction. These interpretations embrace some of the most radical phases of glacial action, and hence the correctness of the conception that the rather slender Herman beach represents the whole time occupied by the formation of the several moraines and the intervening retreats of the ice front becomes a subject of the highest importance.

The present writer ventures to suggest that the whole history of Lake Agassiz may not have fallen within the period of stationary or rising crustal movement, but that the early part of it may have taken place during the latter portion of the period within which the crust was being depressed. There is no difference of view respecting the former higher elevation of the crust and a following depression, which was in turn followed by an elevation. The only question is whether the history of Lake Agassiz fell wholly within the stationary and rising stages, or partly within the falling stage. If the early part of the lake's history occurred while the crust was sinking, the lake would be constantly expanding its borders, and hence its beach-lines would be progressively buried by the advancing waters. In this way it may be supposed that shore-lines contemporaneous with the several moraines and with the stages represented by the inter-morainic till sheets were formed, but were obliterated or buried by the advancing waters. It may be further supposed that this advance continued until after all the adjacent moraines in Minnesota and North Dakota were formed, and that it reached its maximum some little time later; and this may perhaps find some support in the crustal movements of the Atlantic border regions. In this way it is easy to understand how the uppermost or Herman beach might have essentially the same strength in all parts of its length of about 250 miles from south to north, and might ride over the several moraines with seeming impartiality and without notable variation in character. This hypothesis also relieves the interpretation of the necessity of supposing that the retreat of the ice and the formation of the moraines was especially rapid. It has the advantage of not being burdened with any hypothesis at all regarding the rapidity or slowness of the formation of the moraines, nor with any of the hypotheses necessary to account for the extraordinary rapidity of morainic formation and glacial retreat which are postulated in the foregoing pages.

Mr. Upham urges against this hypothesis the formation of the rather large sand deltas around the border of the lake, which he thinks were deposited contemporaneously with the existence of the ice on the adjacent land, for without the presence of the ice in some cases, he urges, the stream which produced the deltas could not have existed. It appears to the present writer, however, that these deltas would have been formed in very nearly the same way under either hypothesis. The chief difference between the two hypotheses, so far as deltas are concerned, would lie in a possible slight variation in the height of the delta surfaces. Under the hypothesis just suggested, the greater part of the material of the deltas must have been deposited when the lake stood somewhat lower than its maximum. The delta summits would not therefore originally have reached to the full height of the uppermost or Herman beach. However, as the shore continued to advance, the streams would have continued to build up these original deltas, and their later deposits, being contemporaneous with the Herman beach, would have brought the deltas up to an accordant elevation, or at least would have tended to do so. An exception to this would perhaps be found in the case of deltas whose rivers became extinct before the lake reached its maximum height, accepting the evidence that there was at least one such. In this case the summit of the delta would doubtless be somewhat lower than it would have been if its formation had been continued until the Herman beach was raised. But even in this case the shore drift and the wind action that followed would modify the original form and altitude of the delta, possibly to an extent sufficient to obscure such limited differences as might distinguish the two hypotheses. It does not seem, therefore, to the present writer that an argument of a demonstrative nature can be based upon the deltas, because its validity must rest upon the rather elusive differences in the heights of the deltas, since it does not appear that it can rest upon the mere existence of the deltas. Indeed, so far as the magnitude of the deltas is concerned, that hypothesis which postulates the greater length of time in the formation of the surrounding glacial drift is the more favorable to large deltas, especially to large deltas of sand as distinguished from deltas of coarser material that would be the normal result of exceptionally rapid melting.

The present writer does not agree with Mr. Upham in regard to a high rate of glacial movement, although he formerly entertained much the same view. A high rate of motion enters into the interpretation of the phenomena under consideration as a factor in the explanation of the supposed rapid production of the till under Mr. Upham's interpretation. If the alternative interpretation be adopted, it is relatively immaterial what rate of motion prevailed.

It is to be observed that a rapid movement of the ice is antagonistic to a rapid retreat, because the two are directly opposed to each other. With given conditions of wastage the slower the ice movement the more rapid the retreat. A rapid motion, however, would probably be helpful in the rapid production and transportation of glacial débris, and so it might shorten the time required to form the till sheets and the moraines.

In respect to the evidence drawn from existing Alaskan glaciers in support of rapid motion, the present writer regards the measurement first cited, assigning a rate of 70 feet per day, as untrustworthy. The later measurement, by Dr. Reid, giving a rate of 7 feet per day, is believed to be entitled to confidence, but even this rate is a maximum. The average of the measured portions of the glacier is much less than 7 feet per day, and certain unmeasured lateral lobes are nearly stagnant. It is further to be observed that the Muir glacier is a trunk stream, the joint product of the ice streams draining a large area. Moreover, these descend from mountain heights. They are therefore radically different from ice-sheets which spread out in all directions on plains or plateaus.

The evidence cited from Greenland is selective and exceptional; indeed, selective and exceptional evidence is about the only class that can be cited from Greenland. No average measurements, nor anything approaching to average measurements, have been made. The high rates of movement of the Jacobshaven glacier, as given by Helland, and of the Great Karaiak glacier, as given by Drygalski, and other similar measurements, are not at all questioned, but these are quite exceptional, and almost as far as possible from being representative. They exhibit extraordinary movements through deep, constricted straits, where the ice is forced by the vast accumulations of great areas in the rear, and where the warm season appears to exert its earliest and greatest effects. The amounts of ice discharged in the form of bergs from these two glaciers is very much greater than from any other known points on the ice front of Greenland. It is perfectly obvious that the average border of the Greenland ice-sheet does not move at a rate even distantly approximating that of these two straits. If it did so, the whole coast of Greenland must be overwhelmed almost immediately, because the competency of the summer heat of that region to hold back the edge of the ice by melting is very slight. Drygalski estimated the annual surface melting at 7 feet. Even this is much greater than the annual surface melting of the Inglefield Gulf region, judged by that of 1894. While estimates are few, and even these may need much qualification, it is nevertheless certain that the average movement of that portion of the border of the Greenland ice-cap which lies upon the land is extremely small. Of that portion which ends in the sea only a small fraction has a high rate of motion, as is shown by the lack of activity in the discharge of icebergs. When it is considered that the land border is very much greater than the sea border, and that of the sea border a portion has a relatively slow movement, it will be evident that the average rate of movement for the border of the great ice-sheet of Greenland can not be high; and the average rate of this border is the nearest available analogue to the border movement of the still more extended periphery of the ancient American or Laurentian glacier.

The present writer also differs with Mr. Upham in his views respecting the amount and distribution of the englacial drift. That considerable débris is borne in the basal portion of the ice is not questioned; indeed, the term "englacial drift" was proposed by the present writer in recognition of its importance. Our best evidence of the amount and distribution of this is derived from the continental glacier of Greenland. It is there observed that débris prevails in the lower 50 or 75 feet of the ice-sheet, and occasionally reaches up to 100 feet, or perhaps even 150 feet. The amount of this débris, if it were let down directly upon the glacier's bottom by melting in situ, without concentration by the forward motion of the ice, would be measured by a very few feet, or by a fraction of a foot. The forward motion of the ice concentrates this at its edge, so that it may there reach, theoretically, any dimension, entirely without regard to its amount in any given vertical section of the ice. The thickness of the deposit formed from the englacial drift is quite as much dependent upon the length of time during which the edge of the ice remains at one line as upon the amount of drift which the ice may carry in any given vertical section. No safe inferences from the thickness of deposits of englacial drift can therefore be drawn with reference to the amount of englacial material present in any given portion of the glacier. If the ice were absolutely stagnant the deposit of englacial drift would be precisely that which was held in the ice above the point of deposit. If there was any forward motion of the ice while it was being melted away, there would necessarily be a concentration. If there be 1 foot of englacial débris in a given section, and the ice moves forward 40 feet while the external heat causes a retreat of 1 foot, the englacial deposit should be 40 feet deep. The thickness of the englacial drift may therefore be quite as much an expression of prolonged time as of a large content of débris within the ice.

The present writer differs with Mr. Upham also in his conception of the way in which the englacial débris becomes at length exposed and deposited. Instead of rising toward the surface of the glacier, it is believed, on the basis of observations in Greenland, to pursue a course nearly parallel with the base, on the whole, and to come out at the extremity of the glacier. To some slight extent it may become superglacial by ablation, but only to a limited degree. Consonant with this conception, it is believed that eskers and similar formations of gravel are essentially subglacial or marginal.

These fundamental considerations add to the difficulty which the present writer experiences in accepting the idea of the contemporaneity of the Herman beach with the formation of so many important moraines and of such massive sheets of till, together with so great a retreat of the ice margin. This difficulty is enhanced by a comparison of the uppermost beach with the lower ones, which are correlated with much less important glacial action, and yet do not seem to be correspondingly inferior in magnitude.

The difficulty is somewhat relieved by the probability that while the lake was glacier-bound on the north the surface was covered throughout a large part of the year with ice, and during the rest by bergs and berglets, and that, as a consequence, wind action was reduced to a minimum. This may possibly be the line of solution of the problem. Mr. Upham, however, finds but limited evidence of berg deposits. These need not be great if the englacial débris was of small amount; but if it was large the protection of the lake surface from wave action by bergs should find expression in very considerable berg deposits.

A further difficulty is presented by the slightness of the cutting down of the outlet during the period of the Herman beach. If, however, the alternative hypothesis is adopted, the trench of 40 or 50 feet existing in the drift plain previous to the formation of the Herman beach should perhaps be regarded as the work of the outlet during the earlier part of the glacial retreat, instead of being referred to preglacial or interglacial, or at least preretreatal, times. The work done by the outlet and by the ice would be thus brought more nearly into harmony.

In respect to the lowering of the outlet of Lake Agassiz by stages, instead of steady progress, which has been previously discussed, it appears to me worthy of suggestion that the rhythmical action may be due to a rhythmical factor inherent in the mode of degradation of the river valley below the outlet. Whenever the bed of a river is formed of material of unequal resistance, it is scarcely possible for it to sink its channel by a uniform downward cutting. If the bed is formed of horizontal strata, and these have different degrees of resistance, it is almost inevitable that the stream shall develop an alternation of levels and falls, expressing themselves by a succession of slack water and rapids, as is well known. Considered as a mode of excavation, the process is what miners would call "stoping." When one of the stopes, in working up the river, reaches any reservoir or lake that may lie in its course, it promptly lowers it to an amount corresponding to the depth of the stope. If the bed of the river lies upon drift, essentially the same mode is followed, but with some variation in detail. The resistant factor in this case consists of transverse barriers, such as may be formed by bowlder belts, heavy masses of till, aggregates of coarse gravel, and similar inequalities of the deposit. These arrest the down-cutting of the stream for a time and form rapids on their lower sides. These rapids work away at the barrier in stope fashion. Meanwhile the stretch of river above removes the less resisting material of its bottom down to a gradation plane or to an actual base-level with reference to the barrier. This brings about essentially the same condition of alternating slack water and rapids that arises in connection with horizontal strata. When the barrier is cut through, erosion works rapidly up stream through the soft material, and if a lake lies in its course there will follow a sudden lowering. It is not in the nature of the case that a lake drained by a long river flowing over horizontal beds or over drift should be lowered uniformly. It does not seem necessary, therefore, to appeal to a series of sudden accelerations and halts in a movement of the crust to account for the rhythmical drainage of Lake Agassiz and of the many other lakes that exhibit like phenomena, unless there is independent evidence of such movements.

T. C. Chamberlin.

VOLUME OF WATER RECEIVED AND DISCHARGED BY LAKE AGASSIZ.

The present yearly discharge of water by the Nelson River is probably equal to a depth of 10 to 15 inches upon its entire basin, which is approximately the same area that sent its drainage into Lake Agassiz and through the River Warren and the later outlets of this lake to the sea. A half or larger part of the yearly rainfall and snowfall on this basin is returned to the air by evaporation, leaving the volume stated to be carried into Hudson Bay by the river. Through a few weeks in the spring the rapid snow melting and accompanying rains raise all the streams and lakes which are the feeders of the Nelson to their flood stage; and, in contrast, many of the watercourses are dry in summer, autumn, and winter, and the whole river system is reduced to a small fraction of its previous maximum.

But when the ice-sheet was being melted away and Lake Agassiz received its drainage, the volume of water annually discharged from this area was far greater than now. Considering first the rainfall and snowfall of that time, we must doubtless suppose that they somewhat exceeded their present amount, while the evaporation was less. It may be estimated, therefore, that the water thus received and discharged by Lake Agassiz each year was equivalent to a uniform depth of 20 or 30 inches over all its hydrographic basin.

A still larger tribute was derived from the glacial melting, which in a thousand years, more or less, dissolved from this area the greater part of an ice-sheet 2,000 to 6,000 or 8,000 feet thick. The average yearly melting would therefore be equivalent to an added depth of 3 or 4 feet of water, or 36 to 48 inches, making, with the supply from precipitation, approximately 5 to 7 feet upon all the basin.

It thus appears that the inflow and outflow of Lake Agassiz were five to eight times more than those of Lake Winnipeg. Instead of a flood discharge during a few weeks in spring, the rapid ice-melting undoubtedly maintained continuously through the warm half of the year a larger outflow from Lake Agassiz than the spring stage of the Nelson River; but during winters, when the glacial melting stopped, the discharge from the glacial lake, excepting the part due to the capacity of the lake as a reservoir, was comparatively small. In the winter Lake Agassiz, becoming at times mostly frozen over, like the present great Laurentian lakes, would be drawn down to a level several feet below its summer height, and the great outflowing river, as it was during the warm weather, would become reduced to a stream resembling the lowest stage of the Nelson.

FLUVIAL DEPOSITS IN THE RED RIVER VALLEY.

When the bed of Lake Agassiz was gradually uncovered from the water of the receding lake, some parts of its central plain, through which the Red River flows, probably remained as broad, shallow basins of water, which that river and its tributaries have since filled with their fine clayey alluvium. The similar clayey silt brought into Lake Agassiz by its delta-forming affluents, the Buffalo, Sand Hill, Sheyenne, Pembina, and Assiniboine rivers, and others farther north, had been spread over large areas of the lake-bed, but more extensive portions had a surface of till, with no such lacustrine deposit. Over these formations much alluvium has been laid down along all the avenues of drainage of the old lake-bed, and it has filled depressions of the original surface, whether of lacustrine sediments or of till, being distinguishable from the former only by its containing in some places shells like those now living in the shallow lakes of the country adjoining the area of Lake Agassiz, remains of rushes and sedges and peaty deposits, as of the present marshes of the Red River Valley, and occasional branches and logs of wood, such as are floated down by streams in their stages of flood. Thus the occurrence of shells, rushes, and sedges in these alluvial beds at McCauleyville, Minn., 32 and 45 feet below the surface, or about 7 and 20 feet below the level of the Red River, of sheets of turf, many fragments of decaying wood, and a log a foot in diameter at Glyndon, Minn., 13 to 35 feet below the surface, and numerous other observations of vegetation elsewhere along the Red River Valley in these beds, demonstrate that Lake Agassiz had been drained away, and that the valley was a land surface subject to overflow by the river at its stages of flood, when these remains were deposited.[1] Even at the present time much of the area of stratified clay that almost continuously forms the central part of the valley plain is covered by the highest floods, and probably no portion of it is more than 10 feet above the high-water line of the Red River and its tributaries. The position of the thick beds of fine silt and clay in the central depression of the Red River Valley shows that they were not mainly deposited by the waters of Lake Agassiz, which must have spread them somewhat equally over both the lower and higher parts of the lacustrine area, but instead appears to prove that at least their upper and greater part was brought by the rivers which flowed into this hollow and along it northward after the glacial lake was withdrawn.

ASSOCIATED GLACIAL LAKES.

The review of the history of Lake Agassiz will be completed by bringing into comparison with it the contemporaneous formation of great glacial lakes on the northern borders of the United States and the adjoining southern edge of Canada, and in its northwestern interior, from the city of Quebec on the east to the elbows of the South and North Saskatchewan rivers and to the head streams of the Mackenzie on the west. The glacially dammed Laurentian lakes, and a very large extension of Lake Ontario or Iroquois, and the later glacial Lake St. Lawrence, east to Quebec, northwest in the Ottawa Valley, and south in the basin of Lake Champlain and the Hudson Valley, were quite probably, as before noticed, portions of the avenues of outflow from Lake Agassiz after it had fallen below the Lake Traverse outlet and before Hudson and James bays were so far uncovered from the ice-sheet as to be occupied by the sea and receive the northeastward outflow of the Winnipeg and Saskatchewan basin. In Minnesota and South and North Dakota prophecies of Lake Agassiz had been given by the earlier glacial lake of the area now drained by the Blue Earth and Minnesota rivers, which may be named Lake Minnesota, and by a long and narrow contemporaneous lake in the James River Valley, which Prof. J. E. Todd

[1] Geology of Minnesota, Vol. II, pp. 529, 530, 663, 664, 668, and 669. See notes of wells, Chapter X, in McCauleyville, Wilkin County; Glyndon, Clay County; and Andover, Polk County, Minn.; and in Johnstown, Grand Forks County, and near Grafton, Walsh County, N. Dak.

has explored and named Lake Dakota. Farther to the northwest the glacial Lakes Souris and Saskatchewan were tributary to Lake Agassiz, and had a most interesting history in their changes of outlets and relationship to the Sheyenne, Pembina, and Assiniboine deltas of this lake. Pl. III, in Chapter I, shows on a small scale the position and extent of the glacial Lakes Minnesota, Dakota, Souris, and Saskatchewan, with their relationship to Lake Agassiz.

Even beyond the present continental watershed which divides the tributaries of Hudson Bay from those of the Arctic Ocean, glacial lakes covering large areas now drained to the Mackenzie flowed into Lake Agassiz, and portions of the courses of their outlets have been discovered. The recession of the ice-sheet upon all the country from Quebec to the Peace River pent up vast lakes in front of its steep and high barrier, until the present lines of drainage along the slopes of the land were opened and the Glacial and Champlain epochs were ended.

THE LAURENTIAN LAKES.

This term, which is a synonym for the five great lakes, Superior, Huron, with Georgian Bay, Michigan, Erie, and Ontario, outflowing by the River St. Lawrence, may also include the smaller Lake Champlain, tributary to the St. Lawrence by the River Sorel or Richelieu. During the earlier stages of the glacial recession many small lakes were formed along the northern side of the great watershed that separates the Mississippi, Ohio, Susquehanna, Delaware, Hudson, and Connecticut rivers from the St. Lawrence, with outflows to the south across each principal depression in the southern rim of the St. Lawrence basin. But at length, as the ice further retreated, these became merged into a few large glacial lakes, the precursors of the present great lakes of our northern frontier. Finally there existed in succession two of these bodies of water, each much larger than Lake Superior, but smaller than Lake Agassiz, which more especially claim attention. They have been named by Prof. J. W. Spencer Lake Warren and Lake Iroquois.[1]

[1] Proc. A. A. A. S., Vol. XXXVII, for 1888, pp. 197–199. "The Iroquois beach: a chapter in the geological history of Lake Ontario," Trans. Royal Society of Canada, Vol. VII, sec. 4, 1889, pp. 121–134, with map; and "The deformation of Iroquois beach and birth of Lake Ontario," Am. Jour. Sci. (3), Vol. XL, pp. 443–451, Dec., 1890.

From the western part of the basin of Lake Superior a glacial lake outflowed to the Mississippi at the lowest point of the present watershed between the Bois Brulé and St. Croix rivers, in northwestern Wisconsin. The bed of the old outlet is 1,070 feet above the sea, or 468 feet above Lake Superior, and it is bordered by bluffs of drift about 75 feet high, showing that when the course of outflow began here the West Superior glacial lake was approximately 550 feet above the present lake level. The divide in this former watercourse is a swamp, extending several miles in a valley eroded 75 to 100 feet below the adjoining country, the distance between its bluffs being mostly about 1 mile, but in the narrowest place only about 1,000 feet. The highest part of the swamp at the divide is 1,070 feet above the sea, but it has probably been filled 20 or 25 feet since the lake forsook this mouth, which was thus lowered by erosion to 450 feet, approximately, above the present Lake Superior. Springs in the swamp, outflowing partly to the Bois Brulé and partly to the St. Croix, are nearly 60 feet above the long and narrow Upper St. Croix Lake, which is 1,011 feet above the sea. This and the similar but larger Lake St. Croix (low and high water 667 to 687 feet above the sea, with maximum depth of 25 feet at the stage of low water), through which the river of this name flows near its mouth, lie in portions of the glacial river course which have now become dammed at the upper lake by the gravel and sand deposits of tributaries, and at the lower lake by those of the Mississippi, raising the level of the mouth of the St. Croix since the departure of the ice reduced the river to its present size.[1]

Silts referable to the Western Superior glacial lake are found near Superior and Duluth, and its delta deposits and shore-lines are traceable here and there along the northwestern shore of Lake Superior in Minnesota, but it may well be doubted whether they extend into Canadian territory. Before the ice-sheet had retreated so far as to uncover the region about Port Arthur, its departure from Wisconsin and the greater part of Michigan had probably permitted Lake Superior to become confluent with Lake Michigan, thus forming the glacial Lake Warren, with outlet by Chicago to the Des Plaines, Illinois, and Mississippi rivers. Like the beaches

[1] Geology of Minnesota, Vol. II, pp. 642, 643.

of Lake Agassiz, the shores of the Western Superior lake and of Lake Warren show that the departure of the ice was attended by a northward uplift of the land.[1]

Lake Warren was probably contemporaneous with the maximum extension of Lake Agassiz, and it may have continued until that lake began to outflow northeastward. It belonged to stages in the departure of the ice-sheet which appear to have permitted confluent sheets of water to stretch as a single lake from the western end of the basin of Lake Ontario over the whole or the greater part of the four higher Laurentian lakes. During the glacial retreat from Lake Michigan and the western portion of Lake Erie each of these areas had an outlet to the Mississippi, that of Lake Michigan crossing the height of land close west of Chicago, only 12 or 15 feet above the lake and approximately 595 feet above the sea, while the outflow from Lake Erie passed over the lowest point of the watershed between the Maumee and the Wabash, 770 feet above the present sea-level. The departure of the ice from the southern peninsula of Michigan, however, gave to the glacial Lake Erie, with its extension northward over Lake St. Clair and the southern end of Lake Huron, a lower outlet across the watershed of the Shiawassee and Grand rivers, allowing the Western Erie glacial lake to flow into the glacial Lake Michigan or Warren by a pass which is now 729 feet above the sea. Soon after this the further recession of the ice permitted Lake Warren to extend as one level through connecting straits from Lakes Ontario and Erie to Lake Superior, discharging its surplus waters by the Chicago outlet.

Subsequent stages of the glacial recession, uncovering an outlet from the Lake Ontario basin by Rome to the Mohawk and Hudson, and the history of the Niagara River and of the glacial Lake Ontario or Iroquois, have been ably discussed by Gilbert.[2] On a different theory, not recog-

[1] The recent explorations of the ancient elevated shore-lines about Lake Superior and the northern parts of Lakes Michigan and Huron by Dr. A. C. Lawson and Mr. F. B. Taylor, the earlier work by Spencer, Gilbert, and others about Georgian Bay and Lakes Erie and Ontario, and the history of the eight distinct large glacial lakes which successively, and in part contemporaneously, occupied the basins of these Laurentian lakes, are reviewed by the present writer, with citations of the somewhat voluminous literature of this subject, in the American Journal of Science (3), Vol. XLIX, pp. 1–18, with map, Jan., 1895.

[2] "Changes of level of the Great Lakes," in The Forum, Vol. V, pp. 417–428, June, 1888; and "History of the Niagara River," in Sixth Annual Report of the Commissioners of the State Reservation at Niagara, for 1889, pp. 61–84, with three maps (also in Smithsonian Annual Report, 1890).

nizing an ice-sheet and referring the high ancient beaches of this basin to marine submergence, the same field has also been elaborately studied by Spencer.[1] According to the glacial theory held by Gilbert, which seems to me the true one, while the retiring ice-sheet still rested against the Adirondack Mountains, and thence stretched across the St. Lawrence Valley to the Laurentide highlands north of Montreal and Quebec, the glacial Lake Iroquois, outflowing at Rome, formed a well-marked beach which Gilbert has mapped, with determinations of its height by leveling, from the Niagara River east to Rome and north to the vicinity of Watertown. The Canadian portion of this beach, surrounding the western end of Lake Ontario and running along its northern side to the vicinity of Belleville, has been similarly traced by Spencer. The height of Lake Ontario is 247 feet, and that of the old outlet crossing the watershed at Rome is 440 feet above the sea-level. Thence the highest Iroquois beach, in its course adjacent to the eastern end of Lake Ontario, has a gradual ascent of about 5 feet per mile along a distance of 55 miles northward to the latitude of Watertown, where the highest beach is 730 feet above the sea, showing that a differential uplift of about 290 feet has taken place, in comparison with the Rome outlet. From Rome westward to Rochester the beach has nearly the same height with the outlet, but farther westward it descends to 385 feet above the sea at Lewiston and 363 feet at Hamilton, at the western end of Lake Ontario. Continuing along the beach north of the lake, the same elevation with the Rome outlet is reached near Toronto, and thence east-northeastward an uplift is found, similar to that before noted east of the lake, its amount near Trenton and Belleville, above Rome, being about 240 feet.

Only two surfaces of former levels, which are supplied by the old shores of Lakes Warren and Iroquois, conduct us from Chicago to Watertown and the mouth of Lake Ontario. Between the level of Lake Warren, at the eastern end of Lake Erie, and the latest level and highest beach of Lake Iroquois, at the western end of Lake Ontario, while it outflowed at Rome, there is a vertical fall of approximately 500 feet; and from the latest in the series of several Iroquois beaches near Watertown, where they

[1] Papers before cited; also Am. Jour. Sci. (3), Vol. XLI, pp. 12–21 and 201–211, with maps, Jan. and March, 1891.

occupy a vertical range of about 80 feet, the lowest being the last formed, corresponding to the highest beach at Hamilton, there is a fall of about 400 feet to the St. Lawrence at its outflow from Lake Ontario through the Thousand Islands. These two levels, and the respective descents of 500 and 400 feet, bring us to the sea-level of the Champlain epoch, or time of departure of the ice-sheet of the Glacial period, which was the barrier of these glacial lakes; for fossiliferous marine beds overlying the till extend inland along the St. Lawrence Valley to Ogdensburg and Brockville, close below the Thousand Islands and at the same level, within a few feet, as Lake Ontario. From Lake Warren to the Champlain ocean we thus have an apparent descent of 900 feet. But the first and third of the levels which are thus brought into close geographic correlation, namely, Lake Warren, Lake Iroquois, and the sea, are separated chronologically by the time of existence of the intermediate Lake Iroquois, and we must seek to eliminate the changes of levels which occurred within that time.

If the earliest beach of Lake Iroquois had been taken for this comparison, there would have been probably about 150 feet more of fall from the level of Lake Warren at the western end of Lake Ontario, and 80 feet more of fall from Lake Iroquois to the sea. The 230 feet thus found measures the differential rise of the area of Lake Ontario during the early part of the time between the dates of Lake Warren and of the sea at Ogdensburg. But this differential uplifting meanwhile affected the whole lake region, extending westward over the area that had been occupied by the glacial Lake Warren; and it is probable, as shown by the beaches of Lake Agassiz, that the greater part—indeed, nearly all—of the 265 feet of gradual change in levels between Chicago and the eastern end of Lake Erie took place during the time of the glacial Lake Iroquois and previous to the time of the sea-level in the St. Lawrence Valley, with which Chicago and Lake Warren are compared. There was also a small amount of differential rise of the Ontario basin during the latter part of the time of the glacial recession, between the formation of its latest beach with outflow by Rome to the Mohawk and the complete departure of the ice, or more probably the melting of an avenue through the ice-sheet, on the area crossed by the St. Lawrence, to which the ocean was then extended. To carry back our comparison of Chicago and Lake Warren with the sea-level to the stage of the glacial recession when the Niagara and the Mohawk were first uncovered from the ice, we have then to subtract from the 900 feet of apparent descent an undetermined amount, which probably exceeds 230 feet, and very likely may be fully 300 feet. The height of the Chicago outlet above the sea-level at the time of greatest extension of Lake Warren is thus found to have been about 650 or 600 feet, which differs only slightly from its present height of 595 feet. Chicago having had nearly the same elevation as now, we learn from the shore-lines of Lake Warren that the country adjoining the eastern end of Lake Erie was at that time depressed more than 200 feet, while the region north of Lake Superior was about 500 feet lower than now. The Rome outlet of Lake Iroquois was at first 50 or 100 feet above the sea-level, and it was uplifted to about 300 feet above the sea while it continued to be the outlet, and to probably 350 feet, lacking less than 100 feet of its present height, by the time of the extension of the sea to Ogdensburg and Brockville.

Before proceeding to consider the later great extension of Lake Iroquois we may glance rapidly over some of the explanations of the ancient elevated shore-lines of the Laurentian lakes which have been offered by successive writers. Mr. Thomas Roy, a civil engineer of Toronto, in a paper communicated in 1837 by Lyell to the Geological Society of London, regarded the body of water that formed the terraces and beach ridges near Toronto as an immense lake, with surface at one time about 1,000 feet above the sea, held in on all sides by formerly higher barriers of land.[1] But Lyell during his travels in this country in 1841–42 examined these shore-lines with Mr. Roy and pronounced them to be of marine origin.[2] In 1861 Prof. E. J. Chapman attributed the deposition of drift in this lake region to a marine submergence exceeding 1,500 feet; but he, like all subsequent observers, was unable to find any marine fossils. The beach ridges he referred to a very extensive fresh-water lake formed in a later epoch when the land was uplifted, the lake being supposed to be held in by a greater elevation of the country between the Adirondacks and the Laurentide high-

[1] Proceedings Geol. Soc. London, Vol. II, pp. 537, 538.

[2] Travels in North America, Vol. II, Chapter XX.

lands.[1] During the same year Mr. Sandford Fleming published a detailed description and map of the Davenport ridge and terrace, which are portions of the highest Iroquois shore-line near Toronto, referring them to the action of Lake Ontario when it stood "about 170 feet above its present level."[2] The Geological Survey of Canada, in its valuable Report of Progress to 1863, described these "ancient beaches, terraces, and ridges" on pages 910 to 915, but presented no theory of their origin. In 1877 Mr. George J. Hinde, in a paper on the glacial and interglacial strata of Scarboro Heights and other localities near Toronto, accounted for the drift by the agency of ice-sheets during two great epochs of glaciation, separated by a long interglacial epoch which had a climate nearly like that of the present time. The Laurentian lakes, at the close of the Glacial period, according to this author, were much larger than now, as shown by the old shore-lines; but he is not sure whether their barrier was the receding ice-sheet or "accumulations of glacial débris which have since been removed."[3] The southern high shore-lines of these lakes, in the United States, have been regarded by Whittlesey, Newberry, Claypole, and Gilbert, as of fresh-water formation, the lakes having been held higher than now by the ice-sheet during its departure; and Spencer and Taylor are the only recent writers who have examined this region and believe the beaches to be sea shores.[4]

None of these writers has studied the question, Where was the ice-sheet latest a barrier across the St. Lawrence Valley? The directions of glacial striæ and transportation of drift answer that the ice-sheet in this region during the closing stage of glaciation was thickest upon a belt crossing the St. Lawrence nearly from east-southeast to west-northwest in

[1] Canadian Journal, new series, Vol. VI, pp. 221–229 and 497, 498.

[2] Ibid., Vol. VI, pp. 247–253.

[3] Canadian Journal, new series, Vol. XV, pp. 388–413.

[4] C. Whittlesey, "On the fresh-water glacial drift of the Northwestern States," 1864, pp. 17–22, in Smithsonian Contributions, Vol. XV. J. S. Newberry, in Report of the Geological Survey of Ohio, Vol. II, 1874, pp. 50–65, with three maps. E. W. Claypole, "The lake age in Ohio," pp. 42, with four maps, in Trans. Geol. Soc. Edinburgh, 1887. G. K. Gilbert and J. W. Spencer, papers before cited.

Since this page was first written, Mr. F. B. Taylor has claimed a marine origin for some of the ancient beaches about portions of these lakes, and for deltas in the Mohawk Valley ("The highest old shore-line on Mackinac Island," Am. Jour. Sci. (3), Vol. XLIII, pp. 210–218, March, 1892; "The deltas of the Mohawk," Am. Geologist, Vol. IX, pp. 344, 345, May, 1892; and later papers in the Am. Geologist, Vols. XIII–XV, 1894–95).

the vicinity of Quebec. Thence its currents pushed up the valley by Montreal, and also down the valley, filling the broad estuary of the river to the gulf; and on that tract, at or below Quebec, doubtless the last remnant of the ice barrier was melted away, allowing the sea ingress westward to Lake Champlain, to the mouth of Lake Ontario, and to Allumette Island, in the Ottawa. Previous to this, while an arm of the sea had been washing the ice border and thus increasing its speed of retreat in the Gulf of St. Lawrence and west toward Quebec, the glacial lake's waves on the other side of the narrowing ice belt in this valley had likewise hastened its departure. Gradually this lake, which I have named Lake St. Lawrence,[1] had extended beyond the basin of Lake Ontario to fill at length the lower part of the Ottawa basin, probably to the mouth of the Mattawa, and it had spread eastward around the northern side of the Adirondacks to Lake Champlain and Montreal, and down the St. Lawrence Valley probably to Quebec or farther, when the ice dam between it and the sea disappeared. The glacial Lake St. Lawrence, until this time outflowing to the ocean by the Hudson River, then ceased to exist; Lake Ontario became a separate sheet of fresh water; and the sea, at a somewhat lower level than Lake St. Lawrence had held, stretched to the Thousand Islands, where the St. Lawrence River, at first only a few miles long and with scarcely perceptible fall, discharged the outflow of Lake Ontario into the prolonged Gulf of St. Lawrence.

Another branch of this theme needs to be added, telling the history of the continuous Hudson and Lake Champlain Valley during the recession of the ice-sheet, up to the time of this opening of its northern portion to the ocean. The absence of marine fossils in beds overlying the glacial drift on the shores of southern New England, Long Island, and New Jersey, and the watercourses which extend from the terminal moraine on Long Island southward across the adjacent modified drift plain and continue beneath the sea-level of the Great South Bay and other bays between the shore and its bordering long beaches, prove that this coast stood higher than now when the ice-sheet here extended to its farthest limit. A measure of this elevation of the seaboard in the vicinity of New York

[1] Am. Jour. Sci. (3), Vol. XLIX, pp. 1-18, with map, Jan., 1895.

during the Late Glacial or Champlain epoch is supplied, as I believe, by the shallow submarine channel of the Hudson, which has been traced by the soundings of the United States Coast Survey from about 12 miles off Sandy Hook to a distance of about 90 miles southeast from the Hook.[1] This submerged channel, lying between the present mouth of the Hudson and the very deep submarine fjord of this river, ranges from 10 to 15 fathoms in depth, with an average width of $1\frac{1}{4}$ miles, along its extent of 80 miles, the depth being measured from the top of its banks, which, with the adjacent sea-bed, are covered by 15 to 40 fathoms of water, increasing southeastward with the slope of this margin of the continental plateau.

During the whole or a considerable part of the time of the glacial Lakes Iroquois and St. Lawrence, this area, stretching 100 miles southeastward from New York, was probably a land surface across which the Hudson flowed with a slight descent to the sea. But northward from the present mouth of the Hudson the land stood lower than now, and the amount of its depression, beginning near the city of New York and increasing from south to north, as shown by terraces and deltas of the glacial Lake Hudson-Champlain, which were formed before this lake became merged with Lake Iroquois, was nearly 180 feet at West Point, 275 feet at Catskill, and 340 feet at Albany and Schenectady.[2] Farther to the north, according to measurements by Baron de Geer of the altitudes of the highest shore marks in the part of the St. Lawrence basin which was filled by the glacial Lake St. Lawrence, formed by the union of the two preceding, the depression was nearly 657 feet at St. Albans, Vt.; 640 feet on the north side of the Adirondacks, southeast of Moira, N. Y.; 625 feet on Mount Royal, at Montreal; and 718 feet on the hills a few miles north of the city of Ottawa.[3] From these figures, however, both in the Hudson and St. Lawrence basins, we must subtract the amount of descent of the Hudson River, which in its channel outside the present

[1] A. Lindenkohl, Am. Jour. Sci. (3), Vol. XXIX, pp. 475–480, June, 1885, and Vol. XLI, pp. 489–499, June, 1891. J. D. Dana, Am. Jour. Sci. (3), Vol. XL, pp. 425–437, Dec., 1890, with map reduced from a chart of the U. S. Coast Survey.

[2] J. S. Newberry, Popular Science Monthly, Vol. XIII, pp. 641–660, Oct., 1878. F. J. H. Merrill, Am. Jour. Sci. (3), Vol. XLI, pp. 460–466, June, 1891. W. M. Davis, Proceedings, Boston Society of Natural History, Vol. XXV, pp. 318–335, 1891. Warren Upham, Bulletin, G. S. A., Vol. I, 1890, p. 566; Vol. II, 1891, p. 265.

[3] Proceedings, Boston Society of Natural History, Vol. XXV, 1892, pp. 454–477, with map.

harbor of New York may probably have been once 50 or 60 feet in its length of about 100 miles. Before the time of disappearance of the ice-barrier at Quebec this descent may have been diminished, or the seaboard at New York may have sunk so as to bring the shore-line nearly to its present position; but the Hudson Valley meanwhile had been uplifted, so that an outflow from Lake St. Lawrence crossed the low divide, now about 150 feet above the sea, between Lake Champlain and the Hudson. This is known by the extension of fossiliferous marine deposits along the Lake Champlain basin nearly to its southern end, while they are wholly wanting along all the Hudson Valley. Indeed, the outflowing river from Lake St. Lawrence or the Hudson during the subsequent postglacial epoch channeled the lower part of this valley to a depth of about 100 feet below the present sea-level, proving that the land there, as Merrill points out, stood so much higher than now during some time after the ice retreated.

When Lake Iroquois ceased to outflow at Rome, and after intervening stages of outlets existing for a short time at successively lower levels north of the Adirondacks began to occupy the Lake Champlain basin, outflowing thence to the Hudson, its surface fell by these stages about 250 feet to the glacial Lake Hudson-Champlain, which had doubtless reached northward along the whole length of the Champlain basin. The level of the resulting Lake St. Lawrence at the later time of ingress of the sea past Quebec fell probably 50 feet or less to the sea-level. During these changes the outflow of Lake Agassiz may have passed in the ways before described to the sea through the Hudson, and afterward to the enlarged Gulf of St. Lawrence, if the sea had not previously come into Hudson Bay.

LAKE MINNESOTA.

Before Lake Agassiz commenced to exist, the receding Minnesota and Dakota lobes of the ice-sheet had each given place to a large lake on the central part of the area from which they withdrew. By the barrier of the Minnesota ice-lobe a lake having an elevation of about 1,150 feet above the sea was formed in southern Minnesota, in the basin of the Blue Earth and Minnesota rivers, outflowing southward by way of Union Slough to the East Fork of the Des Moines. In its maximum extent this lake probably had a length of 160 miles, from Waseca to Big Stone Lake, with a width of 40 miles in Blue Earth and Faribault counties, attaining an area of more than 3,000 square miles. The continued glacial recession afterward opened lower outlets eastward to the Cannon River, and at the time of the Waconia moraine had uncovered the lower part of the Minnesota Valley, permitting the lake to be wholly drained northeastward to the Mississippi.[1] Its existence was thus ended previous to the beginning of Lake Agassiz, which dates from the next ensuing Dovre moraine.

The modified drift from the retreating ice on the upper Minnesota basin was deposited along the lower half of this valley, filling it with stratified gravel, sand, and clay to a depth 75 to 150 feet above the present river from New Ulm to its mouth, which shows that at least this portion of the valley had nearly its present form at the time of final recession of the ice-sheet. It seems also probable that the upper part of the channel above New Ulm, occupied by the River Warren at the time of the Herman beaches, was already a distinctly marked topographic feature when the ice retreated, so that the first outflow from Lake Agassiz took its course at a level some 50 feet below the general surface adjoining Lakes Traverse and Big Stone and Browns Valley.[2] As long as streams poured into this valley directly from the melting ice-sheet, its modified drift, gathered from the ice in which it had been held, continued to increase in depth; but when the ice had retreated beyond the limits of the Minnesota basin, the water discharged here from Lake Agassiz brought no modified drift, and was consequently a most powerful eroding agent. By this River Warren the valley drift, so recently deposited, was mostly swept away, and the channel was excavated to a depth much lower than the present river. But since Lake Agassiz began to outflow northeastward, the Minnesota Valley and that of the Mississippi below, carrying only a small fraction of their former volume of water, have become considerably filled by alluvial gravel, sand, clay, and silt, which have been brought in by tributaries, being spread for the most part somewhat evenly along these valleys by their floods.[3]

[1] Geology of Minnesota, Vol. I, pp. 460, 622, 642.

[2] Compare with Geology of Minnesota, Vol. I, pp. 479–485, describing the chains of lakes in Martin County, Minn., which are apparently due to preglacial or interglacial watercourses that were not wholly filled with drift. Several such chains of lakes are also found in the vicinity of Eckelson, N. Dak. (Chapter IV, p. 144).

[3] "The Minnesota Valley in the Ice age," Proc. A. A. A. S., Vol. XXXII, for 1883, pp. 213–231; also in Am. Jour. Sci. (3), Vol. XXVII, Jan. and Feb., 1884.

LAKE DAKOTA.

Prof. J. E. Todd supplies me the approximate outline of a lake named by him Lake Dakota, which occupied the valley of the James or Dakota River contemporaneously with the foregoing, reaching from Mitchell 170 miles north to Oakes and varying from 10 to 30 miles in width.[1] It outflowed southward by the present course of the James to the Missouri. The Dakota ice-lobe, which had filled this valley and in its recession formed the northern shore of Lake Dakota, was not therefore the cause of this lake in the same way that the lake in the Blue Earth and Minnesota basin and Lake Agassiz owed their existence to the barrier of the ice-sheet in its retreat. The bed of Lake Dakota has a nearly uniform elevation of 1,300 feet, or is within 10 feet below or above this, throughout its length; and during the glacial recession it was covered by a lake whose shores have now a height of about 1,300 to 1,350 feet, probably ascending slightly from south to north as compared with the present sea-level. Professor Todd states that the surface of this lacustrine area in its southern part, from Mitchell to Redfield, is nearly flat till, but thence northward is sand and loess-like silt, while considerable tracts of the eastern border of its north part consist of low dunes.

The outflowing James River was cutting down its channel during the retreat of the ice-lobe, and its erosion was so rapid as to prevent the northern part of Lake Dakota from retaining sufficient depth to outflow eastward into the south end of Lake Agassiz when the way was opened by the farther departure of the ice, receding from the Head of the Coteau des Prairies and beginning to uncover the Red River Valley. A large tract of the sand and silt beds of Lake Dakota, and of a contiguous glacial lake formed in Sargent County, N. Dak., at the time of the Dovre moraine (p. 148), now sends its drainage to the Red River by the head stream of the Wild Rice, which passes north of the Head of the Coteau and enters the area of Lake Agassiz near Wyndmere. The lowest portion of the watershed on this lacustrine deposit, over which the James River would flow east to the Wild Rice River, is scarcely 10 feet above the general level of the James Valley, or 25 feet above the present level of the James River, being at

[1] This lake is partially mapped by Prof. Todd in Proc. A. A. A. S., Vol. XXXIII, 1884, p. 393.

Amherst, on the Aberdeen branch of the Great Northern Railway, 1,312 feet above the sea. The elevation of the upper portion of the lake beds in the vicinity of Oakes, and the lack of evidence that the lake waves have acted at any greater height upon the adjoining surfaces of undulating till and morainic hills, lead to the conclusion that the highest shore-line of the north end of Lake Dakota is not more than 1,345 feet above the sea, showing that there was only a shallow expanse of water above the plain of lacustrine silt. On the north the depth of the channel of the inflowing James River, eroded apparently before the glacial retreat could permit an eastward outlet into Lake Agassiz, indicates that the surfaces of land and water in the James Valley had gained nearly their present relations, Lake Dakota being already drained away, when the Wild Rice River and the south end of the Red River Valley were uncovered by the recession of the ice-sheet. It is evident, therefore, that the long area of Lake Dakota has experienced only slight differential changes of level, at least in the direction from south to north, since the departure of the ice. The James River Valley is thus strongly contrasted with the northward uplifting that has affected the Red River Valley, as shown by the beaches of Lake Agassiz, the highest of which rises from south to north about 6 inches per mile for 30 or 40 miles at its south end, but a foot or more per mile within 40 miles farther north, and, indeed, has an average northward ascent of about 1 foot per mile through an extent of 400 miles along the west side of this lake in North Dakota and Manitoba.

LAKE SOURIS.

As Lake Agassiz gradually extended to the north, following the receding ice barrier, it received successively by three outlets the drainage of the glacial lakes of the Saskatchewan and Souris basins. These streams took the course of the Sheyenne, Pembina, and Assiniboine rivers, each bringing an extensive delta deposit. With the first retreat of the ice from the Missouri Coteau a glacial lake began to exist in the valley of the South Saskatchewan in the vicinity of the elbow, probably outflowing at an early time by the way of Moose Jaw Creek, and through a glacial lake in the upper Souris basin, to the Missouri near Fort Stevenson. Later the outflow from the Lake Saskatchewan may have passed to the Lake Souris by way of the Wascana River, after passing through a glacial lake which probably extended from Regina 60 miles to the west in the upper Qu'Appelle basin. When the Dakota ice-lobe was melted back to the vicinity of Devils Lake the drainage of Lake Souris passed southeast by the Big Coulée, one of the head streams of the Sheyenne, flowing thence for some time southward by the James River to Lake Dakota, but later eastward and southward by the Sheyenne into Lake Agassiz. A manuscript report of a reconnoissance in North Dakota by Maj. W. J. Twining, in 1869, describes the valley of the Big Coulée as 125 feet deep and a third of a mile wide, inclosing several shallow lakes along its course. "This great valley," he writes, "preserves its character to within 12 miles of the Mouse River, and connects through the clay and sand ridge with the open valley of that stream."

The glacial Lake Souris (Pl. XXI) occupied the basin of the Souris or Mouse River from the most southern portion of this river's loop in North Dakota to its elbow in Manitoba, where it turns sharply northward and passes through the Tiger Hills. North of the Souris basin an arm of this lake extended along the Assiniboine from Griswold and Oak Lake to some distance above the mouth of the Qu'Appelle; and the main body of the lake was deeply indented on the east by the high oval area of Turtle Mountain, an outlier of the lignite-bearing Laramie formation, which is well developed on the upper part of the Souris River and forms, with overlying drift deposits, the massive terrace of the Coteau du Missouri on the west. The length of Lake Souris was about 170 miles, from latitude 48° to latitude 50° 35′, and its maximum width, north of Turtle Mountain, was nearly 70 miles.

Until the ice-sheet west of Lake Agassiz had receded so far as to uncover Turtle Mountain, the glacial lake in the Souris basin continued to outflow by the Sheyenne and build up its delta. Next its outflow passed north of Turtle Mountain by the Pembina, perhaps after taking for a brief time the course of the Badger Creek, Lac des Roches, and the Mauvaise Coulée to Devils Lake and the Sheyenne. The channel of outlet by the Pembina, extending about 110 miles from the elbow of the Souris to the Pembina delta of Lake Agassiz, is eroded 100 to 300 feet in depth, probably averaging 175 feet, along the greater part of its course, but it is from

MAP OF THE GLACIAL LAKE SOURIS.

Scale, 20 miles to an inch.

Lake Areas | Deltas | Moraines

Altitudes of Railway stations are noted in feet above the sea.

300 to 450 feet deep, probably averaging 350 feet, along its last 25 miles. It is cut through the plateau of Fort Pierre shale that reaches westward from the Pembina Mountain escarpment. Outside of this valley the shale is overlain by only a thin sheet of till, which varies generally from 10 to 30 or 40 feet in thickness; but the valley itself contains a considerably greater depth of till. From Lakes Lorne and Louise to its delta the Pembina probably flows in its preglacial course, where its old valley became partly filled with till during the Glacial period. The topographic features of this valley will be more fully shown by the following notes of approximate elevations referred to the sea-level, those of the first column being in the bottom of the valley, and those of the second along the top of its bluffs at the general level of the adjoining country.

Elevations along the Pembina Valley (outlet of Lake Souris).

Locality.	Distance in miles from the elbow of the Souris.	Feet above the sea for bottom of the valley and surface of water in rivers and lakes.	Feet above the sea for top of the bluffs inclosing the valley.
Elbow of the Souris, in a valley that has been eroded about 100 feet by the present river flowing to the Assiniboine since the glacial Lake Souris ceased to outflow to the Pembina by Langs Valley	....	1,265	1,475
Divide in Langs Valley, near the line between sections 31 and 32, township 5, range 17, Manitoba, separating Langs Creek, flowing west to the Souris, and Dunlops Creek, flowing east to the Pembina, determined by railway survey	4	1,364	1,475
Bone Lake, 3 miles long and a half mile wide	5–8	1,357	1,480
Grass Lake	10–11	1,355	1,485
Pelican Lake, 10 miles long and about a mile wide, mostly 10 to 15 feet deep, but in its deepest portions about 20 feet, rising 3 feet between its lowest and highest stages	11–21	1,355	1,485–1,510
Junction of outlet of Pelican Lake with the Pembina	22½	1,348	1,510
Lake Lorne; area, about 1 mile square; maximum depth, about 8 feet	23–24	1,346	1,510
Lake Louise, of nearly the same area and maximum depth	25–26	1,345	1,510
Mouth of Badger Creek	27	1,343	1,510
Rock Lake, 8 miles long and one-half to 1 mile wide; maximum depth, 10 feet[1]	30–38	1,335	1,510–1,550
Mouth of Clearwater River	40	1,332	1,525
At the Marringhurst bridge, on the north line of section 16, township 3, range 12, Manitoba	42	1,330	1,480
Swan Lake, 5 miles long and 1 mile wide; maximum depth, probably about 10 feet	50–55	1,310	1,500
At La Rivière, determined by railway survey	67	1,287	1,550
At crossing of the boundary commission road[2]	75	1,265	1,550
At crossing of the old Missouri trail	80	1,250	1,545
At the Mowbráy bridge, on the line between sections 21 and 22, township 1, range 8, Manitoba	85	1,235	1,540
On the international boundary	100	1,125	1,540
At the fish trap, section 30, township 163, range 57, North Dakota, 2 miles west of the Pembina Mountain escarpment and 7 miles west of Walhalla	108	1,050	1,400–1,500

[1]Glenora prairie, north of Rock Lake, a slightly undulating expanse of modified drift, stratified gravel, and sand, extending 6 miles from west to east and 2 to 3 miles wide, has an elevation of 1,510 to 1,500 feet, descending eastward with the valley.

[2]Dr. George M. Dawson notes a wide terrace here, in some places thickly strewn with bowlders, on the southwestern side of the river and about 200 feet above it; and he refers its origin to preglacial erosion of the valley.

At the Mowbray bridge the bottom land is about an eighth of a mile wide and 10 feet above the river. About 40 feet higher is a narrow terrace of modified drift, an eighth to a fourth of a mile wide, reaching along the southern side of the river for 1½ miles to the east, and also well shown in many places on each side of the river for 6 miles or more both to the west and east; but along much of this distance one or both sides of the valley slope gradually from 100 or 75 feet above the river to the bottom land. The higher portions of the sides or bluffs of the valley have steep slopes, rarely interrupted by terraces. But a remarkably broad terrace or plateau, evidently formed during the preglacial or interglacial erosion of this valley, extends on its southern side 3 miles to the east from the Mowbray bridge and road, with a maximum width of about 1½ miles, and an elevation of 1,450 to 1,425 feet above the sea, or about 200 feet above the river. A lakelet half a mile long from east to west lies on the southern part of this plateau at the foot of the bluff that rises thence about 100 feet to the general level of the adjoining country. All the way for 25 miles from this bridge to the Pembina delta, especially in the vicinity of the fish trap, the river flows in a very picturesque valley, whose sides, rising steeply 300 to 450 feet, are roughly seamed and cleft by tributary ravines and gorges, with here and there hills and small plateaus that have been left isolated by the process of erosion. This valley has frequent exposures of the Fort Pierre shales, which also, within a half mile to 1 mile back from the river, form the high plateau through which the river has cut its way The narrowness and depth of the partially drift-filled valley indicate that its area of drainage was no greater in preglacial time than now.

The mouth of Lake Souris where it first outflowed to Lake Agassiz by the Big Coulée and the Sheyenne was approximately 1,600 to 1,500 feet above the present sea-level, being gradually cut down about 100 feet by the stream. But, on account of subsequent changes which are known to have taken place in the relative elevation of the land and water surfaces in this district, the shore-line of the northern part of the lake at the end of its time of outflow to the Sheyenne would now have an elevation of about 1,600 feet at Langs Valley. Therefore, when its channel of discharge was transferred to the new course by Pelican Lake and along the Pembina, the

Lake Souris was suddenly lowered about 125 feet to the level of the top of the bluffs of Langs Valley, and a further lowering of 110 feet was afterward effected by the gradual erosion of this valley. The lake was wholly drained by this outlet, for the general level of the land adjoining the Souris in the vicinity of the mouth of Plum Creek, which is the lowest portion of the lake bed, is about 20 feet above the present divide in Langs Valley. Since the waters of the Souris ceased to flow along this course, the sediments of gravel and sand brought by tributaries have filled portions of the Pembina Valley 10 to 20 feet, forming the barriers of its shallow lakes; and the divide in Langs Valley has been raised probably 10 feet by the deposits of Dunlops Creek.

The ice-sheet was forming its moraine of the west part of the Tiger Hills, and of the Brandon and Arrow hills, when Lake Souris began to outflow by the course of Langs Valley and the Pembina. The extent of Lake Souris was then from the northern part of North Dakota along the Souris and Assiniboine to the lower Qu'Appelle; and the Saskatchewan outflow by its erosion of the Qu'Appelle Valley brought into this lake extensive delta deposits of gravel and sand, which, with similar beds of modified drift brought into it from the melting ice-sheet that was its northeastern barrier, reach from the vicinity of Fort Ellice southeast to Oak Lake and Plum Creek.

After the erosion of Langs Valley had lowered the Lake Souris below the level (about 1,390 feet) at which its outflow could pass instead to the north and northeast by the way of Oak Lake and the Assiniboine, the ice was withdrawn to the north side of the Assiniboine Valley east of Oak Lake, and the deposition of the great Assiniboine delta of Lake Agassiz ensued. A width of only 3 miles of the morainic belt of the Tiger Hills, extending along the north side of Langs Valley and the elbow of the Souris, intervened between that stream and an expanse of till whose surface is lower than the bottom of Langs Valley and descends with northeastward slope to the Assiniboine. The crest of this moraine rises about 200 feet above Langs Valley, but it had probably been cut through nearly or quite to the level of that valley by drainage southward from a small lake formed between the moraine and the receding ice within the angle between the east-to-west range of the Tiger Hills and the north-to-south range of the Brandon Hills. With the withdrawal of the ice front across the Assiniboine this gap through the moraine was soon channeled deeper, and the Souris turned northward at its elbow, leaving its old channel of Langs Valley and flowing with more rapid descent to the Assiniboine in its present course. The gap has been since eroded to a total depth of 350 feet; and thence northward the Souris has cut a channel about 140 feet deep, chiefly in till, which forms steep bluffs that in many places are now being undermined by the stream. Erosion along this part of the Souris is still proceeding rapidly, and the valley has a very new appearance.

LAKE SASKATCHEWAN.

Through the whole period of the existence of Lake Souris, which at first outflowed to the Missouri and afterward to Lake Agassiz, the glacial lake in the basin of the South Saskatchewan, doubtless also at last including the North Saskatchewan, was tributary to it, and the outlet of this Lake Saskatchewan was transferred to lower courses as the border of the ice-sheet receded from southwest to northeast. When the upper part of the Qu'Appelle became uncovered, but its lower portion remained enveloped by the ice, the Saskatchewan outflow probably passed to Lake Souris successively by the Moose Jaw Creek and the upper Souris, by the Wascana and the Moose Mountain Creek, and by the Summerberry and Pipestone creeks. Finally the whole length of the Qu'Appelle was uncovered, and the great glacial river from Lake Saskatchewan flowed along the course of this valley, which is similar to that of the Pembina in its width and depth and the numerous lakes along its bottom. At first this river crossed the divide between the River that Turns and the head of the Qu'Appelle, where it eroded a trough-like channel like that of Browns and Langs valleys; but later it probably found a lower outlet farther north, flowing southward to the Qu'Appelle through the valley of Long or Last Mountain Lake.

The following table, compiled from Hind's report of the Assiniboine and Saskatchewan exploring expedition, brings into view the remarkable topographic features of the Qu'Appelle Valley, and shows the lengths and maximum depths of the lakes through which the river flows. Its elevations are referred to sea-level, approximately, by comparison with the Canadian Pacific Railway.

Elevations along the Qu'Appelle Valley (outlet of Lake Saskatchewan).

Locality.	Miles from elbow of the South Saskatchewan.	Feet above the sea.	Maximum depths of lakes in feet.	Height of bluffs in feet.
Elbow of the South Saskatchewan	....	1,619	....	140
Ponds on the River that Turns	7– 8	1,686	*10	110
Height of land	12	1,704	....	110–140
Sand Hill or Eyebrow Lake	24– 28	1,685	*20	115–150
Buffalo Lake	58– 74	1,635	*20	190
Lake	83– 84	1,624	*15	185
Fourth Fishing Lake	135–144	1,504	54	270
Third Fishing Lake	144–149	1,503	57	270
Second Fishing Lake	150–153	1,501	48	275
First Fishing Lake	154–160	1,500	66	300–350
Crooked Lake	198–203	1,389	36	300–320
Round Lake	218–223	1,364	30	310
Mouth of the Qu'Appelle	268	1,264	....	220

* About.

The area that was occupied by the glacial Lake Saskatchewan during its stages of outflow through the head stream of the Qu'Appelle, afterward by Long Lake, and perhaps still later by the head stream of the Assiniboine, extends from the base of the morainic Vermilion Hills, on the Missouri Coteau, where it is cut through by the South Saskatchewan, some 25 miles above its elbow, to the eastern part of the Pasquia Hills, south of the Cumberland House. At length the glacial recession opened the Lower Saskatchewan Valley, and this lake fell to the level of Lake Agassiz, which appears to have reached up the Saskatchewan to the vicinity of Prince Albert, about 40 miles above the confluence of its north and south branches. Before the ice dam between Lakes Saskatchewan and Agassiz was removed, the former lake, as here described, had covered an area approximately 300 miles long and 25 to 75 miles wide.

It is to be added, however, that before the Saskatchewan Lake was permitted by the glacial retreat to fill a part of the basin so far east as to outflow into the Qu'Appelle, various bodies of water, dammed by the ice-sheet, had existed in its upper portions, flowing southward, as noted in the early part of this chapter, by Lake Pakowki and other courses. If we could, by a vision of the past, see in detail all the successive glacial lakes of Alberta, Saskatchewan, and Assiniboia, and the old rivers flowing from them over the present watersheds, there would surely be revealed a very complex history, which future glacialists can hope to discover only by much patient exploration.

GLACIAL LAKES OF THE PEACE AND ATHABASCA BASINS.

In the preceding chapter I have shown that the ice-sheet probably stretched as one continuous mer de glace from the Atlantic to the Pacific, wholly covering the Rocky Mountains in their low portion adjoining the Peace River. Its thickness there may have been 3,000 to 5,000 feet, and from this central part its surface sloped downward both to the south and north. During the departure of the ice, therefore, its southern border in this region, as elsewhere along its entire extent across the continent, retreated in general toward the north, with embayments here and there between projecting ice-lobes. Thus there came a time when the Peace River basin had become mostly or wholly uncovered from its icy mantle, and held a lake shut in on the north by the receding glacial barrier. West of the one hundred and seventeenth meridian, according to Dr. G. M. Dawson, the elevated plains which are intersected by the deep valleys of the Peace and Smoky rivers and their tributaries are overspread by fine lacustrine silts lying on the glacial drift.[1] The elevation of this silt-enveloped country ranges from 2,000 to 2,500 feet above the sea, and it may be merely a vast delta occupying but a small part of the fully expanded Peace Lake.

The earliest outlet from this glacial lake probably flowed across the present watershed between the Peace River and Lesser Slave Lake, which is about 2,430 feet above the sea; and then, after passing through a smaller glacial lake, or confluent part of the Peace Lake, in the upper Athabasca basin, it may have passed across the divide between the Tow-ti-now River and the North Saskatchewan, on or near the trail from Athabasca Landing to Edmonton. The height of this watershed is about 2,485 feet. Later stages of the glacial retreat would give successively lower outlets, until the

[1] Geol. and Nat. Hist. Survey of Canada, Report of Progress for 1879–80, p. 142 B; Trans., Royal Society of Canada, Vol. VIII, sec. 4, 1890, p. 47.

depression of the watershed at the Methy portage probably afforded, as remarked on a foregoing page, the lowest and latest channel of outflow from the Mackenzie basin to Lake Agassiz.

The watercourse by which the Churchill, bringing the Peace and Athabasca outflow, passed into the Saskatchewan, tributary to Lake Agassiz, begins at Frog portage and extends south-southeastward about 100 miles by a Lake of the Woods, Pelican, Heron, and Birch lakes, Great and Ridge rivers, Beaver, Sturgeon, and Pine Island lakes, to the Saskatchewan at Cumberland House. This was the route of Franklin and Richardson in 1820. The latter states that "by Beaver Lake and its chain of waters Nelson River receives supplies from the very banks of the Missinippi or Churchill River. Indeed, the Beaver Lake chain, which lay in our route, originates within a hundred yards of the latter stream." Frog portage, at this locality, "is 380 paces long. The path leads through a low, swampy wood, and over a flat tract of gneiss rising only a few feet above the waters on each side." The further descriptions of their journey up the Churchill, which "resembles a chain of lakes with many arms, more than a river," and by Isle à la Crosse Lake, Deep River, Clear and Buffalo lakes, and Methy River and Lake to Methy portage, indicate that this was at one time the avenue of outflow from a glacial lake in the Mackenzie basin. Isle à la Crosse, Clear, and Buffalo lakes, which, according to Macoun, have the same level, being stagnant water, filled with green scum in summer, are approximately 1,500 feet above the sea; Methy Lake, 1,700 feet; the crest of Methy portage, 1,760 feet, abundantly strewn with bowlders, probably belonging to a belt of morainic drift; and Clearwater River, a tributary of the Athabasca, at the north end of this portage, 1,100 feet. A very steep descent is made to the Clearwater, which flows westward in a great valley, formed by preglacial erosion, 2 to 3 miles wide.[1]

[1]Narrative of a journey to the shores of the Polar Sea, in the years 1819, 1820, 1821, and 1822, by John Franklin, R. N., F. R. S.; including an Appendix of Geognostical Observations by John Richardson, M. D., surgeon to the expedition.

Also, see Sir John Richardson's Arctic Expedition in Search of Sir John Franklin; and descriptions of Methy portage and its vicinity, by Prof. John Macoun (Geol. Survey of Canada, Report of Progress for 1875-76, pp. 94, 174) and by Dr. Robert Bell (Bulletin, G. S. A., Vol. I, p. 290).

The elevations stated are increased 200 feet above the estimates given by Richardson, which addition (or perhaps 100 feet more) is required by comparison with reliable determinations of elevations on the Saskatchewan and Peace rivers.

CHAPTER VI.

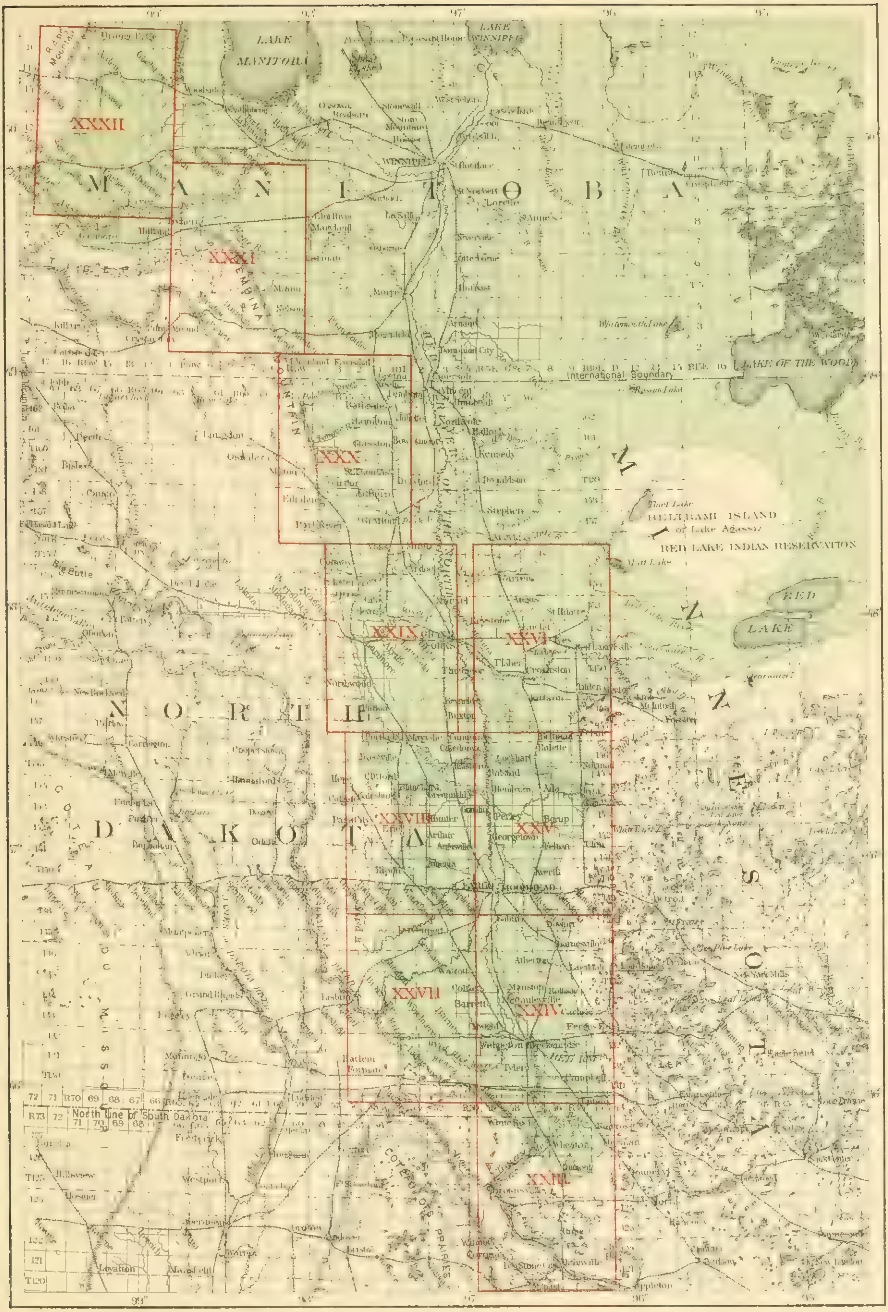
BEACHES AND DELTAS OF THE HERMAN STAGES.

In this and the two following chapters the shore-lines of Lake Agassiz are described in considerable detail, with notes of their altitude and of the topographic features of their tracts marked by erosion, and of the more extensive tracts where beach ridges were accumulated. The fullness and convincing character of the evidence that these are the shore-lines of an ancient lake of vast size, occupying the Red River Valley and the present lake region of Manitoba, are thus impressively exhibited; and the diverse phases of the results produced by waves and shore currents are brought into comparison.

Ten plates (XXIII to XXXII), on the scale of 6 miles to an inch, covering consecutive areas as indicated on Pl. XXII, display the definite geographic location of the shores; and all their more remarkable portions are described, with statement of the sections or often the quarter-sections under consideration, in the text. The arrangement of the sections in each township is shown in fig. 1, on page 11.

Many of the farmers whose houses are built on or near to the old beaches have decided to their own satisfaction, as I learned by conversation with them during the progress of these surveys and levelings, that these beach ridges of gravel and sand are the same as those of now existing lakes of large size, and that consequently the flat Red River Valley so bounded was once the bed of a great lake. These residents will be enabled by the following descriptions and maps to trace the continuity of the shores seen near their own homes to distances of many miles away and, indeed, around all the prairie portion of the ancient lake.

With the progress of agriculture, which is rapidly bringing all this lake bed into cultivation, certain features of the deserted shores that were very distinct at the time of my examination will doubtless be obscured or obliterated. Many of the groves here noticed as occurring along stream courses



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MAP OF THE SOUTHERN PORTION OF LAKE AGASSIZ EXPLORED WITH LEVELLING IN MINNESOTA, NORTH DAKOTA, AND MANITOBA, SHOWING THE LOCATION OF PLATES XXIII–XXXII.

Scale, about 42 miles to an inch.

Area of Lake Agassiz   Terminal Moraines

or elsewhere in the neighborhood of the old shore-lines will probably cease to exist within a century, or in some cases within a score of years. On the other hand, many artificial groves surrounding farmhouses, and lines of trees cultivated on the divisions of property or of adjacent fields, will probably more than replace such loss, making the country more beautiful and less liable to be swept heavily by winds. But the extensive views enjoyed by the writer and his assistant rodman as they advanced along the course of the beaches, mapping them and determining their elevation, will be then hindered by the cultivated groves, tree rows, and hedges. Only upon a prairie country, such as this was when its shore-lines were first traced, can the grandeur of the proofs of existence of glacial lakes, held by the obstruction of the departing ice, be taken in by an unimpeded vision of the smooth lake bottom on one side stretching out to a distance of 10 or 20 miles within sight, of the bordering beach, running as one unbroken ridge of gravel and sand in a nearly direct course discernible for several miles, and of the broad, slightly higher expanse of more undulating and knolly glacial drift outside the lake area.

From these descriptions of the beach ridges and eroded shores of the old lake, its levels at the time of formation of these shore-lines are deducible approximately. The elevations of the crests of the beach ridges, as recorded in these notes, are commonly 5 to 10 feet, or rarely 15 feet or more, above the level held by the lake when the beaches were heaped up by the waves, chiefly during storms. Where the descents of the slopes of these gravel and sand ridges are noted, the lake level was nearly always below the depression which borders the landward side of the beach and was near the foot of the lakeward slope. Cliffs eroded by the lake waves give more definitely the plane of the water surface which cut into the base of the eroded escarpment, usually consisting of till, undermining it and carrying away its material to form a very gently descending slope, which was covered by the margin of the lake.

Fluctuations of the lake level, which doubtless rose in summer a few feet higher than in winter, because of the variations in the volume of water supplied from the melting ice-sheet, have given a variability within limits generally 5 feet and perhaps sometimes 8 or 10 feet apart to the heights of the lake and of its shore deposits and planes of erosion in each of the more than thirty stages which these shore-lines exhibit. The high-water surface of the summers, however, had probably a nearly uniform elevation during many years in each stage, producing therefore a beach or eroded line of nearly constant height. On the other hand, the reduced lake level of the winters, when the superficial melting of the ice-sheet ceased and the lake doubtless became mostly frozen over, was likewise at nearly the same elevation from year to year; but the beach ridges formed by the strong wave action of the autumn, winter, and spring storms, with the effects of the drifting lake ice during the breaking up in spring, would be mostly washed away by the ensuing high water of the summer, when the glacial melting attained its maximum. As the result of these annual oscillations of the lake surface, gravel and sand from the material eroded during the storms of winter, both from bordering cliffs and from the shallow lake bed close along the shore, have been chiefly preserved in beach deposits at the higher plane of the fluctuation reached in summer.

Periodic oscillations occupying several years between successive maxima of the lake level were also probably caused by cycles of increase and diminution in temperature and rainfall, with consequent irregularity in the yearly amount of the glacial melting. The cycles of rise and fall of the great Laurentian lakes have a somewhat uniform average length of ten to twelve years, as stated in Chapter XI, the maximum heights of these lakes being 5 to 6 feet above their lowest recorded stages. But, on account of the great variation of the tribute received by Lake Agassiz from the departing ice-sheet in the alternating warm and cold portions of each year, probably its annual fluctuations of level equaled or exceeded the changes of longer periods in the Laurentian lakes, which receive a somewhat steady supply through all the seasons, but are raised by excess of rainfall during a few years together and then lowered by a series of drier years.

THE UPPER OR HERMAN BEACHES AND DELTAS IN MINNESOTA.

Our description of the highest shore-lines of Lake Agassiz may well begin at the mouth of this lake, the present site of the northern end of Lake Traverse. Thence the uppermost or Herman beach was traced eastward and northeastward through Traverse County and the most northwestern township of Stevens County, Minn., to Herman, in Grant County, nearly 20 miles east of Lake Traverse. From this place the Herman beach runs nearly due north 132 miles to the north side of Maple Lake, in Polk County, about 20 miles east-southeast of Crookston. Beyond Maple Lake the course of this shore-line is known to be nearly east to the south side of Red and Rainy lakes; but it passes through a wooded and uninhabited country where it is impracticable to trace its course exactly and determine its height by leveling.

Along the distance of about 160 miles, as measured by long, straight lines, or about 175 miles, following the larger bends of the shore-line, from Lake Traverse to Herman and Maple Lake, the boundary of Lake Agassiz lies in a prairie region, mostly having a very smooth and regular surface, which could not be surpassed in its adaptability for receiving and preserving a record of the old lake level. The Herman beach lines, single on the southern part of the lake border, but double and even quadruple in Clay County and northward, have been carefully mapped across this expanse of prairie, and their heights have been determined by leveling. The principal features of this series of beaches are described in the following pages.

Especial description is also given of the two chief delta deposits of this part of the old lake border. These were brought into the lake, contemporaneously with the formation of the Herman beach, by the glacial representatives of the Buffalo and Sand Hill rivers. They cover small areas, in comparison with the Sheyenne, Elk Valley, Pembina, and Assiniboine deltas on the west margin of this glacial lake.

FROM LAKE TRAVERSE EAST TO HERMAN.

(PLATE XXIII.)

Within the first 4 miles eastward from the northeast end of Lake Traverse the Herman shore of Lake Agassiz is an eroded bluff of till, rising from the south side of the Mustinka River to a height of 75 to 100 feet above the river and lake. The altitude of Lake Traverse at its lowest and highest stages is 970 and 976 feet above mean tide sea-level. When the lake falls below 973 or 972 feet, which occurs during the dry season nearly every summer, it ceases to outflow by the Bois des Sioux, and that stream becomes reduced to a series of stagnant pools. The eroded bluff noted, and others of the same character lying on each side of the Bois des Sioux at a distance of 3 to 4 miles apart between Lake Traverse and White Rock, were finished by the outflow of the glacial River Warren, but probably their erosion was begun by a stream outflowing here from the Red River Valley during the Aftonian interglacial stage between the Kansan and Iowan stages of ice accumulation and extension.[1]

After following the old lake shore eastward to a distance of about 4 miles from Lake Traverse, the steep bluff gives place, in sections 2 and 11, Walls, to a gentle slope of the surface, which allowed the accumulation of a distinct beach ridge of gravel. This is smoothly rounded, 15 to 20 rods in width, bounded eastward on the side toward the ancient lake by a moderately steep slope which descends 10 or 12 feet, the land 1 to 4 miles distant northeastward within the area that was covered by the lake being 20 to 40 feet below this beach. On the other side this ridge is succeeded by a slight depression 2 to 5 feet deep, beyond which the land soon rises 10 to 15 feet above the beach. The material of the beach is gravel, containing pebbles up to 2 or 3 inches in diameter, but all the surface elsewhere on each side is till. The crest of the beach here is 1,060 to 1,062 feet above the sea.

The beach next passes southeastward through sections 30 and 32, Croke, having in places a maximum altitude of 1,067 feet, being piled several feet above its average height.

Between 2 and 3 miles farther southeast, near the middle of section 9, Tara, the beach ridge sinks to the height of 1,057 feet. Its contour and material, and those of the adjoining areas, are nearly the same as at the locality first described. The width of the gravel beach here is 25 or 30 rods; the smoothed surface of till which descends thence northward is 10 to 20 feet lower in its first mile; on the south the sheet of till is at first for 40 or 50 rods about 5 feet lower than the top of the beach, but beyond this

[1] Am. Geologist, Vol. XV, p. 281, May, 1895. The nomenclature of these subdivisions of the Glacial period was proposed by Prof. T. C. Chamberlin in Chapter XLII of James Geikie's "The Great Ice Age," third edition, 1894, and more fully, first naming the Aftonian stage, in the Journal of Geology, Vol. III, pp. 270-277, April-May, 1895.

MAP OF LAKES TRAVERSE AND BIG STONE AND THE SHORES OF LAKE AGASSIZ NEAR ITS MOUTH.

Scale, 6 miles to an inch.

Lake Area with Beaches   Delta

Altitudes of Railway stations are noted in feet above the sea

it gradually rises to a height 10 to 25 and 50 feet above the beach. The average height of its moderately undulating surface 6 miles to the south, at Graceville, is nearly represented by the railroad at the depot there, 1,109 feet. Farther to the east, through this township, the crest of the beach ranges from 1,057 to 1,062 feet.

For the next 3 miles eastward, lying in the northwest part of Leonardsville, the beach is less conspicuous than usual, but in sections 8, 5, and 4 of this township the shore-line is again distinctly marked by a slight terrace in the till, descending northward in a moderately steep slope 5 to 10 feet, rather than by the usual accumulation of gravel. The top of this terrace is at 1,056 to 1,057 feet.

A few miles farther north, in the southeast part of section 24, Doleysmount, the beach is a low gravel ridge, 20 rods wide and 5 feet high above the adjoining surface, its crest being 1,060 to 1,061 feet above the sea.

These determinations indicate that in Traverse County the surface of Lake Agassiz during its maximum stage was very nearly 1,055 feet above our present sea-level.

In the northwest corner of Stevens County this upper or Herman beach is well displayed in the northwest quarter of section 19, Eldorado, having an elevation of about 1,063 feet. Through section 18 it is 20 to 25 rods wide, with its crest at 1,063 to 1,066 feet, being a gently rounded ridge of sand and gravel, containing pebbles up to 2 or 3 inches in diameter. Its height is 7 to 10 feet above the land next west and 5 feet above the depression next east. The surface on each side is till, slowly falling westward and rising eastward.

In the southeast part of section 7 in the same township the crest of the beach is at 1,067 to 1,070 feet. Here and onward the next 2 miles, through the northwest quarter of section 8, the southeast part of section 5, and the western and northern part of section 4, this formation is finely exhibited in a ridge of gravel and sand 20 to 30 rods wide, 15 feet or more above its base westward, where lay the glacial Lake Agassiz, and 8 to 10 feet above the depression eastward, which divides it from the higher, moderately undulating expanse of till beyond. In the east part of section 5 its elevation is 1,065 feet, and through section 4, 1,065 to 1,072 feet.

This beach near the middle of section 15, Logan, Grant County, is about 30 rods wide, with a broad, nearly flat top, at 1,070 feet, having a descent of about 15 feet on its northwest side to the area of Lake Agassiz and half as much on the southeast, the surface thence rising very gradually in the 1½ miles eastward to Herman. The beach ridge is gravel, the land at each side till.

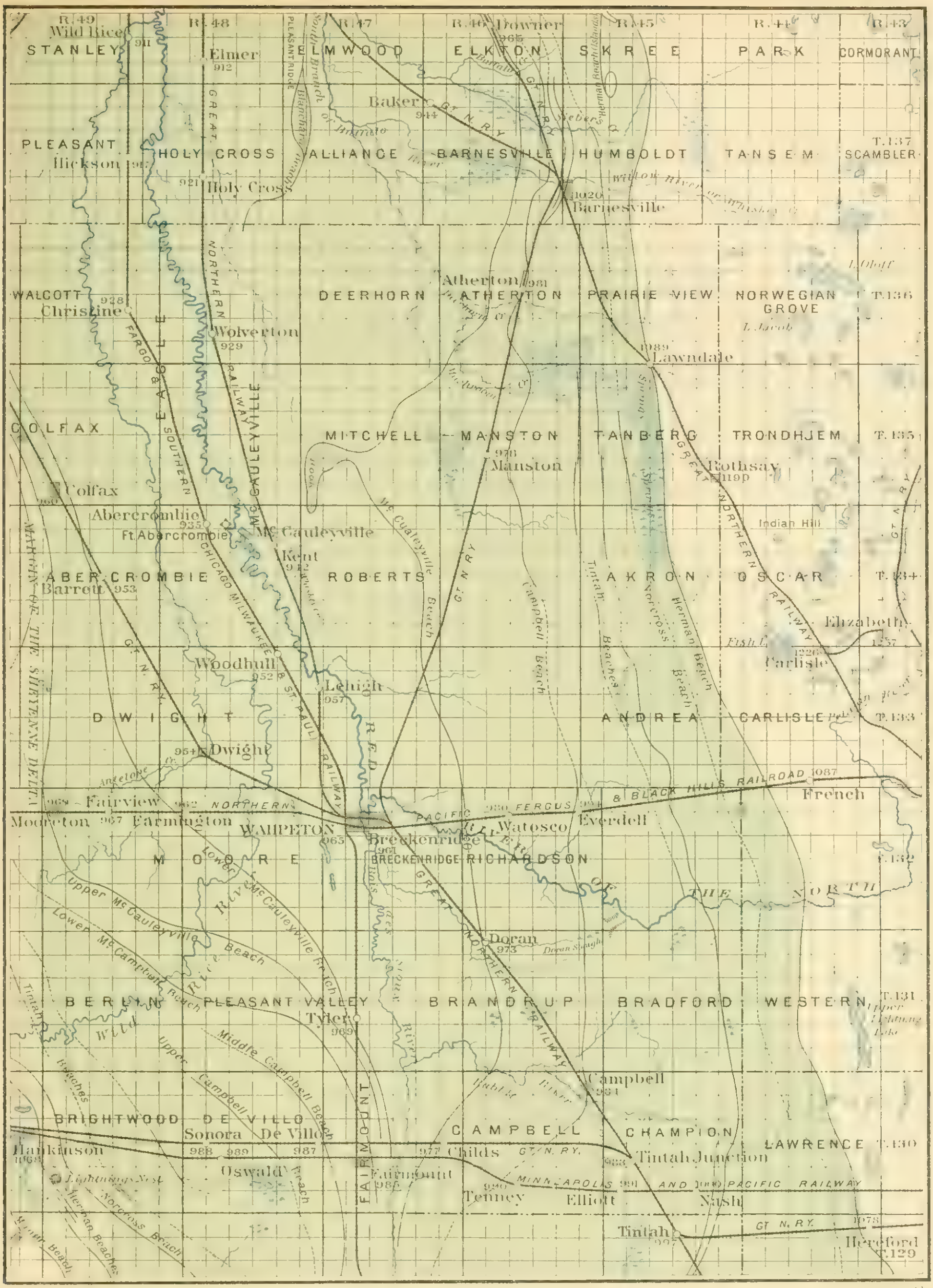
Elevations determined in this vicinity by the railway surveys are as follows: Track at Herman, 1,072 feet above the sea; crest of the beach about 1½ miles northwest of Herman, where it is cut by the railway, and for 50 rods southwestward, 1,064 to 1,066 feet; depression, 40 rods wide, next southeast at the railroad (lowest 20 rods from the top of the beach), 1,060 to 1,063 feet; surface of till at the southeastern snow fences of the railroad, about a third of a mile southeast from the beach, 1,073 feet; at the northwest end of the northwestern snow fences, about 25 rods northwest from the highest part of the beach, 1,054 feet; and at the original one hundred and eightieth mile post, about a quarter of a mile northwest from the last, 1,049 feet.

FROM HERMAN NORTH TO THE RED RIVER.

(PLATES XXIII AND XXIV.)

Several farmhouses are built on the top of the Herman beach between 6 and 10 miles north of Herman. At Joseph Moses's house, in the northwest quarter of section 18, Delaware, the crest of the beach ridge has a height of 1,066 to 1,067 feet, and the piazza of the house is at 1,067 feet. H. D. Kendall's house, at the east side of the southeast quarter of section 12, Gorton, on the western slope of this beach, is at 1,062 feet; while the top of the beach ridge, about 25 rods east of Mr. Kendall's house, is at 1,067 feet.

Crest of the beach through the next 1½ miles north from Mr. Moses's house, along the west side of sections 18 and 7, Delaware, 1,066 to 1,068 feet. The beach for this distance is finely exhibited, having a width of about 25 rods, rising 5 to 8 feet above the depression at its east side and 10 to 15 feet above the land west. L. I. Baker's house sill, in the southwest quarter of section 6, same township, of same height with the top of the beach ridge, on which it is built, 1,068 feet.



MAP OF THE EASTERN SHORES OF LAKE AGASSIZ FROM CAMPBELL NORTH TO BARNESVILLE, COMPRISING WILKIN COUNTY, MINNESOTA, AND PARTS OF ADJOINING COUNTIES.

Scale, 6 miles to an inch.

Lake Area Delta

Altitudes of railway stations are noted in feet above the sea

Beach in section 31, Elbow Lake, not so conspicuous as usual, 1,066 feet; in the southwest quarter of section 18, same township, at the house of Henry Olson, a gracefully rounded low ridge, as elsewhere, composed of gravel and sand, including pebbles up to 3 inches in diameter, 1,065 to 1,066 feet; at Mrs. John S. Ireland's, in the northwest quarter of the same section 18, 1,070 feet; at Dr. J. M. Tucker's, in the northeast quarter of section 2, North Ottawa, 1,071 feet; about a mile north of the last, near the north side of section 35, Lawrence, 1,075 feet; and about a mile farther north, also 1,075 feet. Through nearly the whole of this distance it is a typical beach ridge of sand and gravel.

Crest of beach about 30 rods west of M. L. Adams's house, in the northeast quarter of section 26, Lawrence, 1,075 feet, being 4 feet above the land adjoining this ridge on the east and about 10 feet above the flat land near on the west; in section 23, same township, 1,076 feet; and near the south side of section 10, same township, 1,069 to 1,074 feet.

Extensive sloughs or marshes occur in section 36 and in sections 25 and 24, Lawrence, each being about a mile long, lying on the east side of the beach ridge at Dr. Tucker's and reaching $2\frac{1}{2}$ miles northward; the elevation of these above sea-level is about 1,060 feet.

In the north part of section 10 and the south part of section 3, Lawrence, this shore-line of Lake Agassiz is not marked as usual by a gravel ridge, but by a somewhat abrupt ascent or terrace in the drift sheet of till, the elevation of the top of which, composed partly of gravel, is 1,085 to 1,079 feet; base of this terrace and land westward, consisting of till, slightly modified on the area of Lake Agassiz, 1,060 to 1,050 feet. This escarpment, the eroded shore-line of the lake, passes about 40 rods west of N. S. Denton's house, at the north side of section 10.

Beach in section 34, Western, the most southwest township of Ottertail County, near John F. Wentworth's, 1,070 to 1,075 feet; surface at Mr. Wentworth's barn, 1,072 feet. Beach 25 rods east of Albert Copeland's house, in the southwest quarter of section 28, Western, 1,070 to 1,066 feet; where it is crossed by the old road from Fergus Falls to Campbell, near the northwest corner of this section 28, 1,072 feet; through the next 2 miles north, finely developed, with nearly constant height, 1,072 feet, being 7 to 10 feet above the depression at its east side and 20 feet above the area westward, which was covered by Lake Agassiz; at Michael J. Shortell's, section 9, same township, 1,073 feet; 1 mile farther north, 1,078 feet; and at A. J. Swift's, in the northwest quarter of section 4, 1,076 feet. The beach at Mr. Swift's and for half a mile farther north is well exhibited, and, as in many other places, is bordered on its east side by a narrow strip of marsh.

Beach in the northeast quarter of section 33, township 132, range 44, 1,076 feet; top of large aboriginal mound, situated on the beach here, 1,082 feet; land 30 rods west, 1,060 feet; lakelet 250 feet in diameter, about an eighth of a mile northeast from the large mound, 1,051 feet.

Red River of the North, near the northeast corner of section 33, township 132, range 44, 1,014 feet; on the line between this township and Buse, 1,041 feet; and at Dayton bridge, in the southwest quarter of section 20, Buse, 1,064 feet, being 8 feet below the bridge. S. A. Austin's house foundation in the southwest quarter of section 29, Buse, 1,147 feet. Old grade for railroad at Dayton bridge, about 1,102 feet.

No noticeable delta was brought into Lake Agassiz by the Red River.

FROM THE RED RIVER NORTH TO MUSKODA.

(PLATES XXIV AND XXV.)

Crest of beach near the south side of section 21, township 132, range 44, 1,077 feet; in this section 21, an eighth of a mile north of the road from Fergus Falls to Breckenridge, 1,079 feet; and for the next mile north, 1,077 to 1,080 feet. This is a typical beach ridge, gently rounded, composed of sand and gravel, containing pebbles up to 3 inches in diameter; its width is 30 to 40 rods, and its height above the very flat area on its west side, which was covered by Lake Agassiz (usually somewhat marshy next to the beach), is about 15 feet. On the east there is first a depression of 4 to 6 feet, succeeded within a fourth of a mile eastward by a gentle ascent, which rises 5 to 10 or 15 feet above the beach. The material on each side of the beach is till, slightly modified by the lake on the west. It is all fertile prairie, beautifully green, or in many places yellow or purple with flowers during July and August, the months in which this survey was made. In August, 1881, no houses had been built on this beach, nor within 1 mile from it, along its first 11 miles north from the Red River, the first house found near the beach being in section 26, Akron, in Wilkin County.

Beach at a low portion, probably in the southeast quarter of section 5, township 132, range 44, 1,075 feet. A lake nearly a mile long lies on the flat lowland about 1½ miles west from this low part of the beach. The elevation of this lake was estimated at 1,055 or 1,050 feet; it is only a few feet lower than the general surface around it. Beach, probably near the north side of this section 5, 1,078 feet. On its east side here and for a half mile both to the south and north is a slough, partly filled with good grass and partly with rushes; its width is about a quarter of a mile, and its elevation about 1,070 feet. The land west of the beach descends, within 1 or 2 miles, from 1,060 to 1,050 feet.

Beach at its lowest portion for this vicinity, about a half mile north of the preceding and near the center of section 32, Carlisle, 1,070 to 1,068 feet, being only 2 feet above the marsh or slough on its east side. A railroad grade, abandoned, lies a third of a mile east of this. Beach a fourth of a mile farther north, 1,077 feet, and, about 1 mile north from its lowest portion, 1,075 feet, cut by a ravine, the bottom of which is nearly at 1,063 feet. This ravine is some 30 rods west of the abandoned railroad embankment.

Railroad grade where it crosses the beach, about a mile northwesterly from the ravine mentioned, 1,077 feet. Beach here, 1,076 feet, being 8 to 10 feet above the slough on its east side, and having about the same height above the marsh next to it westward. The material of the beach, shown by the railroad embankment, which is made of it along a distance of a third of a mile, is coarse gravel, with abundant pebbles of all sizes up to 6 inches in diameter, fully half of them being limestone.

Crest of beach in the south half of section 23, Akron, 1,079 to 1,080 feet; in the northwest quarter of this section 23, 1,075 to 1,080 feet. Through sections 14, 10, and 3, Akron, the beach does not have its ordinary ridged form, but is mostly marked by a deposit of gravel and sand lying upon a slope that rises gradually eastward. Its elevation here is

1,075 to 1,085 feet. In the southern part of this distance, probably in the southwest quarter of section 14, the margin of the flat, somewhat marshy area that appears to have been covered by Lake Agassiz is very definite at 1,075 feet, which thus was probably the height of the lake here.

Beach in the southwest quarter of section 34, Tanberg, composed of gravel, nearly flat, 25 to 30 rods wide, 1,084 to 1,087 feet, bordered by a depression of 2 to 5 feet on the east and by an expanse 10 to 15 feet lower on the west. Beach in the northwest quarter of this section 34, also 1,084 to 1,087 feet. Here the land next east does not present the usual slight hollow dividing the beach ridge from the higher land eastward; instead is a springy belt, mostly 1,089 feet, quite marshy, yet slowly rising 2 to 4 feet above the belt of beach gravel. Occasional hummocks, about 2 feet above the general surface and covered with rank grass about 6 feet high, form part of this belt of marsh and shaking bog. Next to the east is a slough about 1,086 feet, or 3 feet below the springy tract, and this is succeeded by a surface of moderately undulating till, which rises gradually eastward.

Sloughs, mostly filled with rushes and having areas of water all the year, occupy a width of 1 to 2 miles next west of the shore-line and beach of Lake Agassiz and extend nearly continuously 10 miles from south to north, from the middle of Akron to the south edge of Prairie View Township. The elevation of this belt of sloughs is 1,080 to 1,050 feet, being considerably lower on its west than on its east border. The highest land westward in the west part of Tanberg, between these marshes and Manston, is about 1,060 feet. Along most of this distance the ordinary beach ridge is wanting.

Great Northern Railway track at Lawndale water tank, 1,089 feet. Here a side-track has been laid, extending about a third of a mile northward, with its northern end some 50 rods east of the main line, to take ballast from the beach, which is well exhibited here and onward, having its typical ridged form. The elevation of its crest is 1,091 to 1,094 feet. It is composed of gravel and sand in about equal amounts, interstratified mainly in level layers, but with these often obliquely laminated. Most of the gravel is quite fine, and the coarsest gravel found here has pebbles only 2 to 3 inches in diameter. About half of it is limestone.

Beach ridge 1 mile farther north, 1,094 feet; three-fourths of a mile north of the last and close south of a ravine, 1,099 feet. Beach about 3 miles north from Lawndale water tank, probably in the south part of section 16, Prairie View, not ridged, but a belt 25 rods wide, of gravel and sand, on a slope of till that rises eastward, 1,080 to 1,102 feet. Beach, a ridge of gravel and sand, a third of a mile north from the last, 1,105 feet. The beach in section 9 of this township is spread more broadly than usual, its higher parts being 1,095 to 1,107 feet. Here the beach deposits are crossed obliquely by several broad depressions 10 to 15 feet deep, running south-southwest. The depression east of all these banks of gravel and sand is about 1,090 feet above the sea.

Entering Clay County, the elevation of this upper or Herman beach at the east side of section 33, Humboldt, is 1,100 feet above the sea. The land thence for two-thirds of a mile east is low and smooth, not higher than the beach. Beyond this the next third of a mile northeastward, in the north part of section 34, is very rocky, with many bowlders up to 6 and rarely 10 feet in diameter, the contour being moderately rolling 10 to 30 or 40 feet above the beach. Farther eastward here and through the next 15 miles north to the Northern Pacific Railroad, the moderately rolling or smoothly hilly till rises 100 to 250 feet above this beach within the distance of about 10 miles between it and the east line of the county.

Elevation of the crest of the beach ridge in the east half of section 28, Humboldt, one-fourth to three-fourths of a mile south of Willow River, 1,098 to 1,100 feet. In the 3 miles westward to Barnesville the area that was covered by Lake Agassiz shows here and there bowlders projecting 1 to 2 feet above the surface, which is till, slightly smoothed by the lake.

Great Northern Railway track at Barnesville, 1,020 feet.

The beach for three-fourths of a mile north from Willow River consists of a belt of gravel and sand, lying on an eastwardly ascending slope of till. Through the next $1\frac{1}{2}$ miles northward, in the northwest quarter of section 22 and in section 15, Humboldt, the shore of Lake Agassiz is not marked by the usual beach of gravel and sand, but instead becomes a belt of marshy and springy land 20 to 50 rods wide, rising by a gentle slope eastward, rough with many hummocks and hollows, in some portions forming a quaking bog, in which horses and oxen attempting to cross are mired.

In the next 2 miles northward, through sections 10 and 3, Humboldt, the beach is nowhere well marked as a ridge, but is mainly a belt of gravel and sand, lying on a slope of till, which gradually rises 30 or 40 feet higher at the east. The lack of typical beach deposits on this shore through the north half of this township is probably due to its sheltered situation in the lee of islands on the northwest. The course of the shore currents, determined by the prevailing winds, seems to have been southward, as on the shores of Lake Michigan.

Highest part of southern island in the east edge of Lake Agassiz, in the northeast quarter of section 5, Humboldt, extending northward into Skree, 1,117 to 1,122 feet. This island was about 1 mile long from south to north. Crest of beach on its west side, a well-developed ridge of gravel near the middle of the north line of section 5, 1,095 feet; and for a third of a mile north-northwest from this, 1,094 to 1,096 feet. On the east side of the beach, as it continues northward, is a slough two-thirds of a mile long from south to north and about 30 rods wide, 1,085 feet. This was evidently filled by a lagoon, sheltered on the southeast by the island and separated from the main lake by the beach. Toward the northeast it widened into a shallow expanse of water 8 to 15 feet deep, about 1½ miles wide, divided from the broad lake on the west by two islands and this beach or bar which connected them. Lake Agassiz here appears to have stood at the height of 1,090 to 1,095 feet.

Top of the beach or bar in the north part of section 32, Skree, a broad rounded ridge of gravel, with pebbles up to 3 or 4 inches in diameter, 1,103 feet, and through the next half mile, in the south half of section 29, 1,102 to 1,104 feet. Along part of this distance the beach ridge is bounded eastward by a steeper descent than usual, the land next east being 1,085 to 1,090 feet above the sea. This beach or bar continues northward in a typical ridge through sections 29 and 20, same township.

Beach or bar at L. Williams's house, in the southeast quarter of section 20, Skree, 1,101 feet; a quarter of a mile farther north, 1,106 feet; three-quarters of a mile north of Mr. Williams's, near the middle of the north line of section 20, 1,110 feet, continuing a very definite ridge through the south half of section 17, 1,109 to 1,110 feet.

Near the middle of this section 17 the beach deposit of gravel and sand ceases at the west side of the northern island, which was situated in the east half of this section and extended also eastward in a long, low projection nearly across the south side of section 16, and northward half way across section 8. Highest part of this island, in or near the northeast quarter of the northwest quarter of section 17, about 1,125 feet. The old shore of the north half of this island has no beach ridge nor other deposits of gravel and sand, but is plentifully strewn with large bowlders up to 5 and 10 feet in diameter, and many of these project 2 to 5 feet above the general surface. The lake waves eroded here, and deposited the sand and gravel gathered from this till as a beach a little farther south.

North and northeast from this northern island a lower expanse, nearly level and in some portions marshy, resembling the broad, flat valley of the Red River, extends 1½ miles to the east shore of Lake Agassiz, its height being 1,075 to 1,090 feet, or 10 to 25 feet below the surface of the ancient lake. The distance between these islands was 2 miles, and the distance from the summit of the first to that of the second, nearly due north, 4 miles. Each of them rose about 25 feet above Lake Agassiz. The strait between them and the mainland eastward was 10 to 20 feet deep and from 1 to 1½ miles wide, excepting a narrow place near the southeast corner of section 16. East of the northern island the main shore of the lake was indented by a bay a third to a half of a mile wide and about 10 feet deep, stretching 2½ miles southeastward from the lakelet at the northwest corner of section 10 to the west part of section 23, Skree. The shore of the lake east of its islands along this bay and northwesterly to the north line of this township lacks the beach deposits which elsewhere distinguish it.

In its continuation northwestward the shore-line of the old lake runs diagonally across section 32, Hawley, where it again presents the anomalous character of a very springy and marshy belt, 20 to 40 rods wide, rough with hummocks and in many places so deeply miry that it is dangerous for teams. This boggy tract has a gentle descent westward, its lower portion being about 1,085 feet, and its upper border, very nearly level across this entire section, being 1,098 to 1,100 feet, which was almost exactly the height of Lake Agassiz, as shown by its distinct beach of gravel and sand at the south and north. Next eastward rises a moderately undulating slope of till, strewn with abundant bowlders; and rarely a bowlder 2 to 5 feet in diameter is seen on the springy land that marks the border of the ancient lake.

DELTA OF THE BUFFALO RIVER.

(PLATE XXV.)

The delta brought into the east side of Lake Agassiz by the Buffalo River extends about 5 miles southwestward from Muskoda, forming a continuously descending plain of stratified sand and fine gravel, declining from 1,100 feet near Muskoda to 1,073 feet at its southwestern limit in the north part of section 34, Riverton. Here and northward along a distance of 3 miles to the Buffalo River this delta plain is terminated by a steep slope, 25 to 40 feet high, like the face of a terrace. The outer portion of the original delta, beyond this line, has been carried away by the waves and shore currents of the lake when it stood at the lower levels marked by the Norcross and Tintah beaches, as shown in fig. 11.

FIG. 11.—Section across the delta of the Buffalo River. Horizontal scale, one-half mile to an inch.

Northern Pacific Railroad track at Muskoda, 1,090 feet. Threshold of church a quarter of a mile southeast from Muskoda depot, 1,113 feet. Beach here and for a third of a mile south to the Buffalo River, as also at the excavation for the railroad, 25 rods north of the church, nearly uniform elevation of its crest, 1,113 to 1,114 feet. The beach is 35 rods wide, rising 14 or 15 feet in a gentle swell above the edge of the delta of modified drift on the west and descending the same amount to the depression at its east side. It is made up of interstratified gravel and sand, the former prevailing, including pebbles up to 3 or 4 inches and rarely 6 or even 9 inches in diameter, all waterworn. Half or two-thirds of these pebbles and cobbles are limestone. No bowlders occur here, nor are they found in any of the beach deposits of Lake Agassiz.

MAP OF THE EASTERN BEACHES AND DELTAS OF LAKE AGASSIZ FROM MUSKODA NORTH THROUGH CLAY AND NORMAN COUNTIES, MINNESOTA, TO THE SAND HILL RIVER.

Scale, 6 miles to an inch.

Lake Area Deltas

Altitudes of Railway stations are noted in feet above the sea

The area of the Buffalo delta extends 7 miles from north to south, with a width of 2 to 3½ miles. Its average thickness is probably about 50 feet, and its volume is therefore approximately one-sixth of a cubic mile. It would make a very sightly hill if its material were piled on the flat plain of the Red River Valley, for it would cover a circle 2 miles in diameter and rise to a peak about 900 feet high. Lying on the slope which rises east from this valley, however, and being spread over a considerable area with comparatively little thickness, its mass does not especially command attention until investigation reveals that it came almost wholly from drift that was contained within the ice-sheet, being deposited here by the streams from its melting.

The existence of well-defined and conspicuous delta deposits having the altitude of the Herman beach, where the Buffalo and Sand Hill rivers enter the east side of the area of Lake Agassiz, while no such deposits are found where other streams of equal or larger size enter this area, as the Red River, the Wild Rice, and the Red Lake River, seems explicable only by the derivation of the gravel and sand forming these deltas mostly from the englacial drift of the melting ice-sheet upon the adjacent area at the east. Comparatively small tribute was brought into this glacial lake from the erosion of the stream valleys after their areas became uncovered from the ice, excepting where it received the very large rivers flowing from other glacial lakes at the west. Here and there, because of irregularities in the outline of the ice-sheet, by which the drainage of its surface was poured down upon certain limited tracts and was discharged thence along the courses of now existing streams, as the Buffalo and Sand Hill rivers, and because the retreat of the ice was now rapid and anon was interrupted by halt or readvance, with the accumulation of moraines, much of the material which had been inclosed within the basal part of the ice-mass seems to have been washed away by its streams and carried into Lake Agassiz to form deltas.

When such glacial streams encountered no lake to receive their tribute, and flowed far before reaching the sea, the gravel, sand, and fine silt or clay which they brought were spread by the rivers along their courses as plains of modified drift. In some instances, since the ice-sheet disappeared and the drainage from it ceased, these plains are left far from any important stream. Similarly, on the west side of Lake Agassiz, a large delta extending southward from the Elk Valley was deposited by a proportionally large river flowing from the ice-sheet, but no considerable river now enters the lake area there.

Opposite to the Buffalo delta, within a distance of about 30 miles to the east, the ice front was indented by a great embayment or reentrant angle at the time of formation of the eighth or Fergus Falls moraine. While the ice border was receding from the seventh or Dovre to the Fergus Falls moraine, the conditions of its melting were probably unfavorable for the formation of deltas in this glacial lake; but during the accumulation of the Fergus Falls moraine the drainage from the ice border converged toward the Buffalo River and caused its delta to be formed. Again, when the ice-sheet had retreated another stage and was forming its ninth or Leaf Hills moraine, this indentation of the ice front, having fallen back about 40 miles northward from its former position, sent its glacial streams to the Sand Hill River, and a second delta was brought into the lake.

In the same manner, the much larger Sheyenne, Elk Valley, Pembina, and Assiniboine deltas, brought into Lake Agassiz from the west and having likewise the height of the early Herman beaches, are referable chiefly to the drainage from the melting ice-sheet, and in less measure to erosion of the river valleys. The material of all the deltas of this lake is principally modified drift, rather than alluvium like that which the streams now transport and spread over their bottom-lands at every stage of flood.

FROM MUSKODA NORTH TO THE SAND HILL RIVER.

(PLATE XXV.)

In the next 2 miles north of Muskoda the crest of the Herman beach ridge ranges mainly from 1,113 to 1,125 feet above the sea; at its lowest depression, about 1 mile north of Muskoda, its height is 1,105 feet; at William Perkins's house, in the southeast quarter of section 30, Cromwell, 1,122 feet; an eighth to a third of a mile south-southeast from Mr. Perkins's, 1,130 feet. A nearly or quite continuous depression, from a fifth to a third of a mile wide, lies at the east side of this beach, declining in elevation from 1,118 feet near Mr. Perkins's house to 1,100 feet at Muskoda. This distance is about 3 miles.

The surface of Lake Agassiz in its maximum stage was, at Muskoda, 1,105 feet, very approximately, above our present sea-level. Within 5 to 10 miles northward its height seems to have been 1,110 to 1,115 feet.

Beach through the north half of section 30, Cromwell, 1,128 to 1,131 feet, and through the west part of sections 19 and 18, same township, 1,125 to 1,130 feet, composed of sand and fine gravel, not generally in a typical ridge, but often with a depression 2 to 5 feet lower eastward and bounded on the west by a descent of about 30 feet within an eighth of a mile. A surface of slightly undulating till rises very gradually from this beach eastward.

Herman beach at a high portion in or near the southeast quarter of section 1, township 140, range 46, 1,136 feet. For a mile next south from this point it is a finely rounded ridge of gravel, rising northward from 1,130 to 1,136 feet. The depression at its east side is 4 to 6 feet lower; then the surface gently rises at a quarter to a third of a mile from the beach to 1,135 or 1,140 feet, beyond which eastward this nearly level but slightly undulating expanse of till rises only 5 or 10 feet per mile. Beach a fourth of a mile north-northeast from the high point mentioned, probably in the northwest quarter of section 6, Cromwell, 1,128 to 1,127 feet. This is an ordinary beach ridge of gravel and sand, with a depression of 2 or 3 feet next east.

Near the south line of section 29, Keene, both the Herman and Norcross beaches, here about two-thirds of a mile apart, are intersected by a watercourse. At its north side the upper or Herman beach, near the east line of section 29 and in the northwest quarter of section 28, consists of two well-marked ridges of gravel and sand, some 30 rods apart and about 10 feet above the land eastward and between them. These ridges unite in or near the southwest quarter of the southwest quarter of section 21, at the height of 1,130 to 1,132 feet. Beach three-fourths of a mile farther north, probably near the north line of section 21, a typical gravel ridge, 1,134 feet, 10 feet above the land next east; but a sixth of a mile farther northeast this beach ridge is depressed to 1,123 feet.

A lower beach, contemporaneous with the Herman beach farther south, but formed when the surface of the lake in this latitude had fallen slightly from its highest level, is finely exhibited at a distance of one-third to two-thirds of a mile west from the upper beach, through the 4 miles from the south side of section 20 to the northeast corner of section 4, Keene. The elevation of this secondary beach in the south part of section 20 is 1,115 feet; thence to a stream near the east line of the southeast quarter of section 17, 1,118 to 1,123 feet; at each side of this stream, 1,118 feet; northward, in the northwest part of section 16 and in the southwest quarter of section 9, 1,118 to 1 121 feet; and in the north part of section 9, 1,121 to 1 127 feet.

Upper beach through the west part of section 10, Keene, 1,130 to 1,137 feet, increasing in height from south to north. This is a typical beach ridge of gravel, with a rather abrupt descent on its east side to land 6 or 8 feet lower, which thence ascends with a slightly undulating surface eastward. The elevation of the upper beach in this township, 1,123 to 1,137 feet, shows that the height of Lake Agassiz here, during its maximum stage, was about 1,120 feet. The secondary beach was made by the lake after it had fallen 6 to 10 feet.

In section 3, Keene, the crest of the upper beach is at 1,134 to 1,137 feet, 10 feet above the land next east; and the top of the secondary Herman beach, parallel with this and about three-fourths of a mile distant to the northwest, in sections 4 and 34, is at 1,123 to 1,127 feet, being thus 10 feet lower than the highest parts of the eastern beach. Extensive sloughs, inclosing lakelets, lie between these beaches in sections 34 and 35, Hagen, at an elevation of 1,115 to 1,120 feet, but sinking northward to 1,105 feet. The secondary beach continues to the northeast corner of section 26, declining in height northeastward as it approaches the South Branch of the Wild Rice River, being at 1,125 to 1,115 feet.

Upper beach in section 35 and in the south part of section 25, Hagen, 1,140 to 1,142 feet. This is a typical beach ridge of sand and gravel, about 30 rods wide, with the land next southeast 5 to 8 feet lower, and divided from the secondary beach northwesterly by a slough about 1 mile wide, this slough being at 1,115 to 1,105 feet.

Crest of beach at B. O. Helde's house, in the south half of the southwest quarter of section 30, Ulen, 1,138 feet. The flat expanse of the Red River Valley reaches east on the South Branch of the Wild Rice River to section 16, Hagen, probably being there about 975 feet above the sea, or 160 feet below this upper beach of Lake Agassiz, 4 or 5 miles southeast.

Beach through sections 30 and 29, Ulen, extending 1½ miles east-northeast from Mr. Helde's to the South Branch of the Wild Rice River, in a low, gently rounded ridge of gravel, 30 rods wide, 5 to 8 feet above the area of till next southeast and about 15 feet above the surface close at its northwest side, 1,138 to 1,142, mostly 1,140 feet.

South Branch of Wild Rice River, in the southwest quarter of section 21, Ulen, 1,095 feet. The beach is developed as a typical gravel ridge, in or near the west half of section 16, Ulen, a half mile to 1½ miles north of the South Branch, with its crest at 1,140 to 1,143 feet; surface of till an eighth to a quarter of a mile next east, 1,135 feet. Farther east the slightly or moderately undulating expanse of till has an average ascent of about 10 feet a mile for 15 miles to the base of the high land at the White Earth Agency, which is dimly visible, blue, close to the horizon. Westward the surface gradually descends to the Norcross beach, nearly 60 feet lower, which is the farthest land in sight in that direction, about 3 miles distant, beyond which lies the flat Red River Valley.

Entering Norman County, an unusually high portion of the Herman beach is found in or near the southeast quarter of the southeast quarter of section 33, Home Lake, having its crest at 1,149 feet. It holds this elevation for an extent of some 20 rods, on each side of which its height is mostly from 1,139 to 1,145 feet. Its material is coarse gravel, principally limestone, with pebbles and cobbles up to 4 and 6 inches in diameter. Surface close east of this beach, 1,137 feet. A slight swell above the general descending slope westward, about 2 miles distant, has a height very nearly 1,125 feet. This may be the continuation of the secondary beach that was seen in Keene Township. It hides the view farther west, except from the highest point of the beach (1,149 feet), where the distant belts of timber along the Red and Wild Rice rivers are visible.

Beach at J. T. Huseby's house, in the northwest quarter of section 26, Home Lake, 1,147 feet; through 1¼ miles next north, in the northwest quarter of section 26 and the west part of section 23, forming a broad, low ridge of gravel and sand, 1,145 to 1,149 feet. In or near sections 17 and 16, Flom, a prominent, massive hill, called "Frenchman's Bluff," of somewhat irregular form, composed of morainic till, rises 150 feet or more above this beach.

Through the west part of the northwest quarter of section 14, Home Lake, the beach is mostly a typical gravel ridge, with its crest at 1,147 to 1,152 feet. In the northwest quarter of section 11, same township, it curves northeastward and attains an unusually massive development, its crest being at 1,150 to 1,158 feet, rising 15 feet above the land next southeast and 25 or 30 feet above the border of the area of Lake Agassiz at its northwest side.

Crest of beach, a well-marked gravel ridge, near the southwest corner of section 1, Home Lake, 1,156 feet, and an eighth of a mile east-northeast from this, 1,150 feet. J. G. Aurdal's house, foundation, in the northeast quarter of section 6, Flom, 1,148 feet. This is situated on the beach, which here is a deposit of gravel and sand 8 feet or more in depth, lying upon a slope of till that ascends southeastward. Anton Johnson's store, foundation, on this beach, in the southeast quarter of section 31, Fosum, 1,142 feet. Creek flowing northwesterly between the last two, about 1,105 feet. Wild Rice River, 2 miles north of Johnson's store, approximately 1,050 feet.

Secondary Herman beach, a well-marked, broad, smoothly rounded gravel ridge, extending from southwest to northeast, crossed by the township line road at the north side of the northeast quarter of the northwest quarter of section 2, Home Lake, 1,137 feet. It is about 30 rods wide, and rises 5 to 10 feet above the depression at its southeast side.

A broad belt of timber borders the Wild Rice River, lying mostly on its north side, in Fosum and Wild Rice townships, and at the time of this survey, in 1881, no road or bridge afforded a crossing here. Therefore this series of levels was resumed north of the Wild Rice River by starting from Rolette station of the St. Paul, Minneapolis and Manitoba (now the Great Northern) Railway, 892 feet above the sea, near the middle of section 17, Lockhart, about 1½ miles north of the Lockhart farm. Proceeding eastward from this point, the first observations of the upper beach were in Waukon, Sundal, and Garfield townships.

This beach is intersected by the Wild Rice River near the middle of Fosum, and thence it passes north-northwesterly through the west part of Waukon. In sections 7 and 6, Waukon, it is a low, smooth ridge of gravel and sand about 25 rods wide, rising 5 to 10 feet. In the west half of this section 6 and in section 36, Sundal, the old Pembina trail lies on it.

About 2 miles west of the upper beach, a secondary Herman beach, of similar material and contour, probably 20 feet lower, was observed a few rods east of the stake at the middle of the north side of section 14, Strand, having a height of 6 to 8 feet above its base, with a smaller ridge of sand and gravel, 3 feet high above its base, close west of this stake. Again, a half mile farther west, in the northeast corner of section 15, Strand, another Herman beach, probably 10 feet below the last, was noted, having a height of 4 or 5 feet above its base.

Traveling northwestward along the Pembina trail, the upper beach ridge was not distinctly observed after leaving section 36, Sundal, until it is again occupied by the trail in section 9 of this township. The intervening 3 miles are flat and nearly level. Probably the beach, less noticeable than usual, lies within a half mile or 1 mile east of the trail here. In the eastern part of section 9 this beach is about 25 rods wide, rising 5 feet from its east side, and descending 10 feet to its western base, which was the margin of Lake Agassiz.

Thence the upper beach extends nearly due north through the east edge of section 4, Sundal, and section 33, Garfield. In the east edge of the southeast quarter of section 28 and the west edge of the northwest quarter of section 27, Garfield, it is a typical ridge of gravel and sand, with its crest 1,166 to 1,173 feet above the sea. There is a gradual descent toward the west. The depression on the east is a sixth to a fourth of a mile wide, sinking 6 to 10 feet below the beach. Farther eastward the land is moderately undulating till, rising 20 to 30 feet above the beach and bearing frequent groves of small poplars, bur oak, and canoe birch.

Water in the Sand Hill River at the ford of the old Pembina trail, in the west part of section 28, Garfield, ordinary low stage, July 26, 1881, 1,071 feet.

DELTA OF THE SAND HILL RIVER.

(PLATES XXV AND XXVI.)

When Lake Agassiz stood at its greatest height, the Sand Hill River brought into its margin a delta 6 miles long from south to north and 3 miles wide, reaching from the upper beach to the west side of Garfield and Sundal townships (fig. 12). This deposit of stratified gravel and sand has about an equal area and thickness with the delta of the Buffalo River at Muskoda. Its surface descends slowly westward and is crossed by the lower Herman and the Norcross shores, though these lake levels are not generally traceable. The Tintah shores pass along its western margin, which in some portions was worn away to a low escarpment, steeper than its original frontal slope, while the eroded sand and gravel, after being carried some distance southward, but not wholly beyond the delta, were deposited in beach ridges. Upon the delta plain many dunes of small and

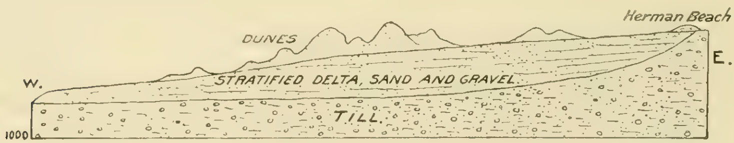


FIG. 12.—Section across the delta of the Sand Hill River. Horizontal scale, one-half mile to an inch.

large size, seen from a distance of 10 or 12 miles across the lower expanse at the west, have been heaped up by the winds, probably mostly before vegetation had spread over this area after the withdrawal of the glacial lake.

As was stated on page 291, in the description of the Buffalo delta, both these river deposits in the edge of Lake Agassiz seem attributable to conditions of the recession of the ice-sheet. Their gravel and sand were doubtless mainly englacial drift and were brought into this lake by streams which had gathered their freight upon the ice surface during the time of formation of terminal moraines. One of these glacial rivers, supplying a part or perhaps nearly all of the Sand Hill delta, flowed from an angle of the ninth or Leaf Hills moraine in a channel which has been traced 16 miles to its junction with the Sand Hill River, as described on page 164. Its sand and fine silt were carried more than 30 miles by the strong current

MAP OF THE EASTERN SHORES OF LAKE AGASSIZ IN THE VICINITY OF MAPLE LAKE AND NORTHWARD, IN POLK AND MARSHALL COUNTIES, MINNESOTA.

Scale, 6 miles to an inch.

Lake Area Delta

Altitudes of railway stations are noted in feet above the sea

of the river in its irregular course before they were deposited in Lake Agassiz, where they at once settled to the bottom of the still water.

In the south half of section 32, Garfield, and in a belt which thence extends approximately north and south, the surface of this delta, as it was originally deposited, falls toward the west with a slope of 25 or 30 feet in 1 mile, from 1,125 or 1,130 feet to about 1,100 feet above the sea. Beneath this plane, however, channels have been eroded by the winds, and sand hills 25 to 75 feet above it have been blown up in irregular groups and series, scattered over a tract about a mile wide and extending 3 or 4 miles southward from the Sand Hill River, in section 29, the northeast part of section 30, and in sections 31 and 32, Garfield, and reaching southward in sections 5 and 8, Sundal. The most southern of these hills is an isolated group in the east part of the northeast quarter of section 18, Sundal. Another isolated group lies north of the Sand Hill River, in the northwest quarter of section 16, Garfield. These sand dunes are in part bare, being so frequently drifted by the winds as to allow no foothold for vegetation; other portions are clothed with grass or with bushes and scanty dwarfed trees, including bur oak, the common aspen or poplar, cottonwood, green ash, black cherry, and the frost grape.

Elevations of the highest points of these dunes, in order from south to north, are approximately 1,190, 1,180, and 1,200 feet. The highest dune appears to be in or near the east half of the northeast quarter of section 30, Garfield.

Secondary Herman beach, a smoothly rounded ridge of gravel and sand 10 to 15 feet high above the adjacent level, 1,148 to 1,153 feet above the sea, about three-fourths of a mile east of the old Pembina trail, in the west half of sections 21 and 16, Garfield, extending 1½ miles north from the Sand Hill River to the cluster of dunes in the northwest quarter of section 16.

VICINITY OF MAPLE LAKE.

(PLATE XXVI.)

The upper Herman beach, the first of the series which was formed in the vicinity of Maple Lake contemporaneously with the single Herman beach farther south, runs approximately from south to north, through or near the northeast corner of section 4, Garfield It is a smooth gravel ridge, in some parts hidden by scattered groves, with its crest 1,165 to 1,175 feet above the sea. Farther east is a large area of woodland. The second Herman beach, in the east part of section 5, this township, and section 32, Godfrey, about a mile west from the upper beach, has a height of 1,149 to 1,153 feet, being a ridge of gravel and sand about 40 rods wide, with very gentle, prolonged slopes toward both the east and west. Natural surface at the northeast corner of section 32, Godfrey, 1,146 feet. Third Herman beach, running north, in the northwest quarter of section 5, Garfield, and the west part of section 32, Godfrey, a half or two-thirds of a mile west from the last, 1,130 to 1,135 feet, consisting of a distinct ridge in its southern part, but farther north being a flat area of gravel and sand, slightly elevated above the land next east.

Second Herman beach, a broad, low ridge of gravel and sand, extending north-northeast through section 28, Godfrey, from its southwest corner to its north line, 1,148 to 1,150 feet. The northward continuation of this beach is a low, flattened ridge, the western one of two parallel ridges of gravel below that of the upper beach, extending northeasterly and northerly through or near the west edge of section 10, Godfrey, 1,150 to 1,154 feet. Through the next 3 miles in section 3, Godfrey, and in the east part of sections 35 and 26 and the northwest quarter of section 25, Tilden, it is a prominent beach ridge, with its crest at 1,153 to 1,161 feet, somewhat steep on its east side, which descends about 10 feet to a belt of lowland and marsh that divides it from the parallel beach a quarter to a third of a mile east.

The eastern one of these parallel beach ridges is only 8 or 10 feet below the average elevation of the upper beach. It probably marks a slight rise of the land here; but no corresponding beach formation has been observed on this latitude in North Dakota. It is clearly continuous 8 miles, the first 4 miles extending northerly and the next 4 miles easterly. These parts are connected in section 25, Tilden, by a graceful curve, that portion of this beach and its extent thence eastward being known as the "Attix ridge," from Henry and William Attix, brothers, who have built their houses upon it. In its northward course, nearly through the middle of sections 10 and

4, Godfrey, its crest is at 1,158 to 1,163 feet; in the west edge of section 36, Tilden, and along its curved course to the northeast and east at the west and north sides of section 25 and in the southeast part of section 24, Tilden, 1,163 to 1,168 feet, and in sections 21 and 22, Grove Park, 1,171 to 1,173 feet. A slough, a third to a half of a mile wide, extends along the east side of this beach in section 3, Godfrey, and in the southeast part of Tilden, having a height of 1,155 to 1,160 feet.

Upper beach in the southwest quarter of section 11, Godfrey, forming a plain of stratified gravel and sand a quarter or a third of a mile wide from east to west, 1,168 to 1,173 feet. This beach near the south side of section 11 becomes a distinct gravel ridge of the usual character, about 25 rods wide, with its crest at 1,173 feet, bordered by a slough 20 to 40 rods wide at its east side. About a third of a mile farther southeast and some 50 rods west of the southwest extremity of Maple Lake, in section 14, Godfrey, the elevation of this beach ridge is 1,175 to 1,178 feet.

Maple Lake, water surface July 28, 1881, 1,169 feet. This lake, 6 miles long and averaging about a half mile wide, has a maximum depth of 20 feet near its southwestern end, and is mainly 10 to 15 feet deep along its central portion.

Upper beach, top of its well-marked gravel ridge in the east edge of the northeast quarter of section 3, Godfrey, about 20 rods north of Mr. Horton's, 1,180 feet. Beyond this point, through its next 2½ miles, curving from a northward to a northeastward and eastward course, this upper beach of Lake Agassiz is magnificently exhibited, forming a massive, gently rounded ridge of gravel and sand about 30 rods across, with its crest 1,178 to 1,186 feet above the sea. A view of this beach ridge is given in Pl. VI (page 26), taken on its top, near the south line of the southeast quarter of section 35, Tilden, and looking northeastward along its course. It is bordered on the southeast side by a tract of slightly undulating till 10 to 15 feet lower, mostly covered with small timber and brush and holding frequent sloughs and lakelets in its depressions. The top of the beach is not wooded, but small trees and bushes originally encroached upon its slopes. A road extends along the crest of its curving portion for a distance of about a mile through section 36, Tilden.

The marsh which borders the northwest side of the northeast part of Maple Lake shows a descent of 5 to 7 feet northwestward, or away from the lake, in its width of 1 to 1½ miles. Maple Lake is prevented from flowing in this direction by a beaver dam near the lake. The creek draining this marsh where it intersects the upper beach near the east line of the northeast quarter of section 27, Grove Park, has a height of 1,163 feet. Here the beach skirting the north side of the marsh is a flat deposit of gravel and sand, a fourth to a half of a mile or more in width, highest next to the marsh, above which it rises 5 to 8 feet in a moderate slope. Its elevation in the north half of sections 26 and 27 is 1,169 to 1,172 feet, being even 1 or 2 feet lower than the Attix ridge, which lies some two-thirds of a mile farther north, in the south half of sections 21 and 22. This belt of beach gravel and sand continues 6 miles in a nearly due-east course, and beyond that it extends still eastward along the north side of a great tamarack swamp, which begins in section 34, Badger, and is said to be 8 miles long. Maple Lake and this tamarack swamp hold the same relation to the upper beach ridge, which was a barrier between them and Lake Agassiz and which now wholly or partially obstructs the drainage of these areas.

Third Herman beach, a small ridge of gravel and sand, extending from southwest to northeast, 8 to 10 rods wide, and rising 4 or 5 feet, crossed by the Crookston road in the southwest quarter of section 23, Tilden, and seen to reach at least a mile each way from this road, 1,146 to 1,149 feet.

Natural surface at the southeast corner of section 15, Tilden, 1,134 feet.

Fourth Herman beach, crossed by the road to Crookston and Red Lake Falls near the center of the southeast quarter of this section 15, 1,132 to 1,134 feet. This is a well-marked gravel ridge, mainly single, but twofold where it is crossed by this road. The distance of 1 mile here between these third and fourth Herman beaches consists of till, with a nearly smooth surface, which has bowlders up to 3 and rarely 5 feet in diameter quite numerously scattered over it. Southeastward from the third to the first or upper beach the surface mostly is sand and gravel, with no bowlders.

EASTWARD TO RED LAKE AND THE BIG FORK OF RAINY RIVER.

(PLATES III AND XII.)

A portion of a shore-line of Lake Agassiz, probably the highest in the Herman series of beaches, has been observed on and near the southwest line of the Red Lake Indian Reservation, between Hill and Lost rivers. It was seen near the north side of sections 31 and 32, and in the central part of sections 27 and 26, township 150, range 40, also for a mile or more thence eastward in the reservation, being 15 to 20 miles east-northeast of Maple Lake. The area is mostly prairie, and the beach is well exhibited. In the southwest part of township 150, range 40, the beach ridge of coarse gravel runs along the northern border of a roughly morainic belt, which is a half to two-thirds of a mile wide. In sections 27 and 26, and onward in the Red Lake Reservation, the beach is a typical gravel and sand ridge, containing pebbles and cobbles, nearly all of Archean gneiss and crystalline schists, up to 6 and 8 inches in diameter. Its trend here for about 3 miles is nearly from west to east. On the south, within about 1 mile, is a typical morainic belt of many hillocks, knolls, and ridges, which cover a width of several miles and rise 100 to 150 feet above the beach and the low, nearly flat tract that was covered by Lake Agassiz on the north, consisting in large part of marshes, through which the Lost and Clearwater rivers flow westward in meandering courses.

About 25 miles farther east in the Red Lake Reservation the road from Red Lake to White Earth crosses a beach of Lake Agassiz, which is probably the highest, being a continuation of the foregoing. This beach runs nearly from west to east, and is approximately 40 feet above Red Lake, or 1,210 feet above the sea. It is a ridge of sand and fine gravel, crossed by the road about 2 miles southwest from Big Rock Creek and Shell Lake. A grove of red pines grows on the beach, but the till on each side bears white pines. Following the road to the southwest, a belt of kames is entered about three-fourths of a mile from the beach, which continues to Sandy River, having a surface of many knolls and short ridges, with no observable parallelism in their trends, the crests being 10 to 20 feet above the inclosed hollows.

The most eastern observation of the upper shore-line of Lake Agassiz in northern Minnesota is by Mr. Horace V. Winchell, on the Bowstring River, more commonly known as the Big Fork of Rainy River, some 60 miles east of Red Lake. In his description of the ascent of this stream Mr. Winchell writes as follows of the locality, probably about 1,250 feet above the sea, where the surface changes from a smooth contour on the north, indicating lacustrine action, to a more undulating and rolling contour on the south, above the level of Lake Agassiz:

At the end of 7½ miles the foot of a rapid nearly one-half a mile long is reached. At the foot of it is a bank of gravel and sand [probably the beach of Lake Agassiz]. It is a very different sort of bank from those seen below here. It is stratified, or partially so, but not horizontally nor all in the same direction. It looks like a stratified river deposit. Under it crops out a little fine bluish-gray clay, of which only a foot or two can be seen. This is supposed to be Cretaceous. * * * There are many limestone pebbles in the bank above the clay, but no shale is seen in it.

This rapid is over an immense number of bowlders. Most of them are hornblendic gneiss, but other rocks are frequent. Many of the bowlders are large and stick up several feet above the water. A short distance up the rapid is a small island which seems to be made of bowlders and is covered with trees and bushes. * * *

Above the rapids quantities of bowlders are seen, while below only a few were encountered. The country does not seem to be of one general level, as before, but is knolly. The banks are of sand and gravel and contain much more gravel than those below the rapids. This is about 95 miles up the river, probably in township 62, range 25. It seems probable that the rapid mentioned above is on the boundary or shore of the glacial Lake Agassiz, and that all of the river below this rapid is included in the ancient basin.[1]

BELTRAMI ISLAND.

The recent survey for the Duluth and Winnipeg Railroad, passing northwest by the east end of Red Lake and the southwest side of the Lake of the Woods, shows that the former of these lakes lies about 40 feet and the latter somewhat more than 150 feet below the highest level of Lake Agassiz. The height of Red Lake above the sea is ascertained to be 1,172 feet, and of the Lake of the Woods, in its stages of low and high water, 1,057 to 1,063 feet. Northeast of Red Lake the Tamarack River drains a large tract of tamarack, spruce, and arbor-vitæ swamp, which reaches to

[1] Geol. and Nat. Hist. Survey of Minnesota, Sixteenth Annual Report, for 1887, p. 434.

the divide between the Tamarack River and the West Branch of the Bowstring River (more commonly called the Big Fork), tributary to Rainy River, the height of the divide being only 15 to 20 feet above Red Lake. Similar low swamp land forms nearly the whole northern and northwestern shore of Red Lake and is crossed by this railroad survey continuously along its first 18 miles beyond Red Lake; but at a distance of 29 miles from the lake the profile shows an ascent crossing the highest beach of Lake Agassiz, which there is 1,215 feet above the sea. The next 17 miles of the profile extend across the northeastern edge of a large island of Lake Agassiz, rising on that line to a maximum height of 1,283 feet, with a moderately undulating drift-covered surface. In the next 15 miles, which comprise the descent on a similar but smoother drift surface from the highest shore of Lake Agassiz to the War Road River, an affluent of the Lake of the Woods, the profile crosses a succession of ten lower beaches of Lake Agassiz, marking stages in the gradual uplifting of the land and subsidence of the lake, their altitudes above the sea being 1,196, 1,172, 1,156, 1,143, 1,127, 1,116, 1,106, 1,099, 1,093, and 1,087 feet.

These data show that Lake Agassiz in its highest stage had a large island northwest of Red Lake, comprising the headwaters of numerous streams flowing outward from it to the Lake of the Woods, Rainy River, Red Lake, the Red Lake River, and the Red River of the North. This island had probably a diameter of 40 miles or more, with an area exceeding 1,000 square miles, of which apparently more than half is in Beltrami County, the portion farther west being chiefly in Marshall County, Minn. For this tract, which had before been supposed to be comparatively low and perhaps wholly beneath the highest level of Lake Agassiz, the name Beltrami Island is proposed, in recognition of the exploration of the region of Red Lake and the Julian or most northern sources of the Mississippi by Beltrami in 1823.[1] As Prof. N. H. Winchell wrote in the historical sketch here cited, this district "is still nearly as wild and uninhabited as when Mr. Beltrami passed through it." The limits of Beltrami Island are shown approximately on Pls. X, XXII, and other maps in this volume.[2]

[1] Geology of Minnesota, Vol. I, 1884, pp. 44–50, with map.

[2] Beltrami Island was first described in the American Geologist, Vol. XI, pp. 423–425, June, 1893; and its earliest mapping was in the Twenty-second Annual Report of the Geol. and Nat. Hist. Survey of Minnesota, for 1893 (pub. 1894), Plate I.

This island lies in the course of northwestward and northward continuation of the Mesabi or eleventh moraine of the series mapped in Minnesota, which next east from the narrows of Red Lake, rises very prominently to a height of 150 to 200 feet for a distance of about 10 miles upon the peninsula dividing the northern and southern parts of the lake. Like nearly the entire western half or two-thirds of Minnesota, this whole region is deeply drift-covered. No outcrops of the bed-rocks have yet been found on the large portion of the Red River basin lying in Minnesota; but the conspicuous escarpment of Cretaceous shales, overspread by drift, along the west border of the Red River Valley, wells penetrating to Cretaceous beds along this great valley plain, and the topographic features of the land rising eastward from it with nearly the same rate of ascent as on the west, lead to the belief that the eastern, like the western, border of this wide valley is formed by an escarpment of Cretaceous shales beneath the drift, and that the moderately elevated area of Beltrami Island consists of these shales enveloped by the glacial and modified drift.

THE UPPER OR HERMAN BEACHES AND DELTAS IN NORTH DAKOTA.

FROM LAKE TRAVERSE NORTHWEST TO MILNOR.

(PLATES XXIII AND XXVII.)

From the southern extremity of Lake Agassiz, in section 18, Leonardsville, Traverse County, Minn., the upper or Herman beach extends northwestward 75 miles to the most southern bend of the Sheyenne River, in Ransom County, N. Dak., and thence its course is nearly due north, but with slight deflection westward, to the international boundary. The mouth of Lake Agassiz was where now a slough 2 to 3 miles wide, with frequent areas of open water, tributary to the Bois des Sioux River, stretches northward from the northeast end of Lake Traverse. On the west side of this slough and of Lake Traverse bluffs of till rise 100 to 125 feet; their tops and the rolling surface of till which extends thence westward are 1,070 to 1,100 feet above the sea.

The beginning of the upper or Herman shore-line west of the Bois des Sioux is in the northeast corner of South Dakota, in sections 10, 3, and

4, township 128, range 48, nearly 2 miles south from the north line of the Sisseton and Wahpeton Reservation. The ancient shore rises with terrace-like steepness 20 or 30 feet above the surface of undulating till which borders it on the northeast. Its material is sand and gravel, with pebbles up to 1½ or 2 inches in diameter, about half of which are limestone. Beyond its steep margin this deposit of gravel forms a belt about a mile wide, approximately level, but with frequent short swells and low, flattened ridges, 5 to 10 or 15 feet above the intervening depressions. Its elevation is 1,060 to 1,070 feet above the sea, or from 90 to 100 feet above Lake Traverse.

For its first 3 or 4 miles the terrace-like lakeward margin of this belt of sand and gravel sweeps with a gentle curve westerly and northerly to a point in the southwest quarter of section 34, township 129, range 48, where it turns quite abruptly, taking a nearly due-west course for the next 3 miles to the west side of section 31 of this township.

In the northwest quarter of section 3, township 128, range 48, a third of a mile east of W. J. Allen's house, the ascent at the margin of this deposit is about 10 feet, to an elevation of 1,060 feet, approximately. The belt of sand and fine gravel is here about a half mile wide. Occasional hummocks, rising 5 to 10 feet and 50 to 100 feet long, which were observed on this part of the belt, appear to have been heaped up by the wind before the protecting mantle of grass and other herbaceous vegetation was spread over it.

Where this formation enters North Dakota, in the southeast quarter of section 32, township 129, range 48, similar dunes, 1,075 to 1,080 feet above the sea, have been excavated for use as plastering sand. Nearly all portions of this tract, and even its dunes, are now covered with a black soil and plentiful vegetation; but certain species preferring dry, sandy soil, as the dwarf rose (*Rosa arkansana* Porter), grow in greater abundance on the sand and gravel belt, and especially among its hummocks and hollows, than on the flat or slightly undulating surface of till at each side.

The inner margin of this belt, marking the shore of Lake Agassiz at its maximum stage, passes in its western course about 60 rods north of the southeast corner of section 32 and turns again to the northwest near the middle of the west side of section 31, township 129, range 48. At the latter locality it is a low, wave-like ridge of sand and fine gravel, about 1,060 feet above the sea. On the south it is bordered by land 3 to 5 feet lower for a width of 1½ miles. J. R. Grimesey's well, 13 feet deep, at the southwest corner of section 31, on this low tract outside the beach ridge, encountered only very fine stratified sand, irregularly laminated and containing numerous tubular limonitic concretions. Farther to the southwest and west, a gently undulating surface of till, scarcely higher than the beach of Lake Agassiz, stretches away several miles, beyond which the highland of the Coteau des Prairies is seen in the far distance.

The Herman beach crosses township 129, range 49, in a diagonal course, entering it a half mile north of its southeast corner and running northwest to the north side of sections 5 and 6. In section 23 and the northeast part of section 22, its elevation is about 1,055 feet, but its dunes rise 3 or 4 feet higher. At the middle of the north side of section 16 it is a ridge of sand and fine gravel about 8 rods wide, rising 4 to 6 feet above the land on each side. Its crest here and for a mile to the southeast and northwest is 1,060 to 1,065 feet above the sea. Northeastward the surface falls about 20 feet in the first mile. On the southwest side of this distinct beach ridge, a smooth, slightly undulating tract 1½ to 2 miles wide, extending through this township, consists of sand and fine clayey silt. Its elevation varies from 1,055 to 1,080 feet, attaining the latter height in the northwest part of the township. This belt, with its continuation southeastward, previously described, was doubtless covered by Lake Agassiz before the erosion of its outlet to the level of the Herman beach; but its stratified sand and silt appear to be modified drift deposited by streams from the melting ice-sheet. The glacial recession here was from southwest to northeast, and this was probably an avenue of drainage during a short time, as was shown on page 150, till the continued retreat of the ice left a considerable expanse of water, the beginning of Lake Agassiz, between itself and the shore.

In the north part of sections 5 and 6, township 129, range 49, and in sections 31 and 32, township 130, range 49, this beach consists of two or three parallel wave-like ridges of gravel and sand, divided by depressions an eighth to a quarter of a mile wide and 5 to 10 feet lower.

This belt reaches north to the Lightnings (or Thunders) Nest,[1] a massive dune of fine sand (Pl. VII, p. 28), partly bare and now wind-blown, but mostly covered with bushes and herbage, situated near the center of section 30, township 130, range 49. Its base on the south is 1,060 feet and its top 1,120 feet, approximately, above the sea. It covers a space about a quarter of a mile in extent from southeast to northwest, with nearly as great width, and rises in two summits of nearly equal height. The Lightnings Nest is the most prominent in a series of dunes, elsewhere rising only 10 to 30 feet, mostly grassed, which extends a mile or more to the southeast and is traceable several miles northwest to the east end of a very conspicuous tract of dunes 50 to 100 feet above the adjacent level, with summits at 1,100 to 1,150 feet above the sea, which stretches about 4 miles in a west-northwest course in the south part of township 131, range 50, 1 to 2 miles south of the Wild Rice River. By winds, eroding and drifting, these sand hills were heaped up from the Herman beach and its associated belt of modified drift, probably soon after the retreat of the ice, though their forms have been constantly changing since that time.

Outside the area of Lake Agassiz, the southwest part of Richland County is till, mostly undulating or moderately rolling, but in part prominently hilly, with rough morainic contour and abundant bowlders. Taylor Lake, approximately 1,050 feet above the sea, $2\frac{1}{2}$ miles west of the Lightnings Nest, is a very beautiful sheet of water, bordered by a sandy shore and a large grove on the north, and by a shore of bowlders and morainic hills 50 to 150 feet above the lake on the west. These hills and most of the lakes farther west in this county have no timber. Northeastward the area that was covered by Lake Agassiz is mostly smooth and nearly flat till, with frequent marshy tracts called sloughs, but with only very rare and small lakelets.

Swan Lake, 3 miles long, reaches from section 3 to section 7, township 130, range 51, having an estimated height of 1,070 feet above the sea, with

[1] A translation of the aboriginal Dakota name

undulating till 5 to 10 feet higher on the northeast and 10 to 20 feet higher on the south and west.

The Herman beach, a ridge of fine sand, 20 to 25 rods wide and about 3 feet high, near the south line of section 36, township 132, range 52, trends to the west-northwest, and has a height of 1,065 feet, approximately. On the north, the exceedingly flat plain of Lake Agassiz, sinking very slowly northeastward, reaches as far as the eye can see. On the south, flat land, covered by Lake Agassiz before the time of this beach, continues 1½ miles, ascending in that distance from 1,060 feet to about 1,080 feet, and moderately undulating till rises beyond to 1,100 and 1,125 feet.

One and a half miles north of this beach the Wild Rice River is crossed by a bridge near the center of section 25, township 132, range 52. The stream in its ordinary stage is 1 to 2 rods wide, with a depth of about 3 feet, and is filled with grass and rushes. Its bottom land, a sixth to a third of a mile wide, is about 10 feet higher and is annually overflowed by the high water in spring. Its bluffs rise about 40 feet above the river at low water, the elevation of their top and of the adjoining plain being, approximately, 1,050 feet. These bluffs and the surface from the Herman beach north to Elk Creek are till, but the country about Wyndmere and south to Elk Creek is stratified, fine clayey sand. Both formations have a very fertile soil, unsurpassed for wheat and all crops proper to this latitude. Elk Creek is a stream similar to the Wild Rice River, but smaller, and the width and depth of its valley are about two-thirds as great.

Northern Pacific, Fergus Falls and Black Hills Railroad, track at Wyndmere, 1,062 feet above the sea; at the Herman beach, 1½ miles west of Wyndmere, track 1,066 feet, and crest of the beach 1,068 feet, rising 8 feet above the adjacent land 20 rods away both east and west; surface along the railroad thence westward 8 miles, 1,062 to 1,066 feet, with Star Lake, a third of a mile in diameter on this level area, only 2 or 3 feet below the surrounding land close north of the railroad in section 5, township 132, range 52; a higher beach of Lake Agassiz, crossed 3 miles east of Milnor, and therefore called the Milnor beach, crest and track, 1,085 feet, 4 or 5 feet above the adjoining land 10 rods away both east and west;

another beach ridge formed during the same stage of Lake Agassiz, a third of a mile farther west, crest and grade, 1,086 feet; land close east, 1,081, and west 1,087 feet; track at Milnor, 1,097 feet.

The Herman beach west and north of Wyndmere has an irregular surface, with frequent hummocks of sand heaped 5 to 10 feet above adjacent hollows. Most of these dunes are now grassed. From near Wyndmere this beach, with frequent small dunes, extends north through the west edge of township 133, range 51, and thence westerly to another tract of prominent dunes 50 to 100 feet above the adjacent surface, with their top at 1,100 to 1,150 feet, which extends about 10 miles in a west-northwest course from the southwest part of township 134, range 52, to the east part of township 134, range 54, terminating about 2 miles east of the Sheyenne River. Like the similar high dunes south of the Wild Rice River, these are mainly covered by herbage, bushes, and small trees; but many portions are now being drifted by the winds, so that they are wholly destitute of vegetation. These dunes mark the course of the Herman beach, here greatly increased in volume by delta deposits from the Sheyenne River.

Morainic knolls and hills, rising 20 to 50 feet, with plentiful bowlders, lie close west of Milnor, extending in a belt from southeast to northwest. They are referred to the seventh or Dovre moraine, as described in Chapter IV. Near Lisbon, about 15 miles northwest from Milnor, some of these morainic hills are quite conspicuous, rising 100 feet or more above the surrounding country.

Evidence of a stage of Lake Agassiz 20 or 30 feet higher than that of the Herman beach is found, as before noticed, in many places along the southern part of its boundary in North Dakota. The portion of this glacial lake formed earliest by the recession of the ice seems to have reached from Lake Traverse to the Sheyenne River, and its level appears to have been then nearly that of the general surface and the top of the bluffs bordering Lake Traverse. An explanation of the conditions probably producing this Milnor stage of the incipient glacial lake, with the reasons why it was limited to a comparatively short extent on the southwestern border of the lake area, has been presented on pages 150 and 211.

FROM MILNOR NORTH TO SHELDON.

(PLATE XXVII.)

The highest level of Lake Agassiz near Milnor is marked by the Milnor beach, already mentioned, where it is crossed by the railroad. This beach is fine clayey sand, in somewhat irregular and interrupted low ridges and terraces, abutting at the west on undulating till, which gradually rises 10 or 20 feet higher, while on the east a descent of 10 or 15 feet within about 20 rods is succeeded by a flat area, which thence sinks very slowly northeastward. The elevation of the Milnor beach at the railroad is 1,086 feet, and at Mr. G. V. Dawson's house, at the middle of the east side of section 22, township 133, range 54, 1,092 feet. Its course between these points is north-northwest, and this is continued to the mouth of a former channel of the Sheyenne River, near the center of section 4 in this township, 3 miles east from the most southern bend of the river.

During all the stages of Lake Agassiz the Sheyenne River brought into it much sediment, carrying the clay farther than the sand and gravel, which were laid down near the river's mouth. Extensive areas of these originally flat beds have been changed by wind action to irregular groups and belts of sand hills or dunes, which vary from a few feet to more than 100 feet in height above the surrounding level. Besides the large tract of these dunes before described east of the Sheyenne River, others of even greater extent and equally conspicuous border the river and reach 2 or 3 miles from it in the northeast part of township 135, range 54, and along its next 15 miles.

Watercourses formerly occupied by this stream are found west of the Milnor beach. One of them is marked by a sandy flat, which reaches from the present course of the Sheyenne River, in section 1, township 133, range 55, southeastward through township 133, range 54, to the vicinity of Milnor. Another runs from near the middle of the southwest quarter of section 32, township 134, range 54, about $1\frac{1}{4}$ miles east-southeast to the middle of section 4, township 133, range 54. This is a channel 30 to 50 rods wide, about 40 feet below a ridge of coarse gravel, which extends along its northeast side, dividing it from the lower area that was covered by Lake Agassiz and from the present valley of the river. The crest of the ridge is nearly flat upon a width of 10 to 30 rods, and is 75 to 100 feet above the river, being highest westward. It contains pebbles and cobbles of all sizes up to 6 inches in diameter, about half being limestone and nearly all the others granitic. This ridge or plateau of gravel is a remnant of an old delta plain of the Sheyenne River, apparently deposited before the formation of the Milnor beach, above which it rises some 40 or 50 feet, which suggests that the deserted channel of that depth on its south side was probably eroded during the Milnor stage of Lake Agassiz. Similar gravel occurs on the side and verge of the bluff, 100 feet high, northwest of the Sheyenne River, in the southwest quarter of section 29, township 134, range 54, but a rolling surface of till extends thence northwest.

The height of the Sheyenne River in section 32, township 134, range 54, is 1,039 feet above the sea; and on the west line of the northwest quarter of section 29, township 135, range 54, 1,021 feet. Its bed through these townships is mostly 4 to 6 rods wide, with water 1 to 2 or 3 feet deep, and is strewn in many places with cobbles and bowlders up to 2 or 3 feet and rarely 6 or 8 feet in diameter. Its bottom land near the south bend, about a third of a mile wide, is 15 or 20 feet above the ordinary low stage of water, and during a term of fourteen years preceding this survey in 1885 it had not been overflowed; but driftwood, found by the first immigrants, proves that the river sometimes reaches this height. Bluffs of till here, in the southwest corner of township 134, range 54, rise 100 to 125 feet above the stream.

Bluffs of till close west of the Sheyenne River, in section 20, township 134, range 54, 1,100 to 1,110 feet; moderately rolling till a quarter of a mile farther west, 1,115 to 1,125 feet; same in sections 17 and 18, 1,090 to 1,130 feet; and on the east side of the river, in sections 21, 16, and 17, 1,085 to 1,075 feet, descending northeastward. Prominent swell of till west of the Sheyenne River, in the southeast quarter of section 30, township 135, range 54, having four aboriginal mounds on its crest, 1,113 feet; top of these mounds, 1,117 feet, very nearly. Highest portions of the area of undulating till seen westward from this section 30, 3 or 4 miles distant, 1,125 to 1,150 feet.

Surface at Charles G. Froemke's house, in the northwest quarter of section 29, township 135, range 54, 1,075 feet; bottom land of the Sheyenne River close west, 1,039 to 1,029 feet; ordinary low water of the river, 1,021 feet.

Portion of area of Lake Agassiz, a strip a fourth to a third of a mile wide, west of the Sheyenne River, in sections 32 and 5, a half mile to 2 miles south of Mr. Froemke's, 1,065 to 1,075 feet. Herman beach one-fourth to two-thirds of a mile east of the Sheyenne River here and extending southeasterly toward the western limit of dunes in the east part of township 134, range 54, 1,073 to 1,079 feet. Crest of this beach, a low ridge of sand and fine gravel, at J. Altmann's house, near the middle of section 20, township 135, range 54, 1,073 feet. Within 10 or 15 rods east there is a descent of about 10 feet. This beach ridge runs north and northeasterly to near the northeast corner of this section 20, and thence it passes eastward about 3 miles, having an elevation of 1,075 to 1,065 feet to where it is intersected by the Sheyenne River, near the northeast corner of section 14. North of the river it continues about a half mile in section 12, its elevation being 1,065 to 1,070 feet, to the west end of a tract of dunes 25 to 100 feet above their vicinity, with summits at 1,100 to 1.150 feet, which extends thence about 15 miles eastward. This Herman beach was sufficient to turn the course of the Sheyenne River along its west and north side for a distance of 8 miles, from section 9, township 134, range 54, north and east to section 14, township 135, range 54, though it is only a ridge of sand and gravel 5 to 10 feet higher than the smoothed area of till, occasionally covered by 1 to 3 feet of sand, which lies west of it and in which the river has now cut its channel 50 to 60 feet deep.

Rolling surface of till in the south edge of section 9, township 135, range 54, 25 to 40 rods north of the Sheyenne River, 1,080 to 1,090 feet. Most of this section 9 is nearly level till at 1,080 to 1,085 feet, with occasional large hollows 20 feet lower. It seems to have been smoothed by Lake Agassiz at the time of the Milnor beach. Westward is slightly undulating till, having an elevation of 1,085 to 1,125 feet for 2 or 3 miles, as far as the surface lies within view.

Herman beach in the northwest quarter of section 10, township 135, range 54, 1,075 to 1,080 feet. This is a deposit of gravel and sand extending along the verge of the plateau of till just described in section 9. Fifteen or 20 rods to the east the elevation is 1,065 feet, and it sinks slowly thence eastward to about 1,050 feet at the west base of the dunes in sections 12 and 1 of this township.

Lakelet back of this beach, situated in the east edge of the southeast quarter of section 4, township 135, range 54, about 50 rods long from south to north, 1,060 feet, being 25 feet below the average of the adjacent undulating till. Shallow lakelet 40 rods across, close east of the beach, a quarter of a mile east from the northwest corner of section 3, also 1,060 feet; adjoining land, 1,065 to 1,070 feet, excepting on the west, where the Herman beach has an elevation of 1,080 feet, with undulating till beyond it a few feet higher.

Herman beach at the middle of the west side of section 34, township 136, range 54, Sheldon, 1,082 feet; surface 25 rods east, 1,070 feet, thence descending slowly eastward. Here and for 1½ miles south, through section 3, this beach is a flattened ridge of sand and fine gravel, 25 or 30 rods wide, with a depression 3 to 6 feet deep along its west side. In the northwest quarter of section 28 its elevation is 1,080 feet.

Fargo and Southwestern Railroad track at Sheldon, 1,080 feet. Wells in Sheldon village are 10 to 15 feet deep; in sandy clay, free from gravel or bowlders, 6 to 10 feet, with sand below. These deposits belong to the Herman beach, which is here spread upon a width of about a half mile.

DELTA OF THE SHEYENNE RIVER.

(PLATE XXVII.)

The delta deposited by the Sheyenne River in Lake Agassiz reaches from the Lightnings Nest 50 miles northwest to the south bend of the Maple River, and has a maximum width of nearly 30 miles to the northeast from the south bend of the Sheyenne. It probably covers an area of 800 square miles to an average depth of 40 feet, its volume being, therefore, about 6 cubic miles. Large tracts of this delta are channeled by the winds and heaped up in dunes, as before noted, which rise to heights of 25 to 100 feet or more above the average height of its expanse. Fig. 13 presents a section crossing this delta from east to west.

The deposition of the delta proper, and also of the fine lacustrine silt extending beyond its plateau to the Red River, took place mainly during the upper Herman stages. The plateau, gently descending eastward, is crossed by the Herman and Norcross shore-lines, and in part by the Tintah and Campbell shores on its eastern and southeastern border. From the Maple River 8 miles east to Leonard, however, and thence southeasterly about 25 miles, its margin has been eroded and changed to an abrupt escarpment, or at least a somewhat steep slope, by the lake waves during the Tintah, Campbell, and McCauleyville stages. This front of the delta, 75 to 25 feet above the flat low land of the Red River Valley adjoining its base, decreases in prominence as it is followed southward. It passes close

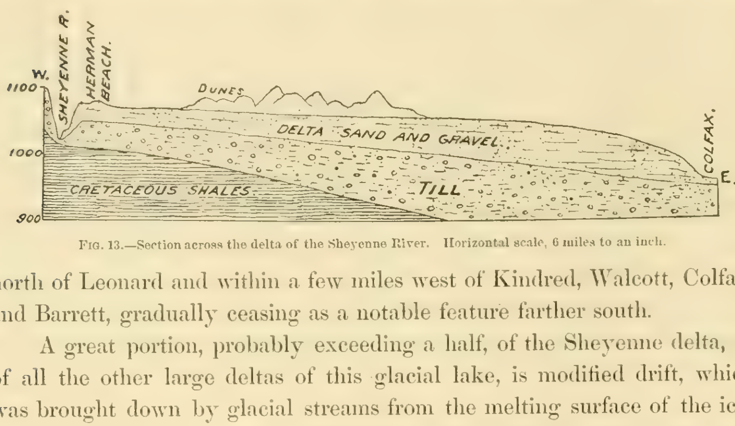


FIG. 13.—Section across the delta of the Sheyenne River. Horizontal scale, 6 miles to an inch.

north of Leonard and within a few miles west of Kindred, Walcott, Colfax, and Barrett, gradually ceasing as a notable feature farther south.

A great portion, probably exceeding a half, of the Sheyenne delta, as of all the other large deltas of this glacial lake, is modified drift, which was brought down by glacial streams from the melting surface of the ice-sheet. The coarser gravel and much sand that were supplied from the ice to the head streams of the Sheyenne during the time of formation of its delta were deposited along the outer side of the great moraines south of Devils Lake; the finer gravel and a great volume of sand were carried by the Sheyenne to this delta; and the finest silt and clay of the great glacial river were spread in the quiet water of the lake, over a much larger adjoining area of its bed, from near Breckenridge northward beyond the mouth of the Sheyenne.

MAP SHOWING THE GREATER PART OF THE SHEYENNE DELTA OF LAKE AGASSIZ AND CONTIGUOUS BEACHES, NORTH DAKOTA.

Scale, 6 miles to an inch.

Lake Area Delta Moraine

Altitudes of railway stations are noted in feet above the sea.

Much alluvium was also supplied from the erosion of the Sheyenne Valley, which, with that of the Big Coulée (the avenue of discharge from the glacial Lake Souris to the Sheyenne and Lake Agassiz), probably averages three-fourths of a mile in width and 150 feet in depth along a distance of 200 miles. This channel is cut in the drift sheet, mainly till, and in the underlying, easily eroded Cretaceous shales. The volume of the material supplied from it would be equal, according to these estimates, to about three-fourths of the Sheyenne delta, or perhaps three-eighths of both the delta and the finer clayey sediments that were deposited farther out in the lake. But the valley of the Sheyenne, in considerable portions of its extent, was also a preglacial valley. If it retained in a considerable degree its trough-like form beneath the ice-sheet, as was evidently true of the Minnesota Valley,[1] its erosion and its tribute to the Sheyenne delta would be less than the proportion estimated.

FROM SHELDON NORTH TO THE NORTHERN PACIFIC RAILROAD.

(PLATES XXVII AND XXVIII.)

The Herman beach, terrace-like, at Hugh McIntosh's house, in the south edge of the northwest quarter of section 8, Sheldon, has its crest 1,083 to 1,084 feet above the sea. His well, near the top of the beach, 22 feet deep, is soil and sandy clay to a depth of 7 feet, then sand 15 feet to water. Till rises to the surface 20 rods farther west. About 30 rods east, on land 10 feet lower, a well 10 feet deep is all caving sand below the black soil, which is 1 or 2 feet deep.

Maple River in section 32, Highland, about 2 miles northeast from its most southern bend, 1,019 feet. It is 20 to 40 feet wide and 1 to 3 feet deep, with cobbles and bowlders in many portions of its channel. Herman beach, a sand and gravel deposit, extending a quarter of a mile from south to north on the verge of the bluff of till west of Maple River in the northwest part of this section 22, 1,072 to 1,077 feet. In the north edge of the northwest quarter of this section, the northeast corner of section 31, and the east edge of section 30, it is a plateau-like tract a fourth of a mile wide, with a subsoil of sand and fine gravel, 1,086 feet, from which both east and

[1] "The Minnesota Valley in the Ice age," Proc., A. A. A. S., Vol. XXXII, for 1883, pp. 213–231. Geology of Minnesota, Vol. I, 1884, pp. 479–485, 581; Vol. II, 1888, p. 134.

west a gentle slope falls 5 feet within 20 or 30 rods. In the northwest quarter of section 20 and the west half of section 17, Highland, it is a gracefully rounded ridge, 1,085 to 1,087 feet, with descent of about 5 feet on its west side and 10 to 15 feet within as many rods on the east. The surface east of the Maple River in this township has an elevation of 1,075 to 1,065 feet, declining toward the north and east. In the east half of Pontiac, the next township on the west, a surface of till, moderately undulating near the beach of Lake Agassiz, but prominently rolling at a distance of 3 miles to the west, rises to 1,150 and 1,175 feet in the vicinity of the Maple River above its south bend.

The Herman beach, a broad, flattened ridge of sand and gravel, passes in a north-northeast course through the center of section 8, Highland, its elevation being 1,083 feet. A smoothed surface of till, 1,082 to 1,087 feet, with occasional sloughs in depressions 15 to 20 feet deep, occupies the west half of this section 8; and close east of the beach a flat of till on the east line of the section, at 1,065 to 1,070 feet, was the bed of the lake.

Continuing northeastward, the beach is offset a mile to the east, in sections 4 and 3, Highland, so that the greater part of section 4 was a bay of Lake Agassiz during its Herman stage, with bottom at 1,080 to 1,065 feet, inclosed on the west, north, and east by beach deposits. The highest portion of the hook or spit east of this bay is in the southwest quarter of section 3, 1,093 to 1,096 feet. It is composed of sand and fine gravel, with pebbles mostly less than an inch, but occasionally 2 inches in diameter, forming a smoothly rounded swell 30 to 40 rods wide. This cape, projecting south and west a mile into the lake, was accumulated by the southward drift of the beach material along the shore, caused by northern winds, as is also observable at various other places on both the east and west shores of this glacial lake and on both sides of Lake Michigan at the present time.

Herman beach in the west edge of section 26, Eldred, 1,094 feet. On the east side of the beach here, near the center of this section, is a slough filled with rushes and containing water all the year; its elevation is about 1,065 feet, that of the land on its east side, in the east part of this section, being about 1,075 feet. In the northeast quarter of section 34 the beach is intersected by a sluggish creek, apparently formed by springs within a half mile northwest, its ravine being fully 40 feet below the general level of the beach and the land westward. Again, in the southwest quarter of section 26 the beach is cut by a dry channel, the outlet in rainy weather from a small slough.

Through the west half of section 23, Eldred, the beach is a low, smoothly rounded ridge of sand and fine gravel, about half of which is limestone and the rest granite or other Archean rocks. As in the 3 miles next southward, it is largely composed of fine gravel, and pebbles abound, often covering half the surface of the knolls made by gophers. Most of the pebbles are less than an inch in diameter, but some measure 2 and a few 3 inches. The elevation of this beach ridge is 1,092 to 1,100 feet; on the north line of this section its height is 1,099 feet. A broad depression 3 to 5 feet below the beach borders its west side. Toward the east there is a descent of about 10 feet in 25 or 30 rods, and thence a gradual slope sinks to 1,060 or 1,050 feet within 1 to 1½ miles.

Undulating till in sections 22 and 15, Eldred, 1,095 to 1,110 feet; crests of prominently rolling till in the west edge of section 11 and the south part of section 10, 1,115 to 1,125 feet; thence northwestward lower undulating till has an elevation of only 1,090 to 1,100 feet for nearly 2 miles, and rises quite slowly beyond. This somewhat irregular contour has caused considerable diversity in the development of the beach, so that its deposits are massed in unusual amount in some places, while elsewhere they are deficient or wholly wanting. In the southwest quarter of the southwest quarter of section 14, Eldred, a swell of gravel, with pebbles up to 2 inches or rarely 3 inches in diameter, rises to 1,105 feet, extending about 40 rods from south to north; and similar gravel, at 1,095 to 1,105 feet, occurs in the west part of the northwest quarter of section 23, west of the distinct beach ridge. The northwest part of section 14 is a nearly flat tract, having a subsoil of sand and fine gravel, with an elevation of 1,090 to 1,095 feet. A beach ridge extending south from the east side of a prominent swell of till in the southwest quarter of section 11, at 1,086 to 1,089 feet, has a continuous depression of about 5 feet on its west side and is bordered eastward by land 6 to 10 feet below its crest. In the northwest part of this section 11 and the southeast part of section 3 the shore of Lake

Agassiz is marked by slight erosion in the rolling and undulating surface of till rather than by the usual beach deposits of gravel and sand.

Beyond this, a conspicuous beach ridge 25 to 40 rods wide, elevated 10 feet above the undulating till on its west side and bordered by a still lower surface on the east, extends from the middle of the southwest quarter of the southeast quarter of section 3, Eldred, northwestward to near the middle of the north line of the northwest quarter of this section, where it is interrupted by a drainage gap about 20 feet below its crest. Thence this massive beach ridge continues in a north-northeast course through section 34, Howes, to near the middle of its north line. Its material is sand and gravel, with pebbles up to 1½ inches in diameter. In section 3 its elevation is 1,095 to 1,090 feet, and in section 34, 1,089 to 1,094 feet. It passes onward as a very distinct and typical beach ridge, with the same north-northeast course, through sections 27 and 22, Howes, having an elevation of 1,087 to 1,095 feet in section 27 and 1,089 to 1,096 feet in section 22. Its eastern slope in these sections descends 15 to 20 feet.

About a half mile west from this great beach ridge the east edge of section 4 has irregular deposits of beach gravel and sand in swells and bars 5 feet above the general level, and in the east edge of section 33, Howes, a well-defined parallel beach begins, having a width of 20 to 25 rods and elevation of 1,092 to 1,094 feet, with a depression 2 to 4 feet lower on the west and descent of about 5 feet on the east. This western Herman beach extends as a continuous ridge 2 miles to the north-northeast, excepting a gap where it is intersected by a small stream in the northwest quarter of section 27. Its material is sand and gravel, with pebbles up to 2 inches in diameter, about half being limestone. Both this and the east beach have a black soil a foot or more in depth, and are scarcely inferior to the adjoining areas of till in productiveness. Farther west a slightly undulating or nearly flat surface of till extends from a half mile to 1½ miles before it rises above 1,095 feet, and the highest of its swells, seen 3 to 6 miles away to the west and northwest, do not exceed 1,150 or 1,175 feet. The western Herman beach on the north line of the northwest quarter of section 27 has a height of 1,095 feet; about 6 rods to the south, 1,097 feet; and northeastward, in section 22, 1,092 to 1,095 feet, to its junction with the eastern or main beach in the east part of this section.

A lower Herman beach, formed after the lake level here had fallen slightly, appears in the northwest edge of section 26, Howes, having its crest at 1,072 to 1,075 feet; passing north-northeastward through the west half of section 23, its elevation is 1,075 to 1,080 feet; through section 14, 1,080 to 1,087 feet, being highest near the center of this section; and in the east part of sections 11 and 2 and onward to the southwest quarter of section 36, Buffalo, 1,083 to 1,080 and 1,075 feet. Its maximum development is in section 14, where it is a massive, smoothly rounded ridge of sand and fine gravel, 30 rods wide, with a descent of 15 feet on each side. In sections 26 and 23 it is bordered on the west by a continuous depression 4 to 8 feet below it; and through sections 14, 11, and 2, and in the southwest quarter of section 36, a slough 3½ miles long, mown for its luxuriant marsh hay, having an elevation of 1,067 to 1,072 feet, lies between this and the main beach, a half mile farther west.

Floor of S. P. Gardner's house, in the northwest corner of section 27, Howes, 1,096 feet.

Main Herman beach through the west edge of section 14, Howes, 1,096 to 1,093 feet, declining northward; in the west part of section 11, 1,093 to 1,095 feet; in section 2, 1,092 to 1,095 feet, changing from a north to a north-northeast course; in the southeast edge of section 35 and the northwest edge of section 36, Buffalo, 1,092 to 1,096 feet; and in the west part of section 25, where it is cut by the Northern Pacific Railroad, 1,095 to 1,101 feet. At the railroad cut its crest is 1,099 to 1,101 feet, and the track is 1,092 feet above the sea. Along this distance of 5 miles it is a typical beach ridge of sand and gravel, with pebbles up to 2 inches and occasionally 3 to 6 inches in diameter, about 30 rods wide, rising nearly 25 feet above the slough on the east, and bordered on the west by a continuous depression, mostly about an eighth of a mile wide, 3 to 7 feet below its crest. Slightly undulating till rises beyond to 1,125 and 1,140 feet within 1 or 1½ miles west, which is as far as the surface lies within view.

Northern Pacific Railroad track at Wheatland, 993 feet; on bridge over creek in the east edge of section 25, Buffalo, 4 miles west of Wheatland and three-fifths of a mile east of the Herman beach, 1,076 feet; bed of the creek, 1,057 feet; track at summit, 4½ miles west from the Herman beach, same as the natural surface, 1,208 feet; and at Buffalo, a half mile farther west, 1,202 feet.

FROM THE NORTHERN PACIFIC RAILROAD NORTH TO GALESBURG.

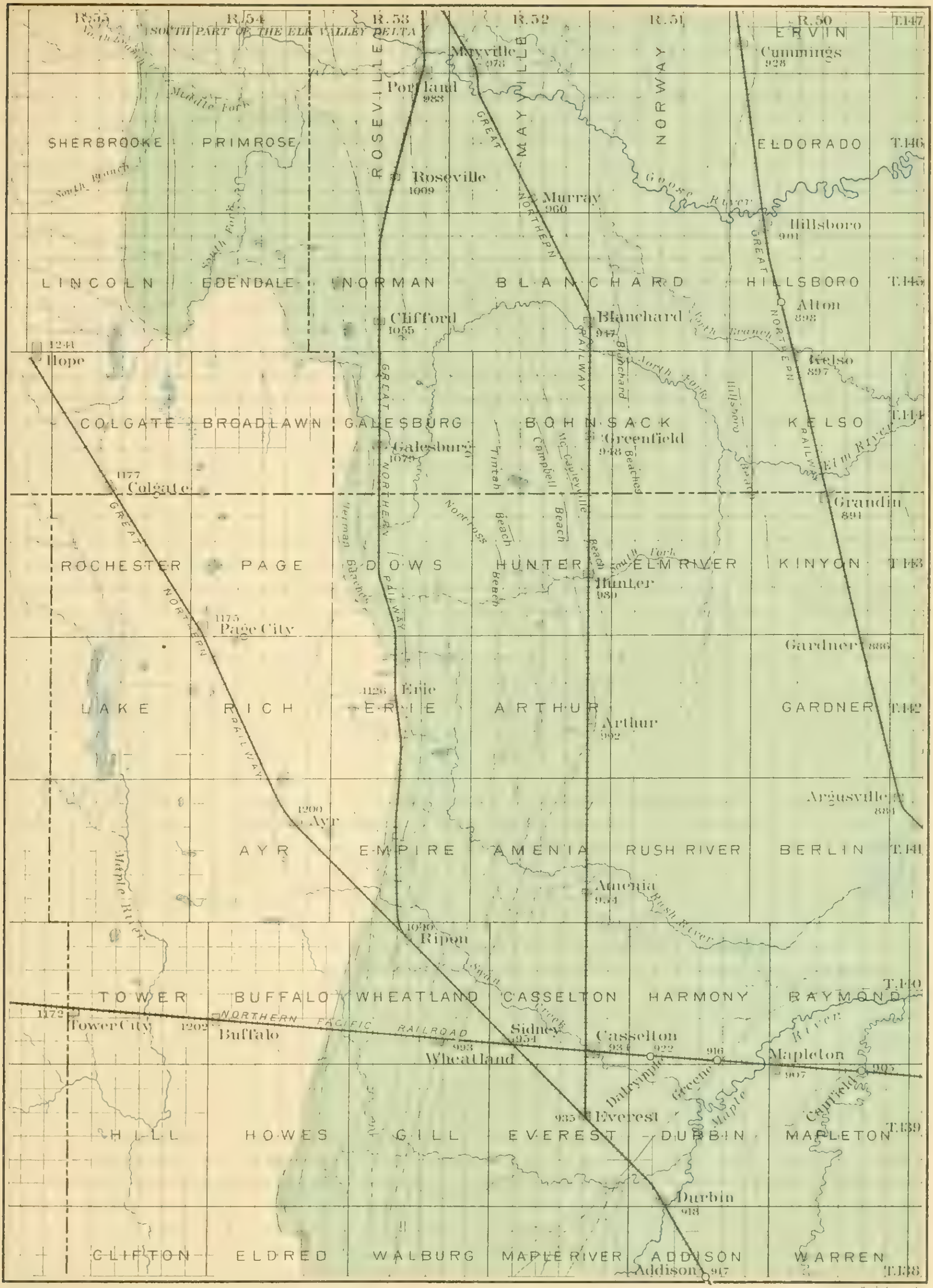
(PLATE XXVIII.)

The Herman beach, a broad, smoothly rounded, continuous ridge of the same material and contour as southward, runs to the north-northeast for the next 4 miles north from the Northern Pacific Railroad, with its crest at 1,097 to 1,100 feet, very constant in elevation. The descent of its east slope is 15 or 20 feet in about 20 rods, and of its west slope about 5 feet. Thence westward the surface is undulating till, in swells 10 to 15 feet above the depressions, rising gradually to 1,150 and 1,200 feet above the sea at a distance of 3 to 5 miles, the farthest seen in that direction. In a broad view this area seems an almost flat plain.

Where this beach is cut by the branch of the Great Northern Railway from Ripon to Hope, near the middle of the line between sections 32 and 33, Empire, its crest was 1,096 to 1,099 feet above the sea. It has been excavated here for ballast to a distance of about 30 rods south from the railway. It is mostly gravel; the pebbles seldom exceed 2 inches in diameter; about half is limestone, and the remainder granitic. The thickness of this beach deposit is only 8 to 10 feet; its east slope falls 12 or 15 feet, and its west slope 5 to 7 feet.

On the floor of this excavation, about 10 rods south from the railway, in the upper foot of the till or bowlder-clay, under the gravel, numerous bones of a mammoth were found in the year 1884. These included a tusk 11 feet long and 9 inches in diameter (tapering to 6 inches at the smaller end, where it was broken off), three teeth, two vertebræ, and several other bones. They were embedded in the top of the till, and the overlying beach formation has yielded no bones, shells, or other fossils.

Southward from this locality the Herman beach is double for a distance of about 4 miles. The secondary beach ridge east of that already described is similar in size and material. Its south end is in the west part



MAP OF THE WESTERN SHORES OF LAKE AGASSIZ, FROM THE VICINITY OF WHEATLAND, CASS COUNTY, NORTH TO PORTLAND AND MAYVILLE, TRAILL COUNTY, NORTH DAKOTA.

Scale, 6 miles to an inch

Lake Area [ ] Delta [ ]

Altitudes of railway stations are noted in feet above the sea.

of section 19, Wheatland, a half mile east from the main beach, and it passes thence north-northeastward through sections 18, 7, and the east edge of section 6, having an elevation of 1,081 to 1,084 feet. It becomes merged with the main beach in the southeast quarter of section 32, Empire. Between these beach ridges is a depression, approximately 1,075 feet, partly occupied by a grassy slough, which is all used as mowing land, having no area of water or bog.

The Herman beach in the southwest quarter of section 28, Empire, at a height of 1,094 to 1,096 feet, is not so distinct as usual, being intersected by Swan Creek and having no well-marked depression along its west side. Farther north in this section it is a ridge of the ordinary type, with its crest at 1,096 to 1,098 feet. In section 21 it is narrowed to 8 or 10 rods in width, but continues as a very distinct ridge with a slight ascent northward, from 1,097 to 1,101 feet. Its east slope falls 15 to 20 feet in about 20 rods, and there is a depression of 3 to 6 feet on the west. Thence a surface of undulating till, seeming nearly flat in a general view, rises gradually westward to about 1,150 feet at a distance of 2 or 3 miles.

This beach ridge passes onward through section 16 and the south part of section 9, Empire, with an elevation of 1,095 to 1,100 feet; but, having been followed thus continuously in a north-northeast course for more than 15 miles, it ceases in the east part of this section 9. Its north end abuts at 1,100 to 1,105 feet upon a terrace slope of till, which rises about 10 feet higher. This forms the east boundary of a slightly undulating expanse of till, which thence gradually rises to 1,150 and 1,200 feet in 2 to 5 miles west and northwest. From section 9 northward through the east part of section 4, and in the west edge of section 34 and the west part of sections 27, 22, and 15, Erie, passing close east of Erie railway station, the Herman shore of Lake Agassiz is marked by such a terrace or escarpment formed by wave erosion, and the usual deposit of beach gravel and sand is absent. The base of the escarpment is at 1,095 feet, approximately, and it rises with a moderate slope 25 to 40 feet.

About a half mile east of this escarpment, however, lies a broad, low ridge of beach sand and fine gravel, having an elevation of 1,085 to 1,090 feet. Its course is from the west part of section 10 north-northeast through sections 3 and 34, and nearly due north through the east edge of sections 27, 22, and 15. The descent eastward is more gentle than usual, falling only 6 to 10 feet in a quarter of a mile, beyond which is a flat area of till. On the west a depression 3 to 5 feet deep, partly occupied by a grassy slough, intervenes between this beach ridge and the wave-cut escarpment. On the north line of section 15 the crest of the ridge is at 1,092 feet; the depression west, 1,088; the base of the escarpment, 1,092, and its top, about 1,115 feet.

Great Northern Railway from Ripon to Portland, track at tank and section house close south of Rush River, 1,094 feet; at Erie, 2 miles farther north, 1,126 feet; summit about 1 mile north of Erie, 1,131 feet; South Branch of the North Fork of Elm River, bridge, 1,081 feet; bed of creek, 1,062 feet; track at summit 1 mile north, 1,089 feet; at Galesburg, 1,079 feet; North Branch of the North Fork of Elm River, bridge, 1,076 feet; bed of creek, 1,063 feet; track at Clifford, 1,055 feet. At Erie and westward the surface is prominently rolling till, which rises within 3 miles to a height of 100 feet above the shore of Lake Agassiz.

In sections 10 and 3, Erie, the Herman beach is again well exhibited in its usual character. On the north line of section 10 it is a gently rounded ridge of sand and gravel, with pebbles up to 2 inches and rarely 3 or 4 inches in diameter, half being limestone; its width is about 20 rods; the elevation of its crest is 1,106 feet, and the slopes fall 10 feet on the east and 3 feet on the west. For the next mile northward, through the west part of section 3, this beach ridge has a width of 10 to 15 rods; its elevation is mostly 1,105 to 1,108 feet, with a depression 5 to 7 feet deep along its west side; but in a few places the ridge itself is depressed to 1,099 feet. Passing northward, this beach in the west half of section 34, Dows, is a very smooth, gracefully rounded, wave-like swell, 30 to 40 rods wide, 1,108 to 1,112 feet in elevation, rising 15 feet above its east base and having a depression of 3 to 5 feet on the west. A well in the northeast quarter of the southwest quarter of section 34, on the top of this beach, went through 12 feet of sand and gravel, going into till below. In the southwest quarter of section 27 the beach continues with the same massive development and nearly north course, its elevation being 1,111 to 1,115 feet. In the northwest quarter of this section it becomes a still broader deposit of gravel and sand, a fourth to a third of a mile wide, with no depression on its west side. Here its course is turned northwestward, entering the southeast quarter of section 21 with an elevation of 1,109 feet; but it seems not to be distinctly traceable farther. About a half mile west of this beach a plateau of till, 1,125 to 1,128 feet above the sea, extends a third of a mile from southeast to northwest in the southeast quarter of section 28; but for a mile south and west of this plateau, and for 3 miles northwest, the surface of slightly undulating till averages only 1,105 to 1,120 feet.

The secondary Herman beach, already described in its course east of the Erie escarpment of till, continues northward with an elevation of 1,095 feet, approximately, through the east half of sections 10 and 3, Erie, and sections 34 and 27, Dows. In sections 22 and 16 this beach turns in a gradual curve to the northwest and west, and its crest varies in height from 1,095 to 1,104 feet, being highest in or near the southeast corner of section 16. There it is a ridge of gravel and sand about 30 rods wide, rising 10 to 15 feet above its northeastern base and descending 6 to 10 feet on the southwest to a nearly flat tract of moist mowing land fully a mile wide, with a height of 1,090 to 1,095 feet. Through sections 17, 8, and 5 it again curves to the northwest, north, and north-northeast, having an elevation of about 1,095 feet. In the north half of sections 5 and 4, Dows, a smooth plain with sand subsoil extends a mile eastward from the east base of this beach ridge, descending in this distance from 1,090 to 1,075 feet.

Continuation of this beach northward nearly through the middle of section 32, Galesburg, 1,096 to 1,099 feet. It is a typical beach ridge of fine gravel and sand, 8 to 10 feet above the land on its east side and having a descent of about 5 feet westward, beyond which the surface of undulating till rises in 1 or 1½ miles to 1,125 feet and in the next 2 miles to 1,175 or 1,200 feet. A half mile east from this beach, and only 20 to 30 rods west of the railroad, there is a parallel beach ridge of similar size and material, at 1,090 to 1,092 feet. The former of these beaches, where it crosses the south line of section 20, a fourth to a half mile west of Galesburg, is spread in a broad, nearly flat deposit which rises westward from 1,096 to 1,101 feet. On the west it is bordered by a depression about 8 feet lower.

FROM GALESBURG NORTH TO LARIMORE.

(PLATES XXVIII AND XXIX.)

In section 20, Galesburg, the beach is about a third of a mile wide, its higher western margin being at 1,097 to 1,102 feet. From its crest a slope descends first somewhat steeply and then slowly to the amount of 20 or 25 feet in two-thirds of a mile eastward, having a subsoil of sand and very fine gravel to a depth of 5 to 10 feet, underlain by till, as is shown by wells at Galesburg. Crest of this beach through the west half of section 17, 1,102 to 1,107 feet; in section 6, Galesburg, and in sections 32 and 29, Norman, 1,115 to 1,125 feet, being 10 to 15 feet higher than on the south and north; in sections 20 and 17, about 1,110 feet; in the southwest part of section 8, 1,117 feet; westward through section 7 of this township, and through the northeast part of section 12, township 145, range 54, 1,112 to 1,117 feet. On the line between Traill and Steele counties, where the top of the ridge is at 1,114 feet, it is a typical beach deposit about 25 rods wide, composed of sand and gravel, with pebbles up to 2 or 3 inches in diameter. Its course is due west, and the descent from crest to base on the south is 6 or 8 feet, and northward 12 or 15 feet, beyond which a very gentle slope sinks toward the northeast. A well on this beach, in the east edge of the northwest quarter of section 12, township 145, range 54, went through sand and fine gravel 13 feet, finding till below. Within a few hundred feet farther west the beach is interrupted for a distance of about 1 mile by an area of till some 15 feet lower, with no beach deposits. It reappears, however, as a typical beach ridge of gravel and sand for a distance of three-fourths of a mile in the northwest quarter of section 11 and the northeast quarter of section 10, having an elevation of 1,114 to 1,112 feet, with a slough on its south side 6 to 8 feet lower.

Returning to the vicinity of Galesburg, a slightly higher beach, approximately parallel with the foregoing, remains to be traced. It becomes recognizable in the west edge of section 20, Galesburg, where the border of the area of rolling till that extends thence westward bears occasional deposits of gravel at 1,115 to 1,120 feet. In the east part of section 18 it is a well-developed beach ridge of sand and fine gravel 30 to 50 rods wide, with a depression on the west 4 to 6 feet below its top, which has an elevation of 1,120 to 1,123 feet. Northward in section 7, this beach, continuing at 1,120 to 1,123 feet, is quite broad, without a distinctly ridged form, and is indented from the east by a large slough, whose elevation is approximately 1,100 feet, including several acres of water free from grass and rushes. Crest of beach in the southwest quarter of section 6, Galesburg, 1,122 to 1,126 feet; through sections 31 and 30, Norman, 1,125 to 1,129 feet; and in the west half of section 19, 1,127 to 1,124 feet, sinking slightly from south to north. The farther course of this shore is not marked by continuous beach deposits; but, following the contour line of 1,125 feet, it must turn west in the southwest quarter of section 18, Norman, and extend through sections 13 to 6, township 145, range 54, to the South Branch of Goose River.

Natural surface at the southwest corner of section 3, township 145, range 54, a dozen rods west of the South Branch of Goose River, 1,104 feet. This stream, about 1,070 feet, is 8 to 20 feet wide and mostly 1 to 2 feet deep. Its bottom land, 5 to 10 feet above this stage of low water, varies from 20 to 100 rods in width and is inclosed by bluffs rising 30 to 50 feet, increasing in height southwestward. The valley has no timber, the largest wood growth being willows 5 to 8 feet high and $2\frac{1}{2}$ inches or less in diameter. With the aid of these, however, beavers had constructed dams, and were living on this stream when this survey was made in 1885, one of their dams then occupied being found by my assistant, Mr. Robert H. Young, in the west edge of section 10, township 145, range 54.

Floor of Henry Bentley's barn, in the southwest corner of the southeast quarter of section 6, township 145, range 54, on the Herman shore of Lake Agassiz, 1,123 feet. This is a moderate slope, ascending 12 or 15 feet, eroded in till, which from its top stretches westward about 2 miles in a nearly level expanse. From the south side of section 6, such a low escarpment, with its top at 1,120 to 1,123 feet, extends due north, or a few degrees west of north, about 5 miles.

E. W. Palmer's house, in the northwest corner of the southwest quarter of section 2, township 145, range 55, 1,145 feet. Well here, 27 feet deep: soil and very hard gravel and sand, 2 feet; sand with occasional layers of fine gravel, 22 feet; and darker clayey quicksand, 3 feet, with water. This is on the west part, nearly at the crest, of an unusually high beach of this glacial lake, similar in elevation with the Milnor beach farther south. Including its slopes, it has a width of 60 rods, the nearly flat crest being 40 rods across and in elevation 1,142 to 1,147 feet. The depression on the west falls about 5 feet. In the north part of section 2 this sand and gravel deposit has an irregular contour, not lying in a continuous ridge; its highest portions vary from 1,145 to 1,152 feet. Southward from section 2 it is not continuous, but is interrupted by wide depressions where the surface is till. Beach gravel and sand appear, however, in some amount at Mr. Thomas Ward's, in the southwest corner of section 11, township 145, range 55; also in the southwest part of section 23, nearly 2 miles farther south. Within 1 to 3 miles west from these sections an area of undulating and rolling till rises to 1,200 and 1,250 feet.

Near the middle of the north half of section 23, township 146, range 55, the elevation of this beach is 1,142 to 1,144 feet. It is a ridge of gravel and sand, extending a quarter of a mile from southeast to northwest, with crest 15 feet above the surface on each side. Toward the east it descends in a long slope, but more steeply westward. In section 14 this shore-line curves westerly, the crests of its somewhat irregular beach deposits being about 1,135 feet, with a descent of 10 to 15 feet in 25 rods east. Through section 11 they range from 1,135 to 1,147 feet, being highest in the southeast quarter of the section, where the descent eastward is 20 feet or more. These beach deposits are sand and gravel, with pebbles up to 1½ or 2 inches in diameter, massed in flattened hillocks or swells, mostly ridged lengthwise with the shore and occasionally inclosing hollows without outlet. The formation has a width of a quarter of a mile or more in its northward course through the west part of the east half of section 11. An undulating surface of till rises slowly to the west, while on the east a very smooth expanse of till sinks slowly toward the Red River.

Herman beach ridge, 30 rods wide, in or near the east edge of the southeast quarter of section 2, township 146, range 55, 1,125 feet. Irregular accumulations of the higher beach a quarter of a mile farther west rise approximately to 1,140 feet. These upper deposits and those described in the last two paragraphs indicate that this area, which was covered by a southwardly projecting lobe of the ice-sheet at the time of the accumulation of the eighth or Fergus Falls moraine, experienced an earlier uplift than adjacent tracts of the lake border, giving to this part of the earliest and highest Herman beach an altitude 15 or 20 feet above the normal and regular plane of the corresponding beach deposits on both the south and the north.

Crest of the Herman beach, a definite ridge 25 to 30 or 40 rods wide, through the east half of section 2, township 146, range 55, 1,122 to 1,135 feet, 10 to 15 feet above the land east, and with a depression of 6 to 8 feet on the west. In the south part of section 35, township 147, range 55, the beach ridge is merged in a flat eastwardly sloping area of sand and fine gravel at 1,135 to 1,120 feet, underlain by till at the depth of a few feet. The beach ridge reappears in the north part of this section 35 at 1,125 to 1,130 feet.

Through sections 26 and 23, township 147, range 55, the Herman shore is marked by swells and flattened ridges of sand and fine gravel at 1,130 to 1,143 feet, occupying a width of an eighth to a third of a mile, with a depression of several feet along their west side. Four sloughs, at the elevation of about 1,120 feet, lie within the east part of these beach deposits, or on their east border, in the southeast quarter of section 23. In the south part of section 14 this massive but irregular beach has an elevation of 1,132 feet on the east side of a large slough.

In the middle of section 14, township 147, range 55, the beach assumes a definitely ridged form and extends thus northward along the east side of Golden Lake, which owes its existence to this barrier. Crest of the beach, through the center and north part of section 14, 1,132 to 1,137 feet; in section 11, east of Golden Lake, 1,132 to 1,141 feet; and at Golden Lake post-office, in the east edge of the southwest quarter of section 2, 1,138 feet. An eighth of a mile north from the south end of this lake the action of its waves has eroded the greater part of the beach ridge. The material of the beach exposed by an excavation near the post-office is coarse gravel, with very abundant pebbles up to 3 inches and occasionally 4 to 6 inches in diameter.

Golden Lake water, July 28, 1885, 1,122 feet above the sea; highest level reached by this lake in recent years, 1,128 feet. It is a beautiful sheet of water, $1\frac{1}{4}$ miles long and a quarter to a third of a mile wide. Its west shore is moderately undulating till, with the highest swells 20 to 30 feet above the lake. In a few places its grassed bluffs rise steeply from the water's edge 10 to 20 feet. Farther west the rolling surface of till, seen for a distance of 3 or 4 miles, rises to 1,225 or 1,250 feet. This lake has no trees on its margin, excepting two small cottonwoods, each about 25 feet high, on its northwest shore; bushes grow in several places, mostly on the east; but the greater part of the lake border, like all the surrounding country, is prairie.

Beach ridge through the north part of section 2, township 147, range 55, 1,138 to 1,132 feet. In the south half of section 35, township 148, range 55, it has been mostly eroded by a lake which borders this beach on the east from the north part of section 2 to the north part of section 35, having a length of 1 mile and a width of an eighth to a fourth of a mile. The elevation of this lake is 1,104 feet. It has no trees or bushes, excepting a few willows 4 to 6 feet high, near the middle of its west side, and is wholly surrounded by hard, grassy shores. Crest of the beach west of the north part of this lake, 1,140 to 1,142 feet, and through the south half of section 26, 1,137 to 1,142 feet, similarly bordered on the east by two lakelets, which have approximately the same height as the preceding, 1,104 feet. The land east of these three lakes is flat, 1,113 to 1,117 feet near them, with a very gentle slope descending thence eastward.

More diffuse and irregular beach deposits in north-to-south swells and short, massive ridges of gravel and sand, inclosing occasional hollows with no outlets, some of which hold small ponds and sloughs, extend from the north edge of section 26 northward through the west half of section 23, township 148, range 55, with an elevation of about 1,135 feet. The depression on the west is some 5 feet lower, and on the east there is a descent of 10 feet from the crest to the base of the beach. Fingals Creek, in the northwest corner of section 23, where it intersects the beach, has a height of about 1,110 feet. Undulating and rolling till within 3 or 4 miles westward rises to 1,250 feet.

Herman beach, through the west part of section 14, township 148, range 55, 1,142 to 1,147 feet, being mainly a somewhat typical ridge, with short swells of beach gravel and sand on its east side 10 to 15 feet lower, inclosing hollows, but few or no sloughs. Two lakes at 1,110 feet, approximately, lie close east of this beach, near the center and in the northwest quarter of this section. They are bordered on the east by land 10 feet higher, from which a very gentle descent sinks toward the Red River.

Continuation of this beach ridge northward through the east edge of section 10, township 148, range 55, 1,142 to 1,146 feet, 3 to 5 feet above the depression on its west side. On the east, three lakelets at 1,120 feet, approximately, lie in the west edge of the northwest quarter of section 11, each being about 20 rods long from south to north and 15 rods wide. Crest of beach ridge, 30 to 40 rods wide, extending nearly due north through the east edge of section 3, 1,144 to 1,150 feet; east base, about 1,125 feet; depression on the west, 5 to 10 feet, nearly level upon a width of 40 rods; beyond is an ascent of undulating and rolling till to 1,250 feet within 2 or 3 miles. In the southwest quarter of section 36, township 149, range 55, Lind, this Herman shore is marked by irregular swells and massive short ridges of gravel and sand, with occasional inclosed sloughs. This is succeeded by a half mile of the ordinary continuous single ridge, 1,147 to 1,150 feet.

Magnificent beach ridge, passing north-northwest through the east part of sections 26 and 23, Lind, 1,147 to 1,150 feet. A road, which was formerly an Indian trail, runs on its top here and for several miles northward. This beach is composed of the usual sand and gravel, thickly filled with pebbles up to 2 and rarely 4 inches in diameter. It forms a broad, wave-like ridge 30 to 40 rods wide, including the slopes. On its west side is a depression of 5 to 10 feet, 20 to 60 rods wide, which is moist grass land, excepting a small reedy slough in the south edge of section 11. On the east side of this upper Herman beach there is a very smooth slope descending 25 or 30 feet in as many rods. Next is a nearly level belt 20 to 60 rods wide, increasing in width from south to north, succeeded by a lower Herman beach ridge rising 8 to 10 feet, with its crest at 1,127 to 1,130 feet, or 20 feet below the upper beach. These parallel Herman beaches are very finely developed thus for nearly 6 miles, passing north through sections 23, 14, 11, and 2, Lind, and the southwest part of section 35, township 150, range 55. High portion of the upper beach in the south edge of section 14, 1,153 feet, and depression west, 1,142 feet; crest onward through this section, 1,153 to 1,149 feet. In the north part of section 11 and the south edge of section 2 it is a few feet lower, is irregular in height and outlines because of intersecting water-courses, and has a less continuous and shallower depression on its west side. In section 2, however, both beach ridges are finely displayed, having the same contour as southward. Crest of upper beach in sections 2 and 35, 1,152 to 1,155 feet; depression on the west, 8 to 15 feet, partly occupied by a long slough. The northwest part of section 35, in the course of these beaches, is lower smooth till, with no deposits of sand and gravel.

Goose River, near the north line of the northwest quarter of section 35, and the Little Goose River, in the north part of section 15, township 150, range 55, where they cross the ancient lake shore, are in valleys about 30 feet deep, eroded in till. Each consists of pools 5 to 7 feet deep and 10 to 20 feet wide, alternating with other portions so narrow that one may step across them.

In the east part of the west half of section 26 and the southwest corner of section 23, township 150, range 55, the upper Herman shore is offset a third of a mile east from the remainder of its course and consists of massive, irregular swells of till, partly overspread with gravel and sand, 1,152 to 1,160 feet. Among them are hollows 4 to 6 feet deep, without outlet, and their entire belt, a quarter of a mile wide, is crossed by depressions as low as 1,145 feet. Through section 22 this shore bears a typical beach ridge of sand and gravel, 40 to 50 rods wide, 1,157 feet, with depression of 10 to 15 feet on the west; descent of the eastern slope, 20 to 25 feet in 30 or 40 rods. In section 15 this upper beach, 1,152 to 1,157 feet, has a quite irregular form, chiefly due to erosion by the Little Goose River and its small tributaries. It is again exhibited in its ordinary type through section 10, being a ridge 25 or 30 rods wide, with crest at 1,155 to 1,157 feet, 15 to 20 feet above its east base and with a narrow depression of 4 to 8 feet on the west; through the west part of section 3, township 150, range 55, and the west edge of the southwest quarter of section 34, township 151, range 55, 1,157 to

1,159 feet, excepting gaps cut by small watercourses; and in the east edge of the northeast quarter of section 33, 1,154 to 1,157 feet. Thirty rods west from the northeast corner of this section 33 its elevation is 1,155 feet, with slopes descending 12 feet eastward and 8 feet westward.

Lower Herman beach, a half mile to three-fourths of a mile east of the foregoing, in the west edge of sections 14 and 11 and the east edge of section 3, township 150, range 55, 1,130 to 1,135 feet, from which there is a descent of 5 feet to its west base and 10 feet to the east. From the southeast quarter of section 34, township 151, range 55, this beach passes northeasterly to Larimore.

Upper Herman beach, a well-defined ridge, running north through the east part of section 28, township 151, range 55, 1,155 to 1,159 feet; thence north-northwesterly through sections 21 and 16, 1,157 to 1,160 feet, and through the southwest part of section 9, the northeast part of section 8, and the southeast quarter of section 5, 1,157 to 1,162 feet. Where it is crossed by the Devils Lake line of the Great Northern Railway, in the south part of the northeast quarter of section 5, about $4\frac{1}{2}$ miles west of Larimore, its crest was at 1,162 feet, 4 feet above the track, and it holds the same height for about 50 rods northeastward. Two-fifths of a mile east from this beach the railroad crosses a second beach deposit whose crest and the track are the same, 1,146 feet.

DELTA OF THE ELK VALLEY.

(PLATE XXIX.)

Nearly level land reaches 4 miles westward from Larimore along the Devils Lake railway line, averaging 1,130 feet above the sea, and varying only 2 or 3 feet above and below this level. Beneath the rich black soil here and elsewhere, all about Larimore, are stratified sand and fine silt free from gravel. The beach ridges near this town are consequently composed wholly of sand, quite in contrast with their usually coarser material.

The underlying beds consist largely of sand from the Fort Pierre shale, and were derived probably in part from erosion by the head streams of the Turtle and Goose rivers in this Cretaceous formation, which here constitutes the highland west of Lake Agassiz, thinly covered by till.

Considerable channeling of the valleys in which these streams flow appears thus to have been accomplished before the land was uplifted and the lake receded to its Norcross and lower shores. This delta accumulation, consisting partly of alluvium from stream erosion after the departure of the ice, but evidently in far larger measure of modified drift supplied by streams from the melting ice in which it had been held, occupies a width of 6 to 12 miles, and stretches about 35 miles southward from McCanna, by Larimore, Northwood, and Hatton, to the vicinity of Portland. Its thickness at Larimore, as shown in fig. 14, is 60 feet, and doubtless its average thickness is as much as 30 or 40 feet upon its area of about 300 square miles. It was deposited in the edge of Lake Agassiz during the first and second Herman stages, for these shores marked by beach ridges, are above the

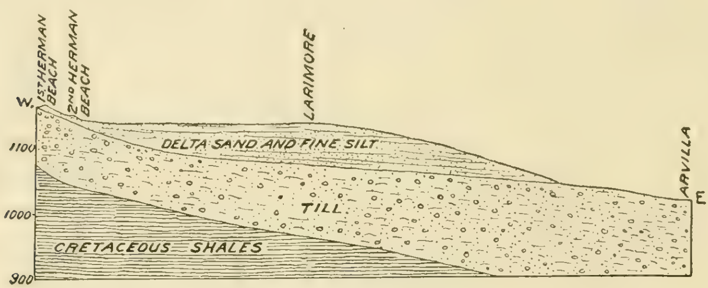
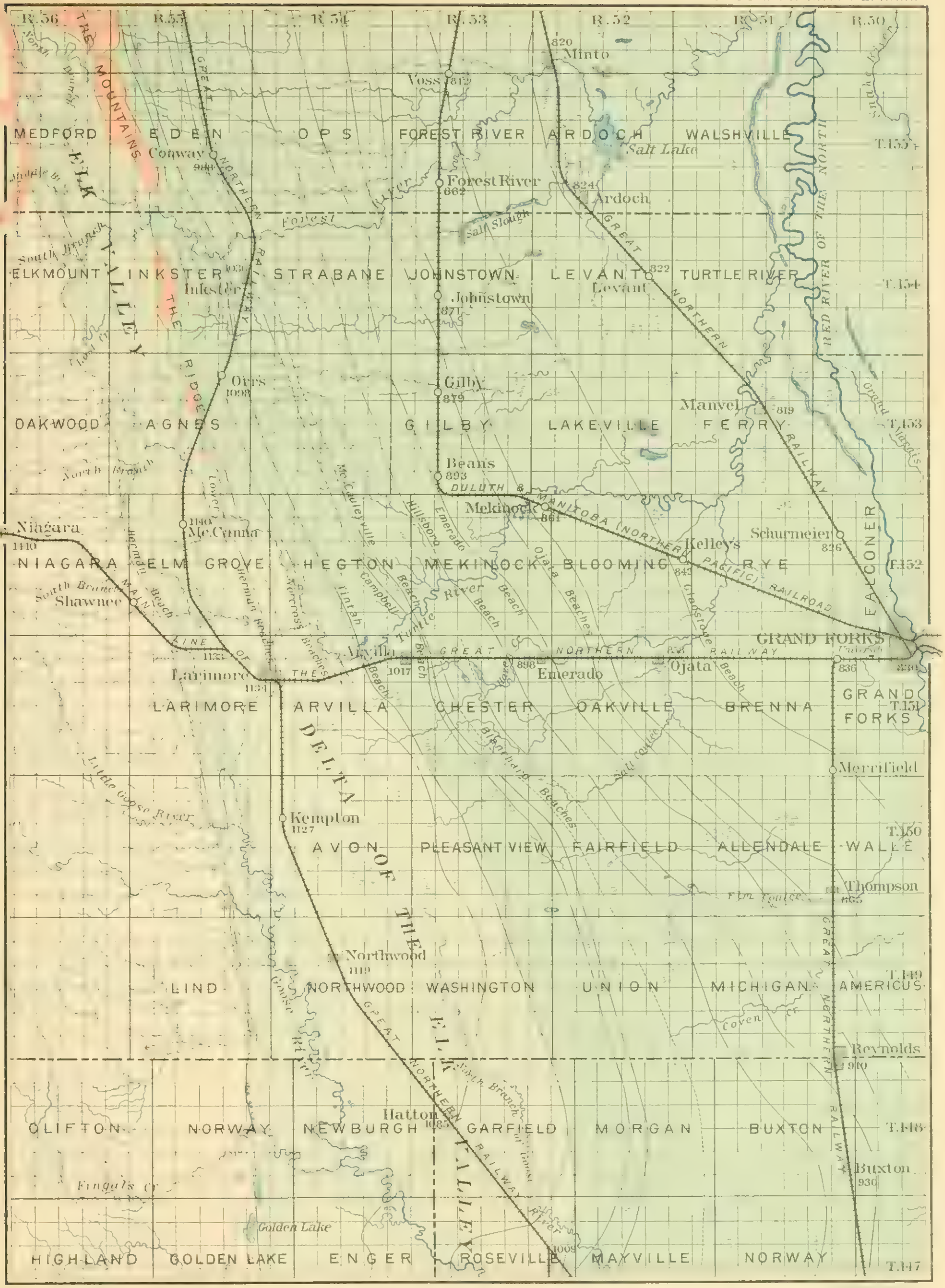


FIG. 14.—Section across the delta of the Elk Valley. Horizontal scale, 3 miles to an inch.

delta; but the third and fourth Herman beaches extend across it, passing close east of Larimore. The Norcross and Tintah shore-lines lie near its eastern boundary, for the greater part upon its edge, but it has not been conspicuously eroded. Farther east the surface is mainly till for the next 15 miles or more, descending toward the Red River, which is bordered on this latitude in North Dakota by a belt of alluvial clay and silt only a few miles wide.

A section of the beds forming this delta is furnished by the well at the Sherman House, Larimore, which was dug 20 feet and bored 40 feet, as follows: Soil, 2 feet; fine sandy and clayey silt, without coarse sand, gravel, or stones, 5 feet; fine yellowish sand, with less clay, being mainly siliceous, 13 feet; and dark sand, very soft to bore through, two-thirds



MAP OF THE WESTERN SHORES OF LAKE AGASSIZ, INCLUDING THE ELK VALLEY DELTA, IN GRAND FORKS COUNTY AND PARTS OF ADJOINING COUNTIES, NORTH DAKOTA.

Scale, 6 miles to an inch.

Lake Area | Delta | Moraines

Altitudes of railway stations are noted in feet above the sea.

Cretaceous shale in particles up to a twentieth of an inch in diameter, 40 feet, with much water. Hard blue till was found at the bottom. The other wells of this town are said to obtain their supply of water at a depth of about 20 feet, in the upper part of this sand derived chiefly from shale. In Northwood and Hatton, also, water is found at depths of only 10 to 20 feet before reaching the base of the delta sand.

The volume of this extensive sand and silt delta is about 1½ or 2 cubic miles. It occupies more than thrice the area of the delta of the Pembina River, but is much shallower, so that they are nearly equal in their cubic contents, or this is the smaller; and it has nine times or perhaps twelve times the volume of either of the two deltas of this lake in Minnesota, lying on the Buffalo and Sand Hill rivers. Yet here no stream of significant size enters the lake area. There are, indeed, not less than a dozen small streams, the headwaters of the Turtle and Goose rivers, which descend to the delta from the till-covered Cretaceous highland on the west; but none of them has a large valley or extensive basin of drainage, and it would be difficult to decide which one of three or four is most worthy of consideration. The delta, however, in its position, the outlines of its extent, and the directions and rate of its slopes, seems independent of them all.

Northward from Larimore and McCanna, where the surface of this delta is highest, a very noteworthy topographic feature of the western border of the lacustrine area has received the name of Elk Valley in its southern portion, and in its northern continuation is called the Golden Valley. These are parts of one continuous belt which was at first the course of a glacial river, and afterward became a sound or strait extending about 40 miles along the coast of Lake Agassiz at its highest stage. It was divided from the main lake by a series of several small islands of knolly and hilly till, occasionally connected together by a low beach embankment or bar, formed by the lake waves. The Elk Valley is commonly regarded as beginning at Larimore, but it may more strictly be said to begin 9 miles farther north, at the most southern of its inclosing islands. It extends north from Larimore 29 miles to Ramseys Groves, on the North Branch of the Forest River, with a width of about 4 miles for the greater part of its extent, diminishing at the north to 2 miles. The narrower prolongation of this tract, known as the Golden Valley, varies from 2 miles to only 1 mile in width along its course of 18 miles to the North Branch of Park River, 1 to 2 miles west of Gardar. Originally the whole length of this belt was called the Elk Valley, which seems to be a translation of its aboriginal name; but the name Golden Valley, proposed for its northern portion by the Ramsey brothers, living at Ramseys Groves, in Vernon Township, has come into universal use for the narrow part of the valley extending thence northward.

The Golden and Elk valleys have no river now running along their continuous depression. Instead it is crossed by numerous streams which form the Turtle, Park, and Forest rivers, descending from the highland west of Lake Agassiz and finding their way between or through the morainic islands east of the valley. But during the stage in the departure of the ice-sheet when these islands were being accumulated on the western margin of its Minnesota lobe, contemporaneous with the formation of the Leaf Hills and with the completion of the prominent compound moraine south of Devils Lake, a great river flowing from the melting ice-fields and laden with their drift ran with a strong current in this long, nearly straight valley, bringing to its debouchure into Lake Agassiz at McCanna the sand and silt of this delta. A portion of its freight was even borne 35 miles onward in the shallow water of the lake, forming the southern part of the delta, which was probably held to the western side of the lake area by the barrier of this ice-lobe. That the sand and silt were thus supplied chiefly from the englacial drift, and only in small part from erosion by the streams that now exist, is proved by the position of the axial thickest and highest portion of the delta, separated from the western shore of Lake Agassiz by a broad, shallow depression in which the numerous sources of the Goose River are diverted from their eastward course and carried to the south in a united stream. Whatever alluvium these tributaries have added to the delta, both while the lake was here and since it was withdrawn, has been insufficient to raise their channels the small amount that would give them passage across the delta in their normal course toward the east.

SHORE WEST OF THE ELK AND GOLDEN VALLEYS.

(PLATES XXIX AND XXX.)

Through section 32, Elm Grove, the upper beach runs northwesterly, its elevation being 1,160 to 1,163 feet above the sea. Its material is coarse gravel, with pebbles up to 6 inches in diameter, in part accumulated as a ridge 10 or 15 feet above the land at its base northeast and 5 to 8 feet above its southwest base, and in part lying on the flank of swells of very stony till, the crests of which are only 5 to 10 feet higher than the beach. This till or morainic drift contains a multitude of granitic and limestone bowlders up to 1½ feet in diameter, but few or none of larger size. In the rolling till which rises thence westward to 1,250 or 1,300 feet within 2 or 3 miles are many granitic bowlders up to 5 feet or more in diameter, exceeding the usual proportion in the till of this region.

In the north edge of section 32 and the south part of section 29, Elm Grove, this beach is the terrace-like border of a nearly level tract of sand and gravel an eighth of a mile or more in width, at an elevation of 1,171 to 1,173 feet. The bordering slope is beach gravel, with its base at 1,155 to 1,158 feet; but the slow descent thence eastward is till, somewhat eroded by wave action and having many small and large granitic bowlders up to 4 or 6 feet in diameter strewn on the surface or partially covered by the soil. In the northeast quarter of section 30 this upper Herman beach is typically developed, being a gracefully rounded ridge of sand and gravel, 25 or 30 rods wide; crest, 1,165 to 1,166 feet; foot of eastern slope, 1,150 feet; depression west, usually 2 to 5 feet, beyond which is a slowly ascending area of smooth, undulating till.

Upper beach through section 19, Elm Grove, a low, rounded ridge of sand and gravel about 25 rods wide; crest, 1,166 to 1,168 feet; base of its east slope on the north line of this section, 1,158 feet. In the southwest quarter of section 18 this beach is cut by the South Branch of the Turtle River; its elevation in this section south of the stream is 1,167 to 1,168 feet. There is no considerable valley here, and the creek runs only in spring or after unusual rains, being reduced to stagnant pools during the rest of the year. Within 2 miles southeast, however, it becomes a living stream, fed by very cold springs, and thence to the secondary Herman beach near Larimore it has cut a valley 50 to 90 feet deep.

Elm Grove, comprising about 5 acres, is on this creek, a third of a mile east of the upper Herman shore-line, which continues north-northwestward through the southwest part of section 18, Elm Grove Township, and the northeast edge of section 13, Niagara, to the west side of Little Elm Grove, 10 acres or more in extent, in the east part of section 12. Along this distance of 1½ miles the surface presents a very favorable slope, from 1,150 to 1,200 feet elevation, on which a beach ridge or definite beach deposits would usually be found well developed; but the waves and currents of Lake Agassiz could not act efficiently here, because this area lay in the lee of islands and of a wave-formed bar or beach several miles to the east, which are the eastern boundary of the Elk Valley. Consequently deposits of beach sand and gravel are scanty on the upper western shore of Lake Agassiz here and for 40 miles northward along the extent of the Elk and Golden valleys, east of which a narrow chain of islands and bars rose above the surface of Lake Agassiz during its highest Herman stage. Between the South Branch of Turtle River and Little Elm Grove the beach formation consists only of a thin covering of sand and gravel spread on the sloping area of till, at an elevation from 1,160 to 1,175 feet. Several of the small grassy channels eroded here, dry excepting in spring and times of excessive rain, are almost completely paved with stones up to 1 or 2 feet in diameter, but few stones occur upon the adjoining surface of till.

From the Little Elm Grove the highest western shore of Lake Agassiz (consisting of a similar slope of till ascending gently westward, with inconspicuous deposits of beach gravel and sand, not accumulated in any distinct ridge, but probably recognizable almost continuously) extends northward through sections 12 and 1, Niagara, and sections 31 and 30, Agnes, to the central part of Bachelors Grove, which it passes through in the west half of section 30. This grove borders the head stream of Turtle River for 1½ miles, with an average width of about a quarter of a mile, thus comprising approximately 250 acres. It is dense woods, chiefly elm and basswood in its east half, but nearly all bur oak for the west half. Much bur oak is also found along several miles of this stream next westward, but it is not seen from the margin of Lake Agassiz, being hidden in the valley, 40 to 50 feet deep, which the stream has eroded in that area of undulating and rolling till.

Herman beach, for the first mile or more north from Bachelors Grove, passing through the northwest quarter of section 30 and the west edge of section 19, Agnes, 1,165 to 1,170 feet. This is mostly a well-defined beach ridge, 20 to 30 rods wide, composed of sand and gravel, with pebbles up to 2 inches in diameter. It rises slowly to a height of 10 or 12 feet above the flat land on the east and is bordered on the west by a depression of 1 to 3 feet, beyond which a smoothly undulating and rolling surface of till rises to an elevation of 1,200 and 1,250 feet at a distance of 3 miles. In the northwest quarter of this section 19 the beach deposit becomes complex, consisting of several irregular ridges rising 5 to 8 feet above their bases, 1,167 to 1,170 feet above sea-level, with inclosed hollows, and the depression close west occasionally sinks to 1,155 feet.

Through sections 13 and 12, the southwest part of section 1, and in section 2, Oakwood, to the grove on the north line of section 2 at the junction of the north and south branches of Lost Creek, and thence northeast and north through section 35, Elkmount, the Herman shore, between 1,160 and 1,170 feet, is not marked by any considerable deposits of gravel and sand. Farther north this shore is distinguished not only by a noticeable change in the topographic features along a nearly level line at 1,170 feet, dividing the very flat area of the glacial lake from the undulating and rolling till on the west, but also by occasional beach deposits. Through the south half of section 26, Elkmount, a somewhat typical beach ridge of sand and gravel, 15 to 25 rods wide, with a depression of 3 to 6 feet on its west side, runs north and northwest, its crest being at 1,175 to 1,170 feet, declining from south to north. On the east its slope falls 5 to 10 feet in 10 to 20 rods; and thence a more gentle descent, with surface of sand and fine gravel, sinks to 1,155 feet within an eighth of a mile. In the northwest quarter of this section 26 the beach ridge ceases and is succeeded northward by an expanse of nearly flat till, which along the north line of this section sinks eastward from 1,175 to 1,155 feet.

Elk Valley, for 12 miles from Elm Grove and McCanna north to the Forest River, is nearly constant in elevation, which is 1,155 feet on its west border and 1,135 feet near its east side, its average width being about 4 miles.

Upper Herman beach, a definite and massive ridge of sand and fine gravel, 25 to 40 rods wide, for a half mile south from the South Branch of Forest River, in the west part of the northwest quarter of section 14, Elkmount, 1,173 to 1,178 feet, passing north and northwest, with a descent of 12 to 15 feet on the east and a depression of 4 to 8 feet on the west.

Beyond this branch of the Forest River, in the north half of section 10, Elkmount, the beach ridge, similar in outline, with its crest at 1,174 to 1,179 feet, is the site of an abandoned railway grade, on account of which its material is well exhibited. It is sand and gravel, and three-fourths of the pebbles, mostly less than 2 inches in diameter, are dark-gray slaty shale. Twenty miles to the south-southeast the same shale in small grains makes fully two-thirds of a stratum of sand that extends from 20 to 60 feet in depth in the well at the Sherman House, Larimore. Pebbles of it were also observed in kame-like deposits of gravel and sand near Balaton, Lyon County, in southwestern Minnesota. During the further exploration of the western shore of Lake Agassiz this shale was discovered in place, and is found to be the bed-rock, of Cretaceous age, which forms the conspicuous escarpment of the Pembina Mountain, though even there it is generally covered and concealed by drift.

Natural surface at the northwest corner of section 3, Elkmount, on the line between Grand Forks and Walsh counties, 1,181 feet. The upper Herman shore passes north-northwesterly through this corner of section 3 and the east part of section 33, Medford, to the Middle Branch of Forest River (farther east formerly called Salt River), which it reaches near the center of the east half of section 28. It has only scanty deposits of beach gravel and sand, nowhere forming a ridge; instead, the surface is mainly till, very flat east of this shore, but undulating or rolling westward.

The South and Middle branches of Forest River occupy valleys 25 to 40 feet deep and 20 to 30 rods wide. They are bordered with groves, or at least a continuous line of trees, along the greater part of their course.

In the northwest quarter of section 28 and the west part of section 21, Medford, the highest shore-line of Lake Agassiz is very distinctly marked, at 1,183 to 1,185 feet, by being the upper edge of a flat slope of till, probably with scanty deposits of gravel and sand, which sinks 20 to 30 feet in the next half mile eastward. Farther east, for the width of 3 or 4 miles across the Elk Valley, the surface elevation is 1,160 to 1,125 feet.

Just west of this shore-line a knolly belt of morainic drift, bearing a marvelous profusion of bowlders, occupies a width of 25 to 50 rods, generally forming a single series of hillocks rising 15 to 30 or 35 feet. These are strewn with bowlders of all sizes up to 5 feet and rarely 8 feet in diameter, so plentiful that they cover a third or even half of the surface. A few masses of limestone were observed, but fully 99 per cent of the bowlders are Archean granite and gneiss. This is the most eastern portion of a semicircular moraine which appears to have been accumulated on the eastern boundary of a lobe of the ice-sheet during a pause in its retreat. From sections 21 and 28, Medford, this moraine continues, with nearly the same features, south and southwest to the southeast quarter of section 32, and thence west-southwest by Pilot Knob, in the northwest quarter of section 5, Elkmount, to the west side of section 1, township 154, range 57, and perhaps beyond. Its hills and knobs rise 25 to 75 feet above the general level of the adjoining smoothly undulating till, their tops being 1,250 to 1,300 feet above the sea. To the north, northwest, and west it reaches, with similar development, in a great curve convex to the northeast, along an extent of 5 or 6 miles, to a cluster of prominent morainic hills rising 50 to 75 feet, situated in sections 2 and 3, Cleveland. This moraine matter was doubtless englacial; among its multitude of both large and small rock fragments a half hour's search failed to discover any marked with striæ or having faces planed by glaciation. On the west the area inclosed by this curving moraine is very smooth, only slightly undulating till, at 1,185 to 1,250 feet, ascending slowly westward.

Another distinct morainic series, similar in its very knolly contour, in its material (excepting a larger proportion of gravel, half of which is the Cretaceous shale before described), and in the great abundance of bowlders, nearly all granitic, branches from the preceding in the north part of section 8, Medford, and sweeps northeast and north through the west half of section 4, and thence northwest and west through sections 32, 29, and 19, Vernon, and sections 13 to 16, Norton, to a group of morainic hills about 75 feet high, a mile northwest of Galt post-office. Between this curved moraine and the nearly parallel northern part of the preceding, 4 miles distant to the south, the surface is very smooth, undulating till, rising slowly toward the west.

These moraines, with their east base at 1,185 to 1,170 feet above the sea, formed the west shore of Lake Agassiz at its highest stage for nearly 7 miles between the Middle and North branches of the Forest River. The North Branch intersects this shore-line near the center of section 20, Vernon, close to the southwest end of Ramseys Groves, which extend thence about a mile along this watercourse in the north part of section 20 and the southeast quarter of section 17. The stream in these sections has no valley, only a channel 20 to 30 feet wide and 10 feet deep.

Golden Valley, on the north line of sections 4 and 5, Vernon, has an elevation of 1,185 to 1,195 feet, showing an ascent of 10 feet from east to west in its width of 2 miles. About the same transverse slope, raising the west side of this valley 10 or 15 feet above its east side, is found along its whole extent of 18 miles, from the North Branch of Forest River to the Middle and North branches of Park River. In the north half of Vernon, and thence northward, the width of this valley varies from 1¾ miles to only 1 mile. It is flat, and consists mainly of clay, free from gravel; but wells find gravel intermixed with the clay, probably till, at a depth of a few feet, and about 20 feet from the surface they sometimes encounter a water-bearing stratum of gravel, chiefly made up of Cretaceous shale.

Natural surface at the southwest corner of section 27, Golden, 1,191 feet. Highest part of Golden Valley south of the South Branch of Park River, along the north line of sections 27, 28, and 29, in this township, 1,199 feet on the east to 1,211 feet on the west. Surface at schoolhouse on the west side of the northwest quarter of section 21, 1,207 feet.

South Branch of Park River at the bridge near the middle of the north line of section 21, Golden, 1,170 feet, approximately; bottom land about a quarter of a mile wide, 10 to 15 feet above the stream; crest of the south bluff rising to the flat belt of the Golden Valley, 1,191 to 1,209 feet, ascending westward; of the north bluff, 1,189 to 1,205 feet.

Golden Valley, on the north line of section 5, Golden, 1,195 to 1,205 feet; 2 miles farther north, on the north line of section 29, Lampton, 1,198 to 1,208 feet. In this northern part of the valley limited tracts of its flat area are strewn with abundant bowlders up to 2 feet, and less frequently 3 or 4 feet, in diameter. They are probably where swells of till rose nearly to the surface of the water in this strait of Lake Agassiz, so that its fine portions were swept away by waves and currents, to be deposited elsewhere in the valley as clayey silt, leaving the masses of rock which could not be thus removed. Approaching the Middle Branch of Park River, the surface of the Golden Valley continues very smooth and flat, but it ceases to have a continuous ascent from east to west, some portions along the center being depressed a few feet. Such a shallow hollow holds a slough about a mile long from south to north and a half mile wide in its broadest part, at 1,193 feet, extending from the north edge of section 20 through the west part of section 17, Lampton, in which a small area of water remains throughout the year. On each side of this slough, and for miles south and north, this valley is a great hay meadow.

The west border of the Golden Valley was the most western shore of Lake Agassiz in its highest stage, but it is only very scantily marked by deposits of beach gravel and sand, because of its sheltered position on the western and leeward side of this narrow strait. From the middle of section 20, Vernon, this shore-line extends in a quite direct course a few degrees west of north 11 miles through the west part of sections 17, 8, and 5, in this township, sections 32, 29, 20, 17, 8, and 5, Golden, and the east edge of sections 31 and 30, Lampton. For the next 3 miles, in the east edge of sections 19, 18, and 7, Lampton, it runs nearly due north. Thence it turns to a northwesterly course through section 6 of this township, and through section 31, Gardar. In this vicinity the Golden Valley terminates.

Bushes and trees clothe the slope on the west side of the Golden Valley along its northern part, extending to the south line of Lampton; but this ascent farther south, also the entire extent of the Golden Valley, the drift hills forming its east border, and the vast plain of the Red River Valley, are prairie, excepting that narrow belts of timber border the water-courses.

Smoothly undulating till rises slowly from the west side of the southern part of the Golden Valley; but in section 30, Lampton, rounded hills of till attain a height about 100 feet above the valley, or 1,300 feet above the sea. Thence northward a smooth slope ascends 50 to 60 feet, or in some portions only 30 or 40 feet, within the first quarter or half of a mile to the west, succeeded beyond by a moderately rolling surface with less ascent.

A terrace of beach sand and gravel, containing pebbles and cobbles up to 6 inches in diameter, extends a third of a mile from southeast to northwest, with a width of 5 to 30 rods, in the northwest quarter of section 33, Lampton, abutting on the west flank of the rolling and hilly deposits of till which make the east border of the Golden Valley. It was formed by currents entering this strait of Lake Agassiz from the north, eroding the bordering hills in the east edge of sections 20 and 29, and thence sweeping this sand and gravel southward. It marks the highest stage of Lake Agassiz, having an elevation of 1,213 to 1,195 feet, declining from north to south, and also sinking 1 or 2 feet from west to east in its width of 100 to 500 feet, being thus slightly higher along its verge than where it rests upon the adjoining hilly till.

Middle Branch of Park River near the middle of the south side of section 5, Lampton, about 3 miles northwest of Edinburgh station, 1,185 feet above the sea; crest of the south bank of the very small valley of this stream, rising to the flat Golden Valley, 1,192 feet on the east to 1,215 feet on the west. The Golden Valley here shows thus a transverse ascent of more than 20 feet in its width of about 1 mile. On the north line of sections 5 and 6, Lampton, the east edge of this valley has an elevation of 1,210 feet, and its west edge, 1,220 feet. About a half mile farther north the height of this belt where it is crossed by a tributary of the Middle Branch is 1,220 to 1,235 feet from east to west, being thus above the highest level of Lake Agassiz.

BEACHES AND ISLANDS EAST OF THE ELK AND GOLDEN VALLEYS.

(PLATES XXIX AND XXX.)

Returning about 45 miles south to Larimore, we have yet to describe the beaches of Lake Agassiz and its islands of rolling and hilly morainic till which divided the strait of the Elk and Golden valleys in Grand Forks and Walsh counties from the main body of the lake.

The crests of the upper or first and the second Herman beaches before described, respectively $4\frac{3}{5}$ and $4\frac{1}{5}$ miles west of Larimore, are 1,162 and 1,146 feet above the sea. The third Herman beach, a third of a mile east of Larimore depot, has its crest at 1,133 feet; and another beach belonging to the same stage of Lake Agassiz, a third of a mile farther east, rises to 1,134 feet, with descent in 30 or 40 rods east 11 feet, and in the same distance west 9 feet. The fourth Herman beach, consisting of four small beach ridges crossed by the railway $1\frac{1}{2}$ to 2 miles east of Larimore, has crests at 1,123 to 1,118 feet, with intervening hollows 3 to 5 feet deep.

The beach seen two-thirds of a mile east of Larimore passes north and north-northwesterly through the east half of sections 7 and 6, Arvilla, and the west half of sections 31 and 30, Hegton, into the southeast corner of section 24, Elm Grove. North of the South Branch of Turtle River it is not a typical ridge, but a series of massive rounded swells of sand 10 to 15 feet high, with their crests at 1,135 to 1,140 feet.

A parallel beach ridge, a third to a half mile west of the foregoing, mostly massive, with typical wave-like form, has an elevation of 1,133 feet close east of Larimore; 1,144 feet at a cemetery close north of the South Branch of Turtle River in or near the southwest corner of section 31, Hegton; chiefly 1,137 to 1,140 feet in its course thence north-northwesterly through sections 36 and 25, the west edge of section 24, and the east half of section 14, Elm Grove; 1,142 to 1,145 feet in the west half of section 11, and 1,143 to 1,147 feet in the east edge of section 3 of this township. Along the west edge of section 11, a duplication of this beach ridge, of the same massive size, lying a half mile farther west, extends a mile south from the North Branch of Turtle River, its crest being at 1,142 to 1,145 feet; but thence southward the general elevation is about 1,130 feet to the broad tract of this height crossed by the railway west of Larimore, excepting that the South Branch of Turtle River has eroded a valley 40 to 75 feet deep. The distance of 1½ miles from Larimore north to this stream is a gradually descending, smooth slope, but its northern bluff rises steeply to a height a few feet above that of Larimore.

Great Northern Railway at Larimore, 1,134 feet above the sea; at McCanna, 1,140 feet; on the bridge over the North Branch of Turtle River, 1,132 feet, 17 feet above the stream; at its summit, in the northeast corner of section 22, Agnes, grade and natural surface, 1,164 feet; at Orr's station, 1,098 feet.

Lower Herman beach, running northwesterly in the northeast part of section 24, Elm Grove, 1,127 to 1,128 feet, with depression of 2 to 3 feet on its west side; in section 13, 1,127 to 1,132 feet; in the west part of section 12 and the northeast part of section 11, 1,130 to 1,135 feet, being in these sections the easternmost in a succession of three beach ridges, the two others of which are 10 feet higher; at E. C. D. Shortridge's house, in the center of section 2, 1,137 feet, forming a broad, flat swell of sand and fine gravel, with a depression of 3 to 5 feet on its west side; in the west part of section 36, through sections 26 and 23, and the southwest edge of section 14, Agnes, a continuous, well-defined beach ridge, 1,140 to 1,149 feet, with a descent of 10 to 15 feet on the east and a depression of about 5 feet on the west; in the east edge of the northeast quarter of section 15 and through the southeast quarter of section 10, Agnes, a deposit of sand and fine gravel, with nearly level top 20 to 30 rods wide, 1,145 to 1,149 feet, from which a slope falls 10 or 15 feet in 20 to 30 rods eastward, while on the west it is bordered by a slough 5 to 20 rods wide, which is partly permanent water and partly mowing land. It is to be noted that the northern two-thirds of the beach here described for a distance of 8 miles corresponds in elevation with the two beaches close east of Larimore and with their continuation northward to the North Branch of Turtle River, marking the third Herman stage of Lake Agassiz; but that the southern part records a slightly lower level of the lake, when it had fallen about 10 feet, or to its fourth Herman stage.

On the west side of this beach a smoothly undulating, broad swell of till, which was an island in Lake Agassiz, lies in the west part of section 26 and the east edge of section 27, Agnes, with a nearly level top of several acres, at 1,182 to 1,190 feet. An aboriginal burial mound, raised 4 feet and having a diameter of about 50 feet, is situated on the highest part of this area. Such localities, overlooking an extensive and beautiful panorama, were frequently chosen for this use, as is shown by many mounds on hilltops and on the margin of bluffs bordering deeply eroded valleys throughout the Northwest.

North of this island the upper Herman beach is represented in the east part of the southeast quarter of section 22 and in the west half of the southwest quarter of section 23, Agnes, by a wide tract of gravel and sand deposits, in irregular ridges and swells rising 4 to 8 feet, mostly trending from north to south, with their crests at 1,164 to 1,170 feet. Next to the north it is a well-defined beach ridge, with crest rising from 1,163 to 1,168 feet in its course of a half mile from south to north through the east edge of the northeast quarter of section 22.

In the southeast quarter of section 15, Agnes, the plain that descends slowly toward the Red River on the east is divided from the Elk Valley on the west by a low swell of till, having an elevation of 1,157 to 1,160 feet, destitute of beach deposits. This is succeeded in the north part of this section and the south part of section 10 by a second island which rose above the highest level of the glacial lake, having a length of 1 mile from south to north and averaging a quarter of a mile wide, its elevation in the southwest quarter of the northeast quarter of section 15 being about 1,187 feet, on the line between these sections about 1,175 feet, and near the center of section 10, at the north end of this irregular ridge, about 1,180 feet. Its material is till, partially overspread in its south half by gravel, which seems to have been brought by the currents and waves of Lake Agassiz from the erosion of its northern portion.

The beach of Lake Agassiz during its highest stage extends north from the north end of this island into the southwest quarter of section 3, Agnes, where it is a ridge about 20 rods wide, with an elevation of 1,165 to 1,172 feet, composed of coarse gravel and sand, inclosing plentiful rock fragments, chiefly granitic, up to 6 inches in diameter, most of which are only very slightly waterworn. Its eastern slope descends 15 to 20 feet in as many rods, and on the west an equal descent takes place within 8 or 10 rods. The steep western slope of this beach or bar, forming the east rim of the strait that filled the Elk Valley, was due to storms on the broad lake, rolling its waves upon the bar and carrying the sand and coarse gravel upward and over its crest. Turning northwestward, this beach passes into the northeast quarter of section 4, where it consists of irregular accumulations of gravel and sand, occupying a width of an eighth to a fourth of a mile, with their crests at 1,155 to 1,162 feet. In the north edge of section 4 it again becomes a definite beach ridge of the same material and contour as in section 3, and thus passes northeast and north through section 33, Inkster, with its crest mostly at 1,165 to 1,172 feet, its lowest part, about 1,162 feet, being near the center of the section. The two islands before described, this beach or bar, and the long island next northward are together commonly called "The Ridge," being the eastern limit of the Elk Valley, which averages 4 miles wide, 1,150 to 1,140 feet above the sea in its eastern and central portions, but rising with a transverse slope to 1,160 feet on its western border.

A third island above the highest stage of Lake Agassiz, 3 miles long from south to north and a quarter to a half mile wide, varying in elevation along its highest part from 1,170 to 1,223 feet, reaches through sections 28 and 21, the west half of section 16, and into the southwest corner of section 9, Inkster. It is till, with somewhat uneven surface, bearing frequent bowlders. Beach deposits occur on the east flank of this island in section 21 at 1,155 to 1,165 feet, and from 1,155 feet a smooth slope of sand and fine gravel falls slowly eastward along the east side of this highland through the greater part of its extent.

In the southeast part of section 8, Inkster, irregular accumulations of beach gravel, with crests at 1,170 to 1,175 feet, 10 to 15 feet above the adjoining depressions of till, extend northward from the island just described; and in the north part of this section 8 the beach sinks within an eighth of a mile from 1,172 to 1,161 feet and changes to a broad, smooth ridge, which thence passes northward through section 5 of this township, in which it is intersected by the Forest River, and through the west half of section 32, Eden, near the center of which it has three aboriginal mounds, 6 to 8 feet in height, on its top. The material of this beach ridge is fine gravel and sand. Its crest on the line between sections 8 and 5 has an elevation of 1,161 feet; an eighth of a mile north, at the verge of the south bluff of Forest River, 1,155 feet; for the first half mile from the bluff north of this river, 1,152 to 1,157 feet; and at the mounds in section 32, 1,156 to 1,159 feet.

Another beach ridge, 20 rods wide, with descent of 10 feet on each side in as many rods, formed during the same stage of Lake Agassiz, lies a half to three-fourths of a mile west from the foregoing, in the northeast quarter of section 6, Inkster. This is the highest land between the main Forest River and its South Branch. It consists of sand and fine gravel, of which a considerable proportion (about a sixth) is Cretaceous shale. The maximum elevation of this ridge, 1,157 to 1,164 feet, is maintained for 50 or 60 rods, from which it sinks to 1,150 feet at each end.

From the north side of section 32, Eden, an island of rolling and hilly morainic till above the highest level of Lake Agassiz, far larger than any of these already described, extends, with the exception of two short gaps, 20 miles northward, varying in width from a half mile to a little more than 1 mile in its southern quarter and from $1\frac{1}{2}$ to $2\frac{1}{2}$ miles through the remainder of its extent. This hilly tract, commonly denominated "the mountains," forms the east border of the Golden Valley. In the north part of section 36, Vernon, it has a depression to about 1,180 feet, which probably was a strait of the glacial lake in its highest stage, an eighth of a mile wide and a few feet deep. Again, in the center of Golden Township, it is intersected by the South Branch of Park River, which has a valley a quarter to a half of a mile wide and about 75 feet deep. The stream in its course of $1\frac{1}{2}$ miles through this belt descends about 50 feet, from 1,165 to 1,115 feet, approximately. It seems almost certain that a depression slightly lower than the Golden Valley on the west originally extended across this rolling and hilly area where it is cut by this stream; but the erosion of its valley has undermined and removed portions of adjoining hills and ridges, so that its inclosing bluffs now rise 50 to 100 feet, their highest points being about 1,225 feet above the sea, or 25 to 30 feet above the east edge of the Golden Valley. All these bluffs and two plateaus left in the midst of the valley are till, yellowish near the top and dark-bluish below.

The elevation of "the mountains" in their southern and narrower portion, through the west part of Eden and the northeast corner of Medford, is 1,190 to 1,225 feet; through the east half of Vernon, 1,200 to 1,250 feet; in the south part of Golden, 1,200 to 1,260 feet, and through the north half of this township and the south half of Lampton, 1,200 to 1,275 feet, being highest in section 28 of the township last named, near the northern end of this hilly tract. These prominent accumulations of till, rising in the west edge of the lacustrine area, seem referable, as shown in Chapter IV, to the ninth or Leaf Hills moraine. They appear to have been formed on the western margin of the Minnesota lobe of the ice-sheet.

The east border of "the mountains," in section 20, Eden, falls somewhat steeply to about 1,135 feet, and thence a flat slope, with no beach ridges, sinks slowly eastward. In the northeast quarter of section 7 in this township a well-defined beach ridge 10 to 15 rods wide, composed of sand and gravel, with pebbles up to 2 or 3 inches in diameter, extends 25 rods south from an eastern spur of the hilly till; crest of this spur, about 1,195 feet; of the beach, 1,172 feet, with depression of 3 to 6 feet on the west. Irregular beach accumulations, 10 to 20 feet lower, continue southward nearly a half mile.

In section 30, Rushford, the eastern border of this rolling and hilly area falls 75 feet or more within a third of a mile, to about 1,100 feet. Its material is till, with scanty deposits of beach gravel and sand, not distinctly accumulated in ridge form. About half way down this slope it shows in some places a more abrupt escarpment, with steep descent of 15 or 20 feet. The same features continue through section 19, except that a series of distinct beach deposits is observable about 25 rods east from the crest of the slope, at 1,170 to 1,175 feet, probably formed during the second Herman stage of Lake Agassiz. A descent of 125 feet takes place within a half mile on the east side of "the mountains," near where it is cut by a large but short ravine, in the southeast quarter of section 12, Vernon, falling from 1,180 to 1,050 feet, approximately, with no well-defined shore-lines observable. A grove lies at the east base of this slope a third of a mile south of the ravine. In the northwest quarter of this section 12 and the west edge of the southwest quarter of section 1, a well-developed beach, in part consisting of two parallel low ridges, has an elevation of 1,170 to 1,177 feet; and in the east edge of section 2, continuing northward, its elevation is 1,177 to 1,184 feet. Its eastern slope falls to 1,170 feet within 10 or 20 rods.

Great Northern Railway at Park River depot, 998 feet above the sea; natural surface at the southeast corner of section 23, Golden, on the road leading west from Park River, 1,178 feet. The crest of the upper Herman beach, crossed by this road 10 rods west from the point named, is at 1,187 feet, but 20 rods southeast and northwest from the road its height is 1,192 feet. This is a typical beach ridge of sand and gravel, with pebbles up to 2 or 3 inches in diameter, mostly limestone and granite. The Cretaceous shale before mentioned is very rare in the till of "the mountains" and in the beaches formed along their east side, indicating that the east limit of this shale is the Pembina Mountain and the western ascent of the Golden Valley, and that the glacial currents by which the drift here was deposited came only from the north and northeast, with no intermixture of currents from west of north.

Highest beach on verge of south bluff of the South Branch of Park River, in the southeast quarter of section 23, Golden, 1,188 to 1,192 feet, with a basin-shaped hollow on its west side 20 feet lower, which changes southward to a depression of about 5 feet. The river bluff is here freshly undermined, showing the depth of the beach sand and gravel to be 5 to 10 feet, lying on till. Lower beach, a quarter of a mile farther east, extending from northwest to southeast, in the southwest quarter of section 24, 1,167 to 1,170 feet.

Lower Herman beach, a massive ridge of gravel and sand, extending in a curved course convex toward the east from the northeast quarter of section 2, Golden, through the southeast part of section 35, Lampton, crest, 1,160 to 1,165 feet; through the northeast edge of section 36 and the southwest corner of section 25, 40 to 50 rods wide, with slightly undulating surface, 1,160 to 1,167 feet; near the middle of the east side of the southeast quarter of section 26, 1,165 to 1,166 feet; and at the quarter-section stake on the north side of this section 26, 1,163 feet.

Near the west line of section 23, Lampton, two Herman beaches abut upon the east flank of the north end of "the mountains," and extend thence north-northwesterly 2 miles to the Middle Branch of Park River. The eastern one, a well-defined ridge of sand and fine gravel, passes close west of the quarter-section stake between sections 15 and 10. The elevation of its crest is 1,161 to 1,166 feet, with increase in height from south to north; the descent on the east is 15 or 20 feet in as many rods, and the depression on the west is 3 to 8 feet deep and 10 rods wide. The other beach ridge is 40 or 50 rods farther west, parallel with the preceding and similar in form and material; its crest, rising slightly northward, is at 1,173 to 1,176 feet. Another distinct beach ridge, but of smaller size, runs in a parallel course through the east part of the southwest quarter of section 9, with its crest at 1,185 to 1,187 feet. These appear to represent together the third and second Herman beaches of the series observed northwest of Maple Lake in Minnesota and east and west of Larimore. The lowest Herman beach in this vicinity passes as a well-marked ridge of gravel and sand through the west part of sections 11 and 2, Lampton, and the east part of sections 34, 27, and 22, Gardar, having a height of 1,145 to 1,150 feet, from which there is a descent of 5 to 10 feet on the east and half as much on the west.

Upper Herman beach, northward from the north end of "the mountains," forming in the northwest quarter of section 21 and the west part of section 16, Lampton, a massive broad ridge, composed of sand and gravel, with pebbles up to 4 or even 6 inches in diameter, crest, 1,197 to 1,207 feet, rising highest northward, where the beach deposit overlies the eastern slope of a wave-like swell of till that rises to 1,212 feet. Small beach ridge, belonging to this stage, in the east edge of the southeast quarter of section 8, Lampton, 1,202 to 1,207 feet. Surface at Evan Edwards's house, in the west part of the southwest quarter of section 9, 1,197 feet, consisting of sand and gravel of this beach to a depth of 10 feet, underlain by till, yellowish in its first 6 feet and dark-bluish below. Summit of a smoothly rounded hillock, probably till, but having few or no bowlders, in the east edge of the northeast quarter of section 8, about 1,230 feet; train of beach gravel and sand extending thence 30 rods southward, 1,217 feet, with descent of 15 or 20 feet on each side.

Continuing beyond the Middle Branch of Park River, this highest beach is well developed in a broad ridge running due north through the west part of section 4, Lampton, with its crest at 1,202 to 1,208 feet. On the east the surface falls 30 or 40 feet, and more slowly beyond, while toward the west a descent of 10 feet is succeeded by a flat surface of till, which rises slowly from the foot of the beach ridge to a swell at the height of 1,215 to 1,225 feet, a half mile away, forming the east boundary of the Golden Valley. This beach is sand and gravel, with pebbles up to 6 inches in diameter. About half of them are limestone; nearly all of the remainder are Archean granite, gneiss, and schists; scarcely one in two hundred is Cretaceous shale. Through the west edge of section 33, Gardar, the elevation of this excellent beach ridge is 1,202 to 1,205 feet, and in the southwest edge of section 28 and the middle of the east edge of section 29, 1,202 to 1,197 feet, decreasing in height and size northward. For a half mile through the southwest quarter of section 33, a slight secondary beach ridge, 4 to 9 feet lower, lies about 30 rods east from the foregoing; its crest is at 1,198 to 1,195 feet, sinking a few feet from south to north; it is divided from the higher beach by a continuous depression about 3 feet deep.

A very massive beach ridge, composed of sand and gravel, with pebbles and rock fragments, the largest only slightly waterworn, up to 6 inches in diameter, passes a few degrees west of north through the center of section 20, Gardar, its crest in the south half of the section being at 1,208 to 1,215 feet, and in the north half 1,215 to 1,223 feet. On the east is a descent of 20 to 30 feet within 25 to 40 rods, and on the west 10 or 12 feet from the highest part of the beach within 10 rods to a nearly level area of till, 1,211 feet, which sinks 40 rods farther west to a long slough, about 1,205 feet, parallel with the beach and a sixth of a mile wide. Beyond this an undulating surface of till, partly covered with bushes and small trees, rises to 1,250 or 1,275 feet within 2 miles, and then in smooth, massive swells to 1,450 or 1,500 feet within the next 2 to 4 miles. These are part of a plateau, thence rising more slowly westward, whose boundary for the next 75 miles to the north-northwest is the conspicuous escarpment called Pembina Mountain.

The north end of this massive beach bears on its crest an artificia embankment 100 feet long from east to west and 20 feet wide, raised 2 feet above the natural surface, its top being 1,225 feet above the sea. This is 10 rods south from where the beach is cut to 1,210 feet by a wide gap, as of some ancient watercourse. In the south edge of the southwest quarter of section 17, Gardar, on the south bank of the North Branch of Park River, about 10 rods east from the ford of the "Half-breed road," this beach has an elevation of 1,220 feet.

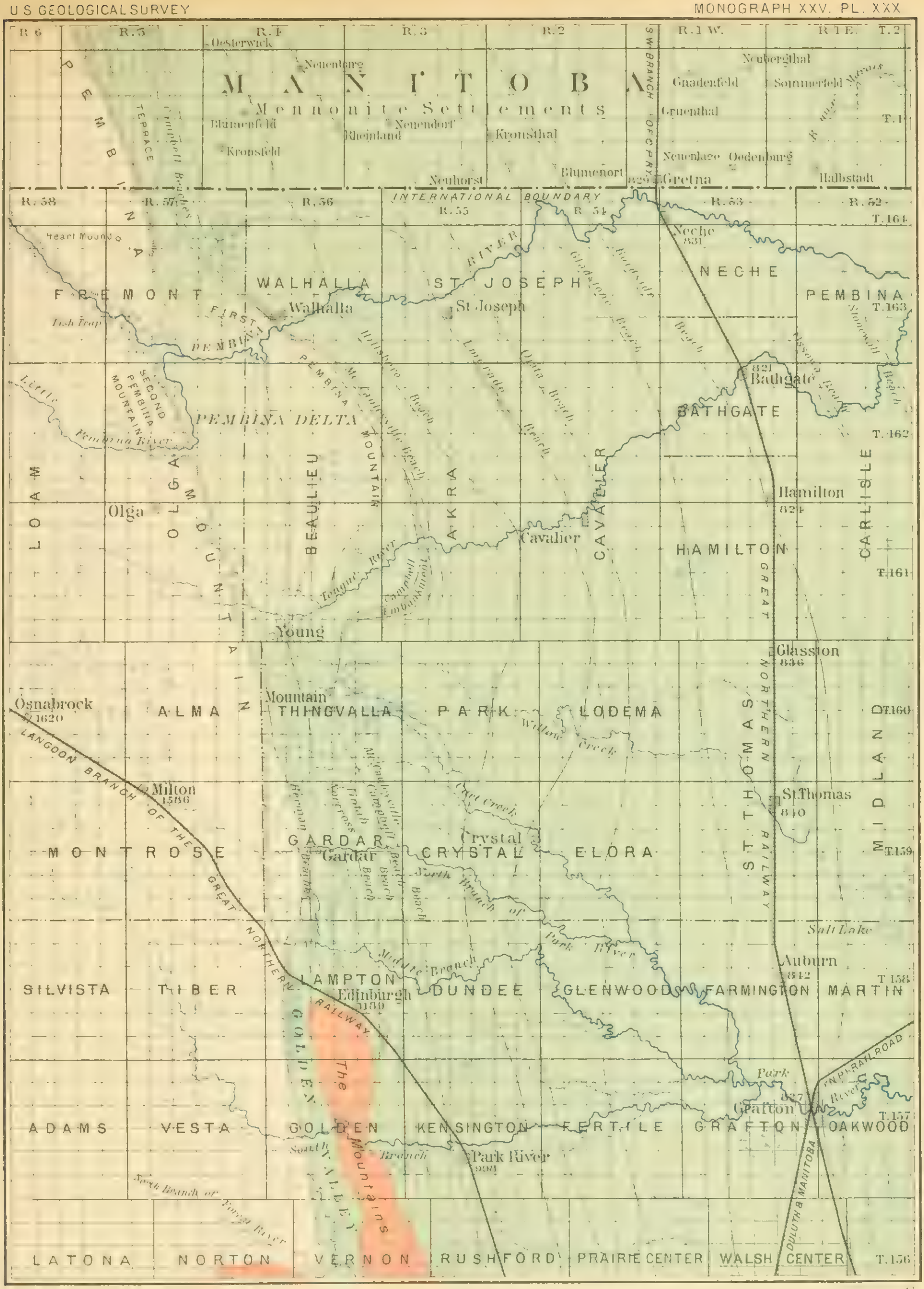
North Branch of Park River at this ford, 10 to 15 feet wide and a few inches deep, 1,203 feet. Surface at the village of Gardar, a mile east, 1,175 to 1,170 feet. Lower Herman beach, passing from south to north along the east side of sections 20 and 17, Gardar, a third of a mile west of the village, about 1,185 feet.

FROM GARDAR NORTH TO THE TONGUE RIVER.

(PLATE XXX.)

Sections 17, 8, and 5, Gardar, rise from 1,190 and 1,200 feet on their east side to 1,220 and 1,225 feet on the west, including, therefore, the upper Herman shore of Lake Agassiz; but they present no considerable deposits of beach gravel and sand. A swell of till, sprinkled with very abundant bowlders, nearly all Archean granite and gneiss, up to 5 feet in diameter, extends from south to north across the line between sections 8 and 5, having its crest at 1,215 feet, from which there is a steep descent of 10 or 12 feet to the west. Sloughs and pools of water, permanent through the year, lie in the west part of section 5, about 1,190 feet above the sea.

The South Branch of Cart Creek, in sections 31 and 32, Thingvalla, is bordered by a belt of timber a half mile wide, but it has only a small channel a few feet below the general surface, and is dry through the greater part of the year. Its alluvial gravel, like that of the Middle and North branches of Park River, is mostly Cretaceous shale, derived from the gorges eroded in this rock at the sources of these streams in the Pembina Mountain.



MAP OF THE WESTERN SHORES OF LAKE AGASSIZ, INCLUDING THE PEMBINA DELTA, FROM PARK RIVER WALSH COUNTY, NORTH THROUGH PEMBINA AND CAVALIER COUNTIES, NORTH DAKOTA, TO THE INTERNATIONAL BOUNDARY.

Scale, 6 miles to an inch.

Lake Area Delta Moraines

Altitudes of Railway stations are noted in feet above the sea.

Along the western border of Lake Agassiz here and northward into Manitoba extends a prominent wooded bluff, the escarpment of a treeless plateau which from its crest stretches with slow ascent westward. This escarpment, commonly called the Pembina Mountain (described in pages 40–42, 93–97), is a very marked feature in the topography for about 75 miles. It is caused by the outcrop, mostly overspread by glacial drift, of a continuous belt of nearly horizontal Cretaceous shale, several hundred feet thick, usually so hard and enduring that it is popularly termed "slate" Its course coincides nearly with the west line of Gardar and Thingvalla townships. Thence it continues in an almost straight course, a few degrees west of north, to the international boundary, beyond which it runs north-northwest nearly 50 miles to the vicinity of Treherne. The base of the ascent is about 1,225 feet above the sea, and its crest approximately 1,500 feet, northward to the Pembina River, beyond which the base sinks to 1,150 and 1,100 feet and the crest to 1,400 and 1,300 feet. The width occupied by the slope varies from a quarter to a half of a mile.

Natural surface at the quarter-section stake on the north side of section 32, Thingvalla, 1,178 feet above the sea. Sections 32, 29, and 20 of this township are mostly till, smoothed by this glacial lake, the depressions having been filled by leveling down the higher portions, where many bowlders partially embedded testify of considerable erosion. A broad ridge of beach sand and fine gravel 3 to 5 feet high extends from south to north through the center of section 29, its crest being at 1,180 to 1,182 feet. This is the third in the series of four Herman beaches observed near Maple Lake, near Larimore, and in Lampton. The higher beaches are probably also recognizable 1 to 1½ miles farther west, near the base of the Pembina escarpment or "second mountain," which is 1,220 to 1,230 feet above the sea; but it is impracticable to trace their course and determine their exact elevation, because woods reach from the base of this escarpment a half mile east, where these beaches belong.

Fourth Herman beach, a broad, low swell of sand and gravel, extending north-northwesterly through the east half of section 20, Thingvalla, 1,166 to 1,172 feet; through sections 17 and 8, an eighth to a quarter of a mile wide, 1,161 to 1,173 feet, having in some places a depth of at least 10 feet, as shown by wells. On the north line of section 20, and again in the north part of section 17, it is intersected by branches of Cart Creek, which occupy valleys about 40 feet deep and an eighth to a quarter of a mile wide. Brush and scattered trees grow in these valleys and on the area between them. Toward the east a descent of 30 or 40 feet is made within the first half mile; westward there is only a slight ascent, to about 1,200 feet, in 1 mile; then a more considerable slope, covered with woods, rises 20 to 40 feet to the base of the "second mountain," on or near the township line.

In the west part of section 8, and again near the northeast corner of section 6, Thingvalla, this beach is intersected by the head streams of Willow Creek, in valleys about 35 feet deep. On the north line of sections 5 and 6 of this township the fourth and third Herman beaches are merged in an undulating tract of gravel and sand a half mile wide, which rises from 1,160 feet on the east to 1,184 feet on the west. A well on the west part of this belt found the beach deposit 6 feet thick, underlain by till, which forms the slightly ascending surface next west.

Base of the second Pembina Mountain, in the east half of section 31, township 161, range 56, 1,235 feet at the south to 1,220 feet northward, coinciding nearly with the upper Herman shore of Lake Agassiz. William Crombie's well, 24 feet deep, near the center of section 30, situated about 50 feet above the Tongue River, a few rods back from the verge of its north bluff, was soil, 2 feet; gravel, nearly all Cretaceous shale, 8 feet; underlain by gravel, nearly all granite and gneiss, with scarcely any intermixture of shale, containing pebbles and cobbles up to 4 inches in diameter, 14 feet, yielding a permanent supply of water. This well is close to the base of the "mountain," at an elevation of about 1,230 feet. Its bed of granite gravel appears to be the upper beach, the overlying shale gravel being a delta deposit brought by the Tongue River.

Surface at Young post-office, in the northeast corner of the southwest quarter of section 32, township 161, range 56, 1,192 feet. The well here, 14 feet deep, is wholly stratified gravel and sand, being a beach deposit of the second and third stages in the Herman series. Third beach, about an eighth of a mile east of Young post-office, a broad ridge of sand and fine gravel, a few feet above the land on its west side, crest, 1,187 feet. Fourth and lowest Herman beach, of similar form with the last, but larger, running a few degrees west of north through the west edge of section 33, 1,173 to 1,175 feet, with depression of 1 to 5 feet on its west side and descent of 25 feet within 30 or 40 rods east.

Tongue River, at bridge near the center of the south half of section 28, township 161, range 56, about 1,110 feet; bottom land, 10 feet higher; top of the bluffs, about 1,150 feet. Gavins reek, in the south half of section 20, about 1,140 feet; valley, 40 feet deep, a sixth of a mile wide.

The lowest Herman beach forms a massive ridge of sand and fine gravel in the northeast quarter of section 29 and the east part of sections 20 and 17, township 161, range 56, with its crest at 1,175 to 1,180 feet.

DELTA OF THE PEMBINA RIVER.

(PLATE XXX.)

The largest tributary to the Red River in North Dakota is the Pembina River, which has cut a valley about 400 feet deep and a mile wide in the plateau of the second Pembina Mountain. During the recession of the ice-sheet this stream was much larger than now, being for a time the outlet of glacial lakes in the basins of the Souris and Saskatchewan rivers.[1] The delta deposited in the margin of the glacial Lake Agassiz by the Pembina River, swollen by a great affluent from the melting ice-fields at the northwest, beyond the present limits of its basin, extends about 16 miles from south to north and has an average width of about 5 miles, with a maximum width of $7\frac{1}{2}$ miles and a maximum thickness exceeding 200 feet. Its mean thickness is probably not less than 150 feet, giving for its volume about $2\frac{1}{3}$ cubic miles, spread upon an area of 80 square miles. Four-fifths of this delta lie south of the Pembina River, reaching nearly to the Tongue River. Fig. 15 shows a section across this delta from east to west about 3 miles south of Walhalla.

Its elevation in the northwest part of section 17, township 161, range 56, is 1,200 feet; thence northward it rises slowly in 2 miles to 1,225 feet in the east part of section 6; and in sections 31 and 30, township 162, range

[1] Pages 267–274, foregoing. Geol. and Nat. Hist. Survey of Minnesota, Ninth Annual Report, for 1880, p. 312. Hind's Report of the Assiniboine and Saskatchewan Exploring Expedition, 1859, pp. 118 and 168.

56, it varies from 1,220 to 1,227 feet. From this crest of the southern part of the delta it slopes slowly east and northeast to 1,080 and 1,090 feet at its eastern border, in sections 25, 24, and 13, which coincides nearly with the east line of this township 162, range 56. Deep valleys, with frequent tributary ravines, have been eroded in it by several small streams. Westward the delta reaches to the base of the second Pembina Mountain, the belt, a half mile to 1 mile wide, next beyond the crest, only about 5 feet lower, being a very flat, beautiful prairie, which rises slowly, like the crest, from south to north. The elevation of this belt in section 18, township 161, range 56, is 1,190 to 1,195 feet, and at Mr. Henry Goff's house, in the middle of the east edge of section 36, township 162, range 57, 1,221 feet. Farther west there is an ascent to about 1,240 feet at the base of the "sec-

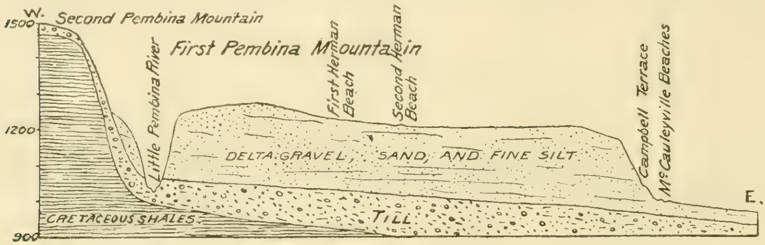


FIG. 15.—Section across the delta of the Pembina River. Horizontal scale, 2 miles to an inch.

ond mountain." Wells on this area penetrate only beds of sand and gravel, easy to dig and needing to be curbed to prevent caving. A large proportion, probably half, of the gravel is Cretaceous shale. Water is obtained at depths varying from 25 to 60 feet.

The part of the Pembina delta thus far described is divided from its central and higher part, which is crossed by the section of fig. 15, by a depression about a mile wide, through which a portion or the whole of the river flowed during much of the time while this delta was being formed. In the southwest corner of section 18, township 162, range 56, this depression is 1,205 feet above the sea, being 20 feet lower than the area on the south. It extends eastward with a slow descent and rises westward to 1,215 feet close east of the Little Pembina River, in section 15, township 162, range 57. This stream flows through the escarpment of the "second mountain," in the southeast quarter of section 22, about a mile south from this lowest part of the divide on its east side. It here turns abruptly from its eastern course, and thence flows north-northwest along the base of the "second mountain" to its junction with the Pembina River, thus leaving the depression just described, which would seem to be its more natural course, and taking in its stead a channel that is eroded through a portion of the delta 50 feet higher.

The most elevated point of this delta, as it now remains, is about 1,270 feet above the sea, near the northwest corner of section 11, township 162, range 57, east of the Little Pembina and south of the Pembina River, and is nearly 300 feet above the junction of these streams, $1\frac{1}{2}$ miles distant toward the northwest. Section 12 of this township and the west part of section 7, township 162, range 56, slope from 1,225 feet on the south to 1,215 feet on the north; their southern part is the highest land crossed between the depression before mentioned and the Pembina River by the line dividing these townships. The level of Lake Agassiz in its highest stage here was 1,220 or 1,225 feet above the sea, being 50 feet below the top of the Pembina delta, as is shown by the beach line of this level, 1,226 feet, in the central part of this section 7, where an eastward descent begins. This is the east verge of the nearly flat area of the delta in sections 12 and 7. Like all of this delta deposit, the material here is sand and gravel, covered by a fertile soil. A small proportion of the pebbles of this gravel is limestone; a large part is Cretaceous shale; but more was derived from Archean formations of granite and gneiss.

The second Herman beach, a ridge of the usual form, is crossed by the road near the east side of the northeast quarter of section 7, township 162, range 56, descending from 1,212 feet to about 1,200 feet in a distance of a third or half of a mile from south to north.

William Roadhouse's well, 110 feet deep, in the northwest quarter of section 8, township 162, range 56, at the elevation of 1,184 feet, is all stratified sand and gravel, with pebbles up to 6 inches in diameter, fully half Cretaceous shale. Water comes in coarse sand at the bottom, filling the lowest 2 feet. Another well of the same description, but 137 feet deep, is a mile farther east, at Wellington Stewart's house, in the southwest quarter of section 4, 1,192 feet above the sea.

On the road from Olga to Walhalla the crest of the east margin of this delta is crossed in the north part of section 33, Walhalla, about 2 miles southeast from the village of this name. Its elevation is 1,190 to 1,196 feet above the sea. This is a beach accumulation, belonging to the third Herman stage. Toward the west and southwest the undulating delta plateau, mostly covered with bushes and occasional trees, is 10 to 30 feet lower for a width of 1 to 1½ miles, averaging about 1,175 feet. Northeast from the crest of this road a short descent is made to a prairie terrace, 30 to 60 rods wide, varying in elevation from 1,182 to 1,169 feet, but mainly within 2 feet above or below 1,175 feet. In general the verge of this terrace is its lowest portion. Thence a very steep descent of 169 feet is made on the road from 1,173 to 1,004 feet, this being the very conspicuous wooded escarpment called the "first Pembina Mountain." It is the eroded front of the great Pembina delta, the eastern part of which, originally descending more moderately, has been swept away by the waves and shore currents of the lake during its Norcross, Tintah, Campbell, and McCauleyville stages. From this section 33 the "first mountain" extends southeast to sections 13 and 24, township 162, range 56, and northwest across the Pembina, passing close southwest of Walhalla and onward to sections 10 and 3, township 163, range 57. Its highest part is intersected by the Pembina River, above which it rises on each side in bluffs of gravel and sand 200 to 250 feet high, with their crest a half mile to 1 mile apart. From this upper portion the delta slopes down gradually toward the southeast and toward the northeast and north, extending only 2 to 4 miles north of the Pembina.[1]

[1] The first Pembina Mountain was visited by D. D. Owen in 1848. He describes it as follows: "Pembina Mountain is, in fact, no mountain at all, nor yet a hill. It is a terrace of table-land, the ancient shore of a great body of water that once filled the whole of the Red River Valley. On its summit it is quite level and extends so for about 5 miles westward to another terrace, the summit of which, I was told, is level with the great buffalo plains that stretch away towards the Missouri, the hunting grounds of the Sioux and the half-breed population of Red River."—Report of a Geological Survey of Wisconsin, Iowa, and Minnesota, 1852, p. 178.

Both the first and second Pembina mountains were examined in 1857 by Palliser, who says of the flat Red River Valley and the Pembina delta: "This plain, no doubt, had formed at one time the bed of a sheet of water, and the Pembina Hill, consisting of previously deposited materials, was its western shore."—Journals, detailed reports, etc., presented to Parliament, 19th May, 1863, p. 41.

Surface at the Bellevue Hotel, Walhalla, 994 feet above the sea; at the post-office, Mr. G. D. Loring's store, 968 feet; Pembina River at the bridge, a third of a mile east of Walhalla, low and high water, 934 to 943 feet.

Highest part of the Pembina delta north of the Pembina River in sections 25 and 26, township 163, range 57, 1,210 to 1,230 feet, rising slowly from east to west; in the west half of section 26 and the east edge of section 27 it is depressed to 1,225 and 1,220 feet; but beyond this it rises to 1,235 and 1,240 feet, next to the foot of the "second mountain."

Natural surface at the quarter-section stake on the north side of section 26, township 163, range 57, 1,191 feet. Third Herman beach, crest 5 rods south of this stake, 1,197 feet, from which there is a descent in 5 rods south to 1,192 feet and in 15 rods north to 1,180 feet. This beach curves thence to the northwest and north, and in the opposite direction runs east-southeast 2 miles to near the center of section 30, Walhalla, where its elevation is approximately 1,192 feet. Other shore-lines of the Herman group were not noticed north of the Pembina River.

In the gravel of this delta, as seen in the bluffs of the Pembina near Walhalla and at noteworthy springs 2 miles to the south, on the south side of the river, in the southwest corner of section 32, the pebbles of some beds are mainly Cretaceous shale, of others mostly limestone, and of others granite, gneiss, and dark trappean rocks. In the aggregate these three classes have a nearly equal representation, and they are more commonly intermingled in the same beds. The shale was doubtless chiefly derived from the erosion of its strata along the glacial watercourse from the Lake Souris, and was occasionally deposited in layers almost unmixed with drift materials; but the other constituents of the gravel were derived from the overlying drift and from the melting ice-sheet. White quartz and moss agate are frequent, and bits of silicified wood occur rarely; but no banded agates were found. Numerous pieces of lignite, rounded by water-wearing, from 2 to 4 inches in diameter, noticed in this delta gravel at the springs, have caused some to look for workable beds of this kind of coal in the vicinity; but the proportion of these fragments is no greater than in the glacial drift generally throughout this region and for hundreds of miles to the south.

The deposition of this delta took place during the highest Herman stage of Lake Agassiz It seems to have been very rapid, the supply of sediments being so great that about the mouth of the Pembina Valley they were accumulated in a fan-like sloping mass to a height of more than 50 feet above the lake level. When the recession of the ice-sheet caused the cessation of its supply of modified drift, and permitted the Souris to flow, as now, to the Assiniboine, the growth of this delta ceased; and its subsequent history is that of the deep channels cut through it by the Little Pembina and the Pembina, and of the steep escarpment sculptured on its east side. From the erosion of this first Pembina Mountain large amounts of gravel and sand were swept southward, notably during the Campbell stages of the lake, when they were deposited in a very massive curving beach ridge that crosses the Tongue River in the west part of township 161, range 55, about 7 miles west of Cavalier. In the Herman stage, while the delta was being accumulated, much fine clay and silt, brought by the same glacial river, were carried farther and spread upon the lake bed along the central part of the Red River Valley, perhaps extending in appreciable amount nearly 100 miles southward to the belt of till that reaches across the valley at Caledonia and forms the Goose Rapids. But on the west side of the lacustrine area this fine sediment is absent, probably because of currents trending offshore; and the surface is till both south and north of the gravel and sand delta, as from Park River north to Gardar and Mountain and nearly to the Tongue River, and from 2 miles north of the Pembina to the international boundary and onward.

During the Glacial period the great valley of the Pembina River west of its delta was only partially filled with drift, for its reexcavation, with the channeling of Langs Valley, tributary to it from the glacial Lake Souris, would have supplied as large a tribute to Lake Agassiz as the entire Pembina delta and the fine silt and clay that are spread over the adjacent lake bed. The volume of the delta, as before stated, is approximately $2\frac{1}{3}$ cubic miles. If an equal amount of fine silt were deposited beyond the delta, both together would measure about the same as Langs Valley and the Pembina Valley from the former mouth of Lake Souris to the delta, namely, between 4 and 5 cubic miles.[1] But much of the Pembina delta and lacus-

[1] See pages 267-272, foregoing.

trine silt was doubtless supplied from the melting ice-sheet at the same time with the deposition of the tracts of modified drift that border the valley north of Rock and Swan lakes; so that the material derived from erosion in this valley was considerably less than would be required to fill it. Moreover, it seems likely that the entire erosion of Langs Valley—that is, of the portion of this watercourse extending from the Souris to Pelican Lake—together with most of the valley along the extent of that lake, was effected by the outflow from the Lake Souris during the time of formation of the Pembina delta; and this large supply from erosion in the upper part of the valley still further diminishes its probable amount along the course of the river below. Thus it is clearly indicated that the Pembina Valley, like the valleys of the Minnesota, Sheyenne, and Assiniboine rivers, was eroded during preglacial time and was not entirely filled by the drift. Comparing this delta with all the other conspicuous deltas of Lake Agassiz, it seems indeed probable that more than half of its mass was supplied directly from the englacial drift of the ice-sheet, and that less than half came from erosion of the valley, which, therefore, along the lower and deeper portion of its course appears not to have been much obstructed by the glacial drift. From this it follows that the extensive high terraces observed on the sides of the Pembina Valley in the vicinity of the Mowbray bridge and westward (page 270) are due to preglacial erosion in the Cretaceous shales, owing to the action of the ice-sheet only their minor features, together with the drift forming their surface.

THE UPPER OR HERMAN BEACHES AND DELTAS IN MANITOBA.

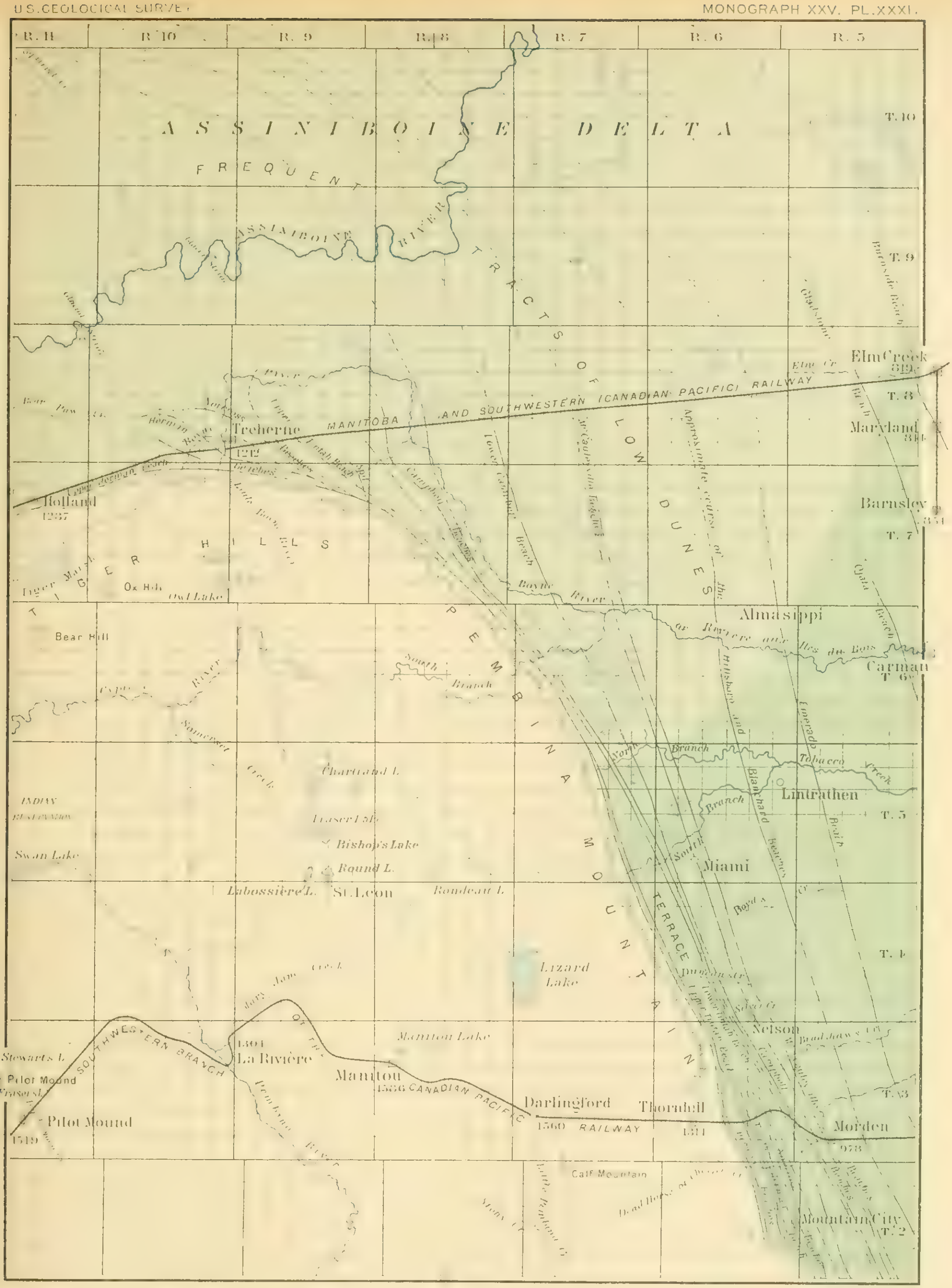
FROM THE INTERNATIONAL BOUNDARY TO THE VICINITY OF NEEPAWA.

(PLATES XXX, XXXI, AND XXXII.)

The west shore of Lake Agassiz enters Manitoba 2 miles west of the east line of range 5, at a distance of 36 miles from the Red River. On the international boundary and for the next 10 miles northward the shores of the highest stages of the lake were on the steep wooded escarpment of the Pembina Mountain, the base of which here is 1,100 to 1,150 feet above the sea, rising slightly northward, and the verge of its top, 1,300 to

1,400 feet. This ascent, forming the steep face of the Pembina Mountain, is made upon a width of about a quarter of a mile.

Where the Pembina Mountain plateau is ascended by the Southwestern Branch of the Canadian Pacific Railway, and for a distance of about 4 miles south and 2 miles north of this railway, the principal line of escarpment is replaced by a moderate slope which is chiefly prairie. Across this tract the Herman beaches of Lake Agassiz are well developed. In order proceeding northward, the first point of examination of the highest beach was near William H Oakley's house, in the south edge of the southwest quarter of section 26, township 2, range 6. It is here a massive rounded ridge of gravel and sand, with descent of 12 to 15 feet in a distance of as many rods both to the east and west from its crest, which is 1,253 feet above the sea. Northward this beach, with similar outline, extends to Francis J. Parker's house, which is built on its crest, having there also a height of 1,253 feet, in the north edge of the northwest quarter of this section. Westward from this beach is an undulating surface of till with few bowlders. Half a mile farther north the beach is intersected by the deep and broad ravine of Dead Horse or Cheval Creek. Beyond this ravine the beach begins near Samuel B. Bowen's house. Its elevation 1 to 1½ miles north-northwest of Mr. Bowen's is 1,255 to 1,259 feet, and it is there spread more broadly than usual, having a nearly flat surface on a width of 20 to 30 rods, bordered on the east by a descent of 10 or 15 feet in 20 rods, and on the west by a descent of about 4 feet. The beach is gravel and sand, with till on each side. It has nearly the same features also a third of a mile farther north, near the center of section 10, township 3, range 6, where it is crossed by the road from Morden to Thornhill, the elevation of its crest being 1,258 feet, but the depression on the west is reduced to only 1 or 2 feet. In the same section this and lower beach ridges are excavated beside the railway for ballast, and are found to consist of sand and gravel, with pebbles seldom exceeding 2 or 3 inches in diameter. About half of the pebbles are light-gray magnesian limestone and about half Cretaceous shale, such as forms the Pembina Mountain, with only a small proportion derived from Archean rocks. Thence the highest shore continues north through the east part of sections 16 and 21, township



MAP OF THE WESTERN SHORES OF LAKE AGASSIZ IN MANITOBA, FROM MORDEN AND THORNHILL NORTH TO THE ASSINIBOINE RIVER.

Scale, 6 miles to an inch.

Lake Area Delta

Altitudes of Railway stations are noted in feet above the sea.

3, range 6, and in section 28 comes to the steep escarpment of Pembina Mountain, with which it coincides along the next 30 miles north-northwest. The elevation of this beach shows that it is the continuation of the highest in the series of Herman beaches in Minnesota and North Dakota.

About a quarter of a mile east of the foregoing is a parallel beach 15 to 20 feet lower, the second in the Herman series. Newton Lane's house, next east of Mr. Oakley's, is built on its crest, 1,237 feet above the sea. It there has a descent of 15 feet or more within an eighth of a mile to the east; but on the west the descent is only 1 or 2 feet or in part wanting, and a nearly level surface of sand and gravel reaches west to the upper beach. In section 10, township 3, range 6, at the road from Morden to Thornhill, this second Herman beach has a height of 1,241 feet, and another beach at 1,247 feet lies between this and the highest, indicating similar conditions in the fall of the lake level as on the northwest side of Maple Lake, in Minnesota, where such an intervening beach also occurs.

Three small parallel beach ridges referable to the third stage in the Herman series are crossed in the west part of section 24, township 2, range 6, by the road leading northwest from Mountain City. The elevation of their crests is 1,198, 1,202, and 1,205 feet. Two miles farther north, near the center of section 35, in the same township, William Miller's house is built on the highest of these, at an elevation of about 1,210 feet. His well, 16 feet deep, is gravel and sand to the depth of 12 feet, with till below. Northward these beaches are traceable through sections 2, 11, 15, and the south part of section 22, township 3, range 6, to Bradshaws Creek, beyond which they pass, with the other Herman and Norcross beaches, along the Pembina Mountain escarpment.

The fourth Herman beach passes through Mountain City, in section 24, township 2, range 6, the post-office and the south end of the principal street being on its crest, at 1,191 to 1,192 feet. Twenty-five rods farther east, at the schoolhouse, is a less conspicuous parallel beach, at 1,183 to 1,184 feet. Both are terrace-like in form, having a descent of 3 to 5 feet or more on the east, but only 1 to 2 feet or none on the west. The continuation of this shore was also observed, like the preceding, through a distance of 6 miles northward.

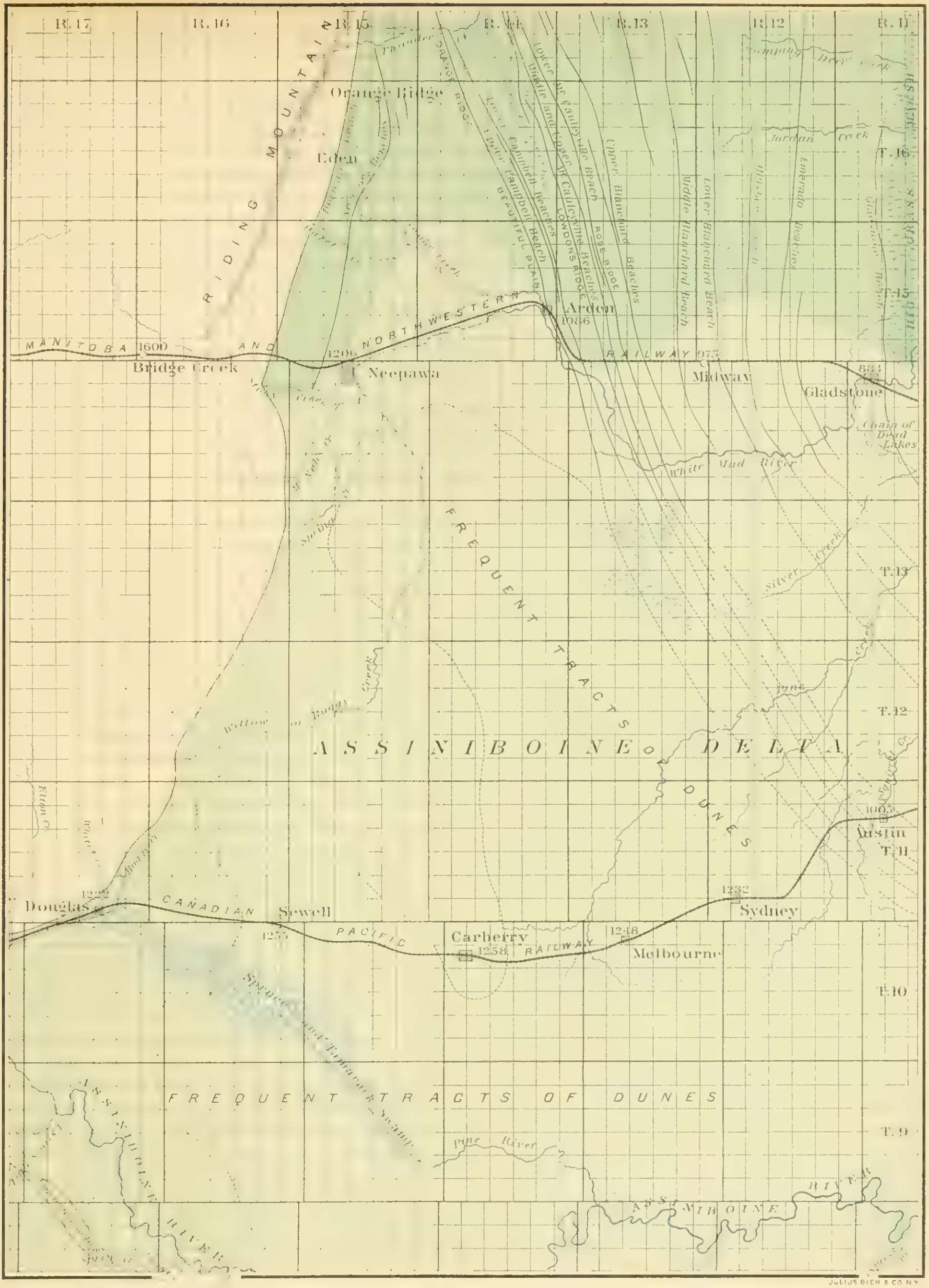
From section 28, township 3, range 6, the Herman shores of Lake Agassiz coincide with the prominent escarpment of the Pembina Mountain through a distance of 29 miles, passing in a nearly straight course north-northwesterly to section 30, township 7, range 8, about 7 miles east-southeast from Treherne. Along this distance the base of the escarpment is 1,100 to 1,125 feet above the sea, and its crest about 1,400 feet. Seen from this elevation, the great plain of the Red River Valley on the east, when overshading clouds give to it in the distance a dark blue or azure color, appears not unlike the vast expanse of the ocean as viewed from an equal height a few miles inland. The highest shore of the glacial lake was about half way up this ascent, and the lower Herman beaches and those of the Norcross stage were between this and the base.

At the north end of the Pembina Mountain the Herman shores of Lake Agassiz turned from a northward to a westward course, and at the sharpest portion of this bend, in section 36, township 7, range 9, the currents along the shore, caused by storms, brought a large amount of gravel and sand from their erosion on each side, and accumulated these deposits in a massive ridge which juts out north-northwesterly a mile or more from the curving line of the escarpment. This gravel and sand spit sinks from nearly 1,300 feet above the sea at its south end, where it rests on the adjoining highland, to about 1,125 feet, comprising deposits of the successive Herman, Norcross, and Tintah stages of the lake.

Five to 6 miles farther west the Herman beaches are well exhibited in the gradual ascent that rises to the Tiger Hills, 1 mile south of Treherne. The highest beach here crosses the middle of the northwest quarter of section 31, township 7, range 9, where it forms a swell of sand and gravel, with pebbles mostly of Cretaceous shale, having its crest 1,272 to 1,273 feet above the sea. In some portions this reaches nearly flat an eighth of a mile south to the base of the Tiger Hills, but elsewhere it is divided from them by a depression of 3 to 5 feet. This appears to be the second (*b*) in the series of Herman beaches, the first of this series (*a* and *aa*) not being found here nor farther north. At the time when that uppermost beach of Lake Agassiz was formed this locality and the country northward are believed to have been covered by the ice-sheet, its termination being at the tract of morainic drift which overspreads the east part of the Tiger Hills, as crossed in township 7, range 9, by the road to the south from Treherne. About 20 and 50 rods north of the beach just described two inconspicuous beach lines, terrace-like sand and gravel deposits, are found at 1,266 and 1,254 feet, referable to subdivisions (b^1 and bb) of the second Herman stage. A little farther north the third Herman beach is represented at Irvine Scarrow's house, in the south edge of section 6, township 8, range 9. This is a slight terrace with crest at 1,243 and 1,244 feet and descent of 4 or 5 feet on its north side. Mr. Scarrow's well, on this beach, 31 feet deep, consists of black soil, 2 feet; interbedded sand and clay, 10 feet; very coarse shale gravel, 5 feet; beds of coarse and fine gravel and sand, 13 feet; and very hard dark bluish till at the bottom, dug into only 1 foot. This well shows an accumulation of shore drift to a depth of 30 feet, swept out by the currents of the lake from the curve where its beaches turned westward. About an eighth of a mile north of Mr. Scarrow's house another beach, also referable to the third Herman stage, descends from 1,236 and 1,238 feet at its crest to 1,230 feet at the base of its northward slope. At the summit of the Manitoba and Southwestern Railway, a mile east of the Little Boyne River, and on the slope thence eastward, very massive beach deposits are accumulated, due apparently to the same action of northwestward currents from the northern end of the Pembina Mountain. The summit of the railway is on such a beach, 1,217 to 1,220 feet above the sea, the fourth in the Herman series, forming a broad swell from which a gentle slope falls on its northeast and southwest sides. Arthur Willett's well here goes to a depth of 42 feet in beds of sand and gravel, obtaining a plentiful supply of good water from their lower portion, without reaching their bottom. A fifth of a mile farther east the railway cuts a beach ridge with its crest at 1,211 feet, also referable to the fourth Herman stage.

The Assiniboine delta occupies the western border of Lake Agassiz from Treherne westward about 60 miles to Brandon, and thence northeastward about 35 miles to Neepawa. The shore of the lake along these distances is not generally marked by a definite beach ridge, the absence of which seems to be accounted for chiefly by the extreme shallowness of the lake upon the delta, so that powerful waves were not driven ashore by storms. The course of the highest shore between Treherne and Brandon, belonging to the time of the second Herman beach, passes first west-southwest along the foot of the Tiger Hills to the north and west side of Campbell's Hill, in section 4, township 7, range 12; thence southwest and south to the Cypress River, near Grange post-office, in section 18, township 6, range 12; thence west-northwestward to Oak Creek and along the south side of this creek, within a mile or less from it, nearly to its mouth; and, crossing the Souris in section 31, township 7, range 16, passes thence northwest to Brandon. Beyond the Cypress a belt of till, moderately undulating or in part nearly flat, from 2 or 3 to 10 miles wide, separates this lake shore from the northern border of the Tiger Hills and the eastern and northern base of the Brandon Hills. S. Martin's house, in the northeast quarter of section 28, township 8, range 17, about 15 miles southeast of Brandon, is built on a small beach ridge of sand and gravel extending from southeast to northwest, only slightly below the highest stage of the lake, which is marked by a moderately sloping parallel escarpment, about 10 feet high, eroded in till a half mile southwest of this beach. The unusually smoothed surface of the till extending thence west and south to the Brandon and Tiger Hills, on the area crossed by the Souris in its course from Gregory's mill to the mouth of Black Creek, is probably attributable to the deposition of its upper portion in a body of water held between these hills and the northwardly retreating ice-sheet before this area was drained to the level of Lake Agassiz by the retreat of the ice from the east part of the Tiger Hills and the north end of the Pembina Mountain.

In the south part of the city of Brandon the second Herman beach, marking the stage *bb* of the table in Chapter IX, is a well-defined ridge of sand and gravel along a distance of about a mile. It extends from east to west, passing an eighth of a mile north of the court-house, and thence close along the south side of Lorne avenue from First to Fourth street. Between Fourth and Sixth streets it is crossed by this avenue, and thence westward lies close on its north side. Its structure is shown by sections where it is intersected by Tenth, Eleventh, and Twelfth streets, exposing a thickness



MAP OF THE WESTERN SHORES OF LAKE AGASSIZ IN THE VICINITY OF THE CANADIAN PACIFIC RAILWAY AND NORTH TO ORANGE RIDGE, MANITOBA.

Scale, 6 miles to an inch.

Lake Area Delta

Altitudes of Railway stations are noted in feet above the sea.

of 10 feet of obliquely bedded sand and gravel, containing abundant pebbles up to 2 inches and rarely cobbles 3 or 4 inches in diameter, about two-thirds being Paleozoic magnesian limestones, from one-tenth to one-fourth Cretaceous shale, and the remainder mostly Archean granites and schists. This beach ridge varies from 10 to 20 rods in width and from 5 to 10 feet or more in height, having a smoothly rounded, wave-like form. The elevation of its crest near the court-house ranges from 1,260 to 1,269 feet above the sea, and at Eleventh and Twelfth streets it is 1,260 to 1,261 feet. No distinct beach ridge of the slightly higher Herman *b* stage of Lake Agassiz was found in the vicinity of Brandon, but evidence of the lake level in that stage is afforded in the southeast part of Brandon by the delta plateau of coarse gravel and sand at the court-house and eastward, which is 1,270 to 1,282 feet above the sea, and by an old water-course crossed 3 to 4 miles west of Brandon on the road to Kemnay, both of which are more fully noticed in the description of the Assiniboine delta.

North of the Assiniboine the highest shore of Lake Agassiz passes from Brandon east and east-northeast by Chater and Douglas, being on or close below the verge of the plateau of till, overspread by delta gravel and sand, which lies close north of the Canadian Pacific Railway. About a mile north of Douglas station this shore is marked by a dune hillock, nearly at the middle of the line between sections 10 and 11, township 11, range 17. Thence its course is north-northeastward, and is indicated by an eroded escarpment, extending 2 or 3 miles, with a height of 10 to 15 feet, and less distinctly observable a few miles beyond. The base of this escarpment where it crosses the south line of section 24 in this township is 1,269 feet above the sea; and the surface at the schoolhouse, a sixth of a mile farther west, is about 20 feet higher. All the area eastward is delta sand and gravel; but the escarpment and the country rising thence slowly north-westward are till. The continuation of this line between a moderately rolling surface of till on the west, with plentiful bowlders and frequent lakelets, and the slightly undulating sand and gravel delta on the east, with low dunes on many parts of its area, passes north-northeasterly in range 16 across the west half of township 12 and the east half of township 13, and thence north through the eastmost tier of sections in township 14, to Stony

Creek. It evidently marks, at least approximately, the highest shore of the glacial lake; but it bears no distinct beach ridge nor line of erosion, partly because the lake was so shallow on the adjoining delta area, and partly because the prevailing trends of the inequalities in the till surface run nearly from east to west, transverse to the course of the shore currents and drift by which beaches would be formed, thus intercepting the scanty deposits of beach gravel and sand in their hollows, instead of permitting them to be accumulated in a distinct ridge.

The Manitoba and Northwestern Railway crosses two beach ridges at 3¾ miles and 3 miles west of Neepawa, the crests of which are respectively 1,323 and 1,304 feet above the sea. These elevations indicate that they belong to subdivisions of the second Herman stage, in the same manner that this stage is represented by three beach lines at Treherne. Each of these ridges has a height of about 7 feet above the adjoining surface and a width of 30 to 40 rods. They consist of sand and gravel, and the railway company has therefore purchased a considerable tract occupied by the lower one of them for its excavation and use as railway ballast. This lower beach probably marks the same lake level as the beach observed at Brandon, having there an elevation of 1,260 to 1,269 feet. Gravel and sand brought into Lake Agassiz by Stony Creek seem to have contributed to the conspicuous development of beach deposits here, while they are wanting or less distinct upon most of the shore southward to Brandon and also northward through the next 12 miles to where the Herman and Norcross shores pass into the steep escarpment that forms the eastern face of Riding Mountain.

DELTA OF THE ASSINIBOINE RIVER.

(PLATE XXXIII.)

At Brandon the Assiniboine enters the area of Lake Agassiz, and thence the gravel and sand delta of this tributary extends eastward 75 miles to Portage la Prairie, northeastward 50 miles to Gladstone, and east-southeastward 80 miles to Almasippi post-office, 9 miles west of Carman. On the northwest this delta is bordered by an expanse of moderately undulating or rolling till which rises slowly above the ancient lake level and

MAP OF THE DELTA OF THE ASSINIBOINE RIVER.

Scale, 12 miles to an inch.

Lake Area Delta Moraines

Altitudes of Railway stations are noted in feet above the sea.

stretches northwestward from Brandon, Chater, and Douglas to the Little Saskatchewan and Oak rivers. From Brandon to Douglas the boundary of the delta is close north of the Assiniboine and the Canadian Pacific Railway; but at Douglas the line dividing the delta sand and gravel and the adjoining surface of till turns north-northeastward and extends about 20 miles in a nearly direct course toward Neepawa, then bends northward in the east part of townships 13 and 14, range 16, and crosses Stony Creek a few miles west of Neepawa. Between Brandon and the mouth of the Souris the delta reaches 3 or 4 miles southwest of the Assiniboine, being there also bordered by a smoothly undulating or rolling tract of till, but the morainic Brandon Hills rise prominently within a few miles farther west. From the Souris east to the Cypress, a distance of nearly 25 miles, the southern margin of the delta is similarly divided from the Tiger Hills by a belt of undulating and rolling till which averages about 5 miles in width. Farther to the east the delta deposits abut directly upon the northern base of these hills from the Cypress River, by Holland and Treherne, to the north end of the Pembina Mountain. Thence to the southeast the head streams of the Boyne, after their descent from the plateau of the Pembina Mountain, cross the southeastward extension of this delta to Almasippi. This portion, however, is not probably a part of the delta as it was at first deposited, but has been derived from the erosion of the eastern front of the original delta by the waves of the lake in its later and successively lower stages, being transported thence southward by shore currents. The same lacustrine action has doubtless extended the delta of gravel and sand generally 5 to 15 miles eastward beyond its original area, thereby giving its eastern face a more gradual slope. As thus enlarged its east boundary runs north from Almasippi to Portage la Prairie, curving eastward between these places, and thence it passes west-northwest to near Gladstone, Arden, and Neepawa. The eastern base of the delta, where it adjoins the flat expanse of the Red River Valley and the country bordering the lower Assiniboine and Lake Manitoba, has an elevation of 850 to 900 feet above the sea; while the high delta plateau, which was submerged only about 50 feet or less by the lake when it was being deposited, and was in part shoals and low islands, has an elevation of from 1,200 to 1,275 feet above the sea.

The western and southern limits of the plateau are those already noted, and on the east its boundary runs north and northwest from Treherne to Sydney and Neepawa. The area of the plateau is about 1,300 square miles, and the eastern slope adds to this fully two-thirds as much, making the total area of this delta somewhat more than 2,000 square miles.

The thickness of the Assiniboine delta is seldom shown by wells, which generally obtain a plentiful supply of water upon this area within moderate depths, ranging from 10 to 50 feet. In some localities, however, near the great valley that the Assiniboine has cut through the delta, the plane of saturation probably lies much deeper, and wells must be sunk 100 feet or more to obtain water. Better measures of the depth of these gravel and sand deposits are supplied by the valleys of the Assiniboine and other streams, which are eroded in their deeper portions 100 to 200 feet below the top of the delta plateau before reaching the underlying till. Deep ravines are especially numerous on the northern part of the delta, where many springs issue near the plane of junction between the porous gravel and sand beds and the till, giving rise to the Squirrel, Pine, and Silver creeks, which flow northeast to the White Mud River. The descent of 200 to 300 feet made within a few miles upon the eastern face of the delta is a further indication of its thickness, which reaches its maximum at the verge of the plateau. In the vicinity of the outcrop of Niobrara beds on the Assiniboine, in section 36, township 8, range 11, the thickness of the delta gravel and sand appears to be about 200 feet; and it probably ranges from 100 to 200 feet along the outer limit of the plateau through the greater part of its extent of more than 50 miles. The average thickness of this very extensive delta is probably between 50 and 75 feet. Computing its volume for an average of 50 feet on an area of 2,000 square miles, it is found to be about 20 cubic miles.

Fig. 16 presents a section crossing the central part of the Assiniboine delta, along the line of the Canadian Pacific Railway from Brandon to Portage la Prairie.

Fifty miles east-southeast from Brandon the highest portions of the surface of the delta south of the Assiniboine and east of the Cypress, where it has not been heaped in sand hills by the wind, are 1,225 to 1,240 feet above the sea, the latter being its elevation in a broad swell near the center of section 24, township 8, range 11. Ten to 20 miles thence westward, between Cypress River and Glenboro, the elevation of the slightly undulating surface of the delta is mostly 1,235 to 1,245 feet, with frequent sloughs and permanent ponds, up to a quarter of a mile or more in extent, lying at 1,225 to 1,235 feet. These ponds abound near Glenboro and for 4 miles east. Along the Canadian Pacific Railway from Sydney westward, by Melbourne, Carberry, and Sewell, to Douglas, 20 to 25 miles north of the foregoing, the undulating delta ranges in elevation from 1,230 to 1,275 feet; and it holds the same height through 25 miles northward, to within 3 miles southeast of Neepawa. Adjoining the undulating and rolling area of till which borders this part of its area on the west, its expanse of gravel

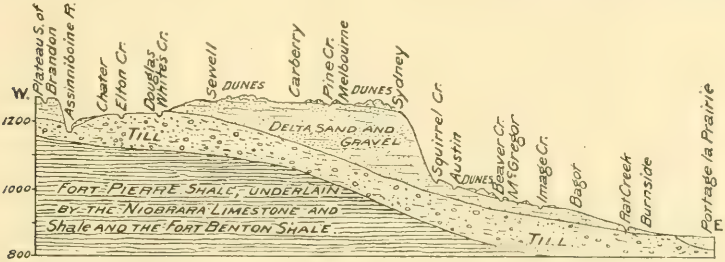


FIG. 16.—Section across the delta of the Assiniboine River. Horizontal scale, 15 miles to an inch.

and sand slowly rises northward from 1,265 and 1,270 feet 2 to 3 miles northeast of Douglas to 1,275 and 1,280 feet between Willow or Boggy and Spring creeks. These elevations represent the plateau before mentioned, which forms the greater part of this delta.

While the extensive area of this plateau, reaching 50 miles from east to west and nearly the same distance from north to south, is thus so uniform in its elevation that its deposition must be attributed to stages of the lake when its level was not much higher, probably those of the Herman beaches *b* and *bb* near Treherne and Neepawa, there is a considerable tract lying on both sides of the Assiniboine in the vicinity of Brandon and Kemnay upon which delta deposits closely associated with this plateau ascend from a few feet to 125 feet above it in a distance of 12 or 15 miles from east to west. A mile north of Brandon the bluff on the north side of the Assiniboine rises about 140 feet above the river to 1,300 feet, approximately, above the sea. It consists of till to a height of 100 feet or more; but its crest and the surface thence northward for 5 miles are mostly undulating gravel and sand to a thickness of 10 to 20 feet, thinly covering the till, which forms the surface farther north. Eastward this bluff, eroded by the Assiniboine since the deposition of this stratified gravel and sand, extends along the north side of the railway by Chater and Douglas, having a height of about 75 and 50 feet, respectively, at these stations, but declining only slightly in the elevation of its crest, which is 1,275 to 1,290 feet. Delta gravel and sand, and on some portions fine silt, cover a width of 3 or 4 miles thence northward through the south half of townships 11 of ranges 18 and 17, having an elevation at their northern limit 1,300 to 1,290 feet above the sea, beyond which the surface, gradually ascending northward, is till. The most eastern point of this higher delta deposit is in section 14, township 11, range 17. Measured thence to its western limit on the north side of the Assiniboine, half way between Kemnay and Alexander, its length is 24 miles. Its width north and south of Brandon is about 12 miles. Through it the Assiniboine has eroded its valley, and has carried it away, cutting also into the underlying till, upon a large area from Brandon east to Chater and Douglas and thence south nearly to the Brandon Hills.

South of the river, at the court-house, in the southeast part of Brandon, very coarse gravel and sand of this higher part of the Assiniboine delta, containing waterworn cobbles up to 6 and 8 inches in diameter, form a plateau mostly 1,270 to 1,275 feet above the sea, but rising to 1,282 feet at a distance of 1 mile to the east. One and a half to 3 miles west of Brandon a similar plateau varies in height from 1,290 to 1,305 feet. Between these small plateaus or plains, which slope about 5 feet per mile to the east and were once continuous, a former watercourse, diminishing from a half to a quarter of a mile in width, passes southeast from the valley of the Assiniboine through the south part of Brandon and thence continues east nearly 3 miles, opening in section 7 or 8, township 10, range 18, upon the broad lower area eroded by the Assiniboine. The bed of this old channel is at

1,250 to 1,255 feet, and it appears to have been eroded at the time of the formation of the Herman beach *bb* in Brandon, when the level of Lake Agassiz was approximately at this height. Three to 4 miles west of Brandon the road to Kemnay crosses another watercourse of similar character, diminishing from 1½ miles to a half mile in width within 2 miles from northwest to southeast, passing from the Assiniboine Valley to the head of Bakers or Stony Creek. Its bed, which is strewn with plentiful bowlders, showing that the erosion here extended through the stratified gravel and sand to till, is about 1,270 feet above the sea, and marks nearly the Herman *b* stage of Lake Agassiz, being about 30 and 40 feet, respectively, below the adjoining areas of delta gravel and sand on the east and west. In 3 miles westward to Kemnay this delta expanse rises 50 to 60 feet, and continues to ascend more slowly in the next 3½ miles to 1,390 and 1,400 feet in sections 1, 12, and 13, township 10, range 21. Thence the surface for the next 6 miles westward, about Alexander, including nearly all of this township and the east edge of that next west, is till.

Many portions of the fine sand deposits of the Assiniboine delta have been channeled and piled by the wind in dunes from 10 to 75 feet high, mostly covered with bushes and a scanty growth of herbaceous plants, but in part destitute of vegetation, which is prevented from obtaining a foothold by the drifting of the sand. On the southeast part of this area these sand hills, seldom exceeding 30 or 40 feet in height, occur in sections 1 to 4, township 7, range 7, and are thence frequent northward upon a width of 10 miles northeast of the Boyne and southeast of the Assiniboine. On the north side of the Assiniboine the most eastern dunes extend to within 3 miles southwest of Portage la Prairie. Both these tracts lie on the lower part of the eastern slope of the delta, and thence westward dunes are found here and there over this entire slope. Even where no distinct hillocks and ridges have been formed, the surface is often channeled and ridged in hollows and elevations of a few feet, though now wholly grassed or covered with bushes or small poplar groves. Upon the delta plateau tracts of dunes, commonly raised 20 to 40 feet above the general level, interspersed with occasional smooth areas where the original surface remains undisturbed, extend on the south side of the Assiniboine from the Cypress to the Souris, occupying a width that varies from 1 to 5 miles. Their southern limit is about 4 miles north of Holland, 3 miles north of Cypress River station, and 2 miles north of Glenboro. One to 4 miles west of the mouth of the Souris an isolated tract of dunes about 3 miles long from southeast to northwest is crossed by Spring Creek near its mouth. North of the Assiniboine much of its delta plateau is occupied by dunes, which extend north to the White Mud River. Their most northern area is a belt that reaches north of this stream through sections 12, 13, 24, and 25, township 15, range 15, to the junction of Hazel and Snake creeks. But the northwestern part of this plateau includes a belt of smooth and fertile land, several miles wide, extending from Carberry north and northwest to the limit of the delta. Also, from Douglas and Chater southeastward a belt of good agricultural land, free from dunes upon a width of 3 to 5 miles, reaches 15 miles along the northeast side of the Assiniboine. On the extreme western and highest part of this delta conspicuous sand hills rise 60 feet above the adjoining surface, with their crests about 1,445 feet above the sea, in sections 6 and 7, township 10, range 20, 2 to 3 miles southwest of Kemnay, and lower hillocks of wind-blown sand continue from these 2 miles to the southeast.

Within 6 miles from the dunes last noted, and from the boundary of this Assiniboine delta, after crossing a belt of till that reaches about 3 miles east and the same distance west from Alexander station, the Canadian Pacific Railway, thence west to Griswold, Oak Lake, and Virden, lies upon the delta which was brought into the Lake Souris by the Assiniboine. In townships 9 and 10, range 22, and township 9, range 23, including the vicinity of Griswold, this deposit consists of fine clayey silt and sand, having a moderately undulating or rolling surface, with broad, smooth swells elevated 10 to 30 feet above the depressions, their tops being 1,400 to 1,435 feet above the sea. Three to 7 miles southwest of Griswold this delta has been much channeled and uplifted by the wind in sand hills, which thence continue 10 miles southeast along the north side of Plum Creek to section 11, township 8, range 22, 4 miles west of Plum Creek village. The crests of these dunes are 1,420 to 1,430 feet above the sea, being 30 to 40 feet above the adjoining surface. Nearly all of them are now covered by grass and bushes.

The Assiniboine delta of Lake Souris has a length of about 85 miles, extending from the north end of this glacial lake south-southeasterly along the Assiniboine to its eastward bend and beyond to Plum Creek and the Souris River. Its width ranges from 5 to 25 miles, averaging about 12 miles. This delta is doubtless shallower than that of Lake Agassiz, but if its average thickness is 25 feet upon this area of 1,000 square miles, its volume is about 5 cubic miles.

An ancient watercourse, now occupied by a body of water called the Big Slough, 13 miles long and mostly 20 to 50 rods wide, but in its west part about three-fourths of a mile wide, extends from southwest to northeast 9 miles through this delta of Lake Souris and thence continues 4 miles east through an area of till. Its west end is 2 miles southwest of Griswold and its east end about a half mile east of Alexander, its whole extent being on the south side of the railway. Its elevation in the stages of low and high water ranges from 1,385 to 1,388 feet, and its depth at low water varies from 2 to 6 or 8 feet. The shores of the Big Slough rise in gentle slopes 15 to 20 feet in 20 to 30 rods, to the general level, not having the usual steepness of banks undermined by streams; yet it doubtless marks the course of a stream that outflowed at one time westward into Lake Souris from a small glacial lake north of the Brandon Hills, and of a later stream that flowed in the opposite direction, eastward from the basin of Lake Souris into the Brandon glacial lake, before that became merged in Lake Agassiz by the departure of the ice-sheet. The succession of events indicated by this channel, together with that of the present Souris and with the great glacial watercourse of Langs Valley, is as follows: Lake Souris outflowed eastward by Langs Valley, Pelican Lake, and the Pembina River until the receding ice formed a lake north of the Tiger Hills and east of the Brandon Hills, which, outflowing south to the Souris, cut a deep gorge through the Tiger Hills moraine, where the Souris now flows through it to the north. Similarly, north of the Brandon Hills, a lake was probably held by the barrier of the ice during its recession from Alexander east by Kemnay and Brandon, outflowing westward to the Lake Souris by the course of the Big Slough. As soon as the continued glacial recession left the Brandon Hills wholly uncovered from the ice, these lakes on the east and north were merged in one, and the outflow from the lake so formed passed south through the Tiger Hills to Langs Valley until that channel was cut down nearly to 1,350 feet. During this stage of a continuous lake east and north of the Brandon Hills, this independent part of Lake Agassiz, before it was merged with the main body of this lake by the recession of the ice from the east end of the Tiger Hills, received an extensive delta, already described as the highest portion of the Assiniboine delta in the vicinity of Brandon and Kemnay, consisting partly of modified drift from the retreating ice and partly of fine sand and silt brought by a stream then flowing east from the Lake Souris delta along the Big Slough. The tribute of the latter is spread over an area of several square miles southwest of Kemnay, and upon it are raised the conspicuous dunes of sections 6 and 7, township 10, range 20. With the retreat of the ice northward from Treherne, the Brandon lake was lowered nearly 100 feet to the level of Lake Agassiz in its Herman *b* stage. For a short time the Souris probably continued to flow southeastward through Langs Valley until the deposition of the alluvium, perhaps 10 or 15 feet thick, brought into that valley by Dunlops Creek, 4 miles east of the elbow of the Souris, raised a barrier a few feet higher than the gap that had been cut through the Tiger Hills north of the elbow, whereby the river was turned through this gap, which it has since eroded 100 to 150 feet deeper.

The modified drift and alluvium that form the plain of coarse gravel and sand sloping eastward from Kemnay to Brandon and reach along the north side of the Assiniboine to Douglas were probably deposited mostly while the barrier of the waning ice-sheet stretched from the Tiger Hills to Riding Mountain, inclosing on its west side a lake that afterwards became the bay of Lake Agassiz covering the Assiniboine delta, but was then held about 100 feet above Lake Agassiz, to which it outflowed by the way of Langs Valley and the Pembina. The deposition of this highest part of the Assiniboine delta, lying above the Herman *bb* beach observed in Brandon, appears to have been in progress through a considerable period, beginning when this Brandon glacial lake was held at an elevation of about 1,400 feet, and continuing while it was lowered nearly 150 feet. During this time the Brandon Lake had three outlets: first, from its two parts, respectively, westward by the Big Slough and southward across the Tiger Hills moraine; second, from the whole lake, when these parts became confluent, by the southward one of these outlets, namely, the gap where the Souris now flows through the Tiger Hills; and, third, by confluence with Lake Agassiz, when this was permitted by the recession of the ice. Much modified drift was probably brought into the Brandon Lake by drainage along the course of the Little Saskatchewan, and it is significant that in the line of continuation of the valley of that stream the plain between Kemnay and Brandon is crossed by a broad watercourse, which was evidently eroded after this lake became merged in Lake Agassiz, thereby falling nearly 100 feet below its former level when outflowing through Langs Valley, but before the Assiniboine had cut its broad valley through this delta. More exactly, as before noted, this watercourse seems referable to the Herman *b* stage of Lake Agassiz, and the similar watercourse about 20 feet lower, passing through the west and south parts of Brandon, was probably formed during the Herman *bb* stage. During these two stages of the lake the principal expanse of the Assiniboine delta was formed, lying only slightly below the levels which the lake then had.

At the time of formation of the Herman *bb* beach the Assiniboine had already eroded a deep and wide valley in its delta at Brandon, and as Lake Agassiz sank to successive lower levels this erosion continued, cutting at least the lower part of the great valley 200 to 300 feet deep, in which this river flows above Brandon, and wearing its channel to a nearly equal depth through its own delta. The Canadian Pacific Railway crosses the Assiniboine about 2 miles east of Brandon, near the division between the main area of its delta in Lake Agassiz and the deep portion of its upper valley. There the high land on each side of the river recedes, allowing the descent to the stream to be made by easy grades on each side and supplying upon the gradual slope south of the river the beautiful site of Brandon. No other point so favorable for this crossing exists within 60 miles to the east or west, where the river flows in a deeper and narrower valley. The greater part of this delta was modified drift derived from the melting ice-sheet on the upper part of the basin of the Assiniboine and on Riding Mountain, being carried down from the latter area by the Bird-tail Creek and the Oak and Little Saskatchewan rivers (p. 190). It was deposited in this delta chiefly during the early Herman stages of the lake, as is indicated by the elevation of the outer part of its principal expanse; and its deposition continued until the ice-sheet was melted away on Riding Mountain and the upper Assiniboine. The erosion of the Assiniboine Valley above Brandon also supplied a considerable part of the delta. During the ensuing stages of Lake Agassiz, to those of Gladstone and Burnside, the border of this great delta was undergoing erosion by the lake waves and shore currents, by which its outer portion was spread in more gentle slopes, extending farther into the lake, and much of it was swept southward along the shore.

By this erosion of the sloping face of the delta, and especially by earlier transportation into the deep water of the lake while the gravel and sand were being deposited in its western embayment between the Tiger Hills and Riding Mountain, a large expanse of fine clayey sediment of the same origin with this delta was spread far into the lake, extending to the east beyond the Red River and to the south beyond the international boundary. This deposit of lacustrine silt covers the till from the eastern and southeastern limits of the delta, as before defined, to the low ridge first east of the Red River, about 10 miles east of Emerson, while similar sediments cover the central part of the Red River Valley southward to Goose Rapids, more than 100 miles east-southeast from this delta. Toward the north and northeast, lacustrine sediments and subsequent alluvial deposits associated with the Assiniboine delta cover the nearly flat country north from Burnside, Portage la Prairie, and High Bluff to Lake Manitoba. On this area the watershed between the Assiniboine and Lake Manitoba is very low, and the river has sometimes overflowed its low banks, sending part of its floods north to the lake, which in turn in its highest stages has occasionally become for a short time tributary to the lower part of this river. But the transportation of the silt in the lake was of less extent in this direction than to the east and south, as is shown by areas of till on both sides of the Big Grass Marsh, west of Lake Manitoba, and from townships 13 and 14, range 5, southeast of this lake, eastward to Shoal Lake, Stonewall, and Lower Fort Garry.

Five to 10 miles west of Portage la Prairie till with frequent bowlders forms the surface, or is underlain only to the depth of a few feet by the sediments associated with this delta. Again, 10 miles farther west, the sandy eastern slope of the delta in the vicinity of McGregor shows very rarely projecting bowlders, the size of the few noticed being from 2 to 6 feet in diameter. They probably lie on till that has been somewhat eroded by the lake waves, so that these bowlders are not embedded in it as usual, while the sand and silt afterward spread there on the surface are not sufficiently thick to conceal them. No bowlders were elsewhere seen on the general surface of the delta and of the great area of associated lacustrine silt, nor in any observed sections of these deposits.

CHAPTER VII.

LOWER BEACHES WITH SOUTHWARD OUTFLOW.

Extensive portions of the lower beaches that were formed while Lake Agassiz outflowed to the south have been exactly mapped, with determination of their heights by leveling. These are described in the following pages, the successive beaches being treated in their order from higher to lower. Four well-defined levels of the glacial lake are exhibited by the shore-lines of its southern part, which have been named, from localities of their typical development in Minnesota, the Norcross, Tintah, Campbell, and McCauleyville beaches. In advancing northward each of these beaches, similarly with the uppermost or Herman series of beaches described in the last chapter, is found to become subdivided into two or more separate and distinct beaches or shore-lines.

The attempts here made to correlate these multiple northern shores of Lake Agassiz with the fewer southern shore-lines rest on the determination of many altitudes along the course of these former planes of the ancient lake levels. The several shores, both at the south and north, were separated from each other partly by the progressing erosion of the outlet, and partly by the gradual decrease of the attraction of the lake by gravitation toward the waning ice-sheet, but more by the intermittent uplifting of this part of the earth's crust, due evidently to its relief from the pressure of the departing ice. Considerable irregularities in this uplifting would be expected, by which the gradients of northward ascent of the beaches would be made variable, being comparatively steep or changing abruptly in elevation in some places, and elsewhere being of small amount or even showing a reversal, that is, a descent toward the north. In this survey, however, I have not discovered any remarkable divergences or exceptions from an approximate parallelism of the beaches. The northward ascent of the highest beach in the Herman series, ranging from 6 to 18 inches per mile, is gradually diminished in the successive lower shore-lines, each having slightly less ascent than the preceding, to the McCauleyville beaches, which rise 1 to 3 or 4 inches per mile. In all of these shore-lines the rate of ascent is found to increase as one advances from south to north.

BEACHES OF THE NORCROSS STAGES.

FROM LAKE TRAVERSE TO NORCROSS AND MAPLE LAKE, MINNESOTA.

(PLATES XXIII TO XXVI.)

The Norcross shore-line of Lake Agassiz lies near the Herman shore on the slope of eroded till which reaches about 4 miles east from the northeast end of Lake Traverse. Thence eastward, from near the south line of section 35, township 127, range 47, Lake Agassiz was very shallow during the Herman stage, and its fall of 20 feet, or, to speak with more correctness, the rise of the land to this amount, between the times of formation of the Herman and Norcross shore-lines, caused the lake margin to fall back about 6 miles from its most southern portion. The Norcross beach, having a height of 1,043 feet above the sea, is crossed by the Fargo and Southern branch of the Chicago, Milwaukee and St. Paul Railway at a distance of nearly 1 mile north of Dumont. It is here a very slight ridge of gravel and sand, rising only 2 or 3 feet above the uniform slope of the very flat expanse of till.

Within the next 3 miles to the east this beach becomes more conspicuous and has been excavated in several places to obtain sand for masons' use. In section 12, Croke, it is a typical beach ridge about 25 rods wide, with a descent of 5 or 6 feet from its broadly rounded crest toward the north and 2 or 3 feet toward the south. At an excavation near the line between sections 11 and 12 its crest has a height of 1,045 feet. The depth of the beach sand and fine gravel, containing pebbles up to an inch in diameter, is 5 feet, with till beneath.

Thence the Norcross beach ridge, mostly 2 to 4 feet high, runs east to Twelve Mile Creek, and beyond turns to the north and northeast. In sections 32 and 33, Clifton, its height is 1,038 to 1,041 feet above the sea;

and in the northwest quarter of section 26, this township, 1,042 feet, with descent of about 5 feet on each side. Crossing next the northwest part of Logan, its crest is at 1,043 to 1,048 feet.

Between a half mile and 1 mile south of Norcross this beach is admirably developed, the elevation of its higher portions being 1,045 to 1,048 feet, from which there is a descent of 3 to 5 feet eastward and of 10 feet westward. It is a massive gravel and sand ridge, about 25 rods wide, including its slopes, lying on till.

Nearly the same features characterize it also at Norcross station, where its height is 1,041 feet. There is a depression 3 feet lower on the southeast, and the surface 10 to 15 rods northwest from the top of the beach, on the side where the lake was, has a height of 1,034 to 1,036 feet. Thence a very smooth plain of till descends to Tintah, Campbell, and the Red River at Breckenridge. About 50 rods northeast from Norcross station the beach attains its greatest height in this village, 1,045 feet. It is a rounded low ridge of sand and gravel, lying on an area of till, and closely resembles the Herman beach, which lies nearly parallel with it at a distance of 3 miles to the east.

Thence northward the course of the Norcross beach has been mapped, mostly without leveling, to the Red River, which it crosses near the northeast corner of section 31, township 132, range 44, in the west edge of Ottertail County. Through this extent of about 25 miles the Norcross shore-line is marked almost continuously by a distinct beach ridge, 3 to 5 feet above the land on the east, and twice as high above the adjoining surface at the west which was covered by the lake while this beach was being formed. Its distance from the Herman beach on the east varies mainly from 3 to 2 miles, but between 1 and 5 miles south of the Red River the two beaches are only 1 mile apart.

Where the Norcross beach is crossed by the road from Fergus Falls to Campbell, near the west line of section 29, Western, it has an elevation very nearly 1,045 feet above the sea. It is a wave-like ridge of sand and gravel, about 15 rods wide, with nearly flat surfaces of till or bowlder-clay on each side. In crossing it the ascent from the east is about 5 feet and the descent toward the west about 10 feet. In sections 19, 18, and 7, Western, where this beach ridge runs nearly due north, the height of its crest, according to my leveling, is 1,043 to 1,045 feet.

Continuing northward beyond the Red River, the Norcross shore-line traverses the northeast corner of township 132, range 45, passing west of a small lake which lies a mile south of the Northern Pacific, Fergus Falls and Black Hills Railroad. Thence its course is nearly north-northwest across the next two townships in this range; but in Tanberg and through the next 10 miles to Humboldt (the next township east of Barnesville) it runs in a nearly direct course only a few degrees west of north. On the west side of the very remarkable marshy and springy belt which lies just within the Herman shore-line in Akron and Tanberg, the Norcross beach rises as a ridge of gravel and sand a few feet high, forming in considerable part the boundary between the bogs, springs, and numerous watercourses on the east and the firm land, capable of cultivation, on the west. In Tanberg it passes along the east border of sections 32, 29, 20, and 17, having at its crest a height of 1,050 to 1,060 feet above the sea.

Close east of the Norcross beach ridge a large spring in the northwest corner of the southwest quarter of section 28, Tanberg, having a diameter of about 15 feet and depth of 10 feet, issues with so strong a current as to throw up the sand at its bottom to a height of 2 or 3 feet into the water. A creek 5 to 15 feet wide and 1 to 3 feet deep, in which many pickerel live, flows from this spring southward along the east side of the beach about a mile, then turning west into the southeast quarter of section 32, where it sinks into the gravelly and sandy ground and is lost.

About 1½ miles east from Barnesville the Norcross beach is well exhibited at D. D. Daniels's house, in the southeast quarter of section 20, Humboldt, being a low, smoothly rounded ridge of gravel and sand, with the elevation of 1,061 feet above the sea.

Through Riverton and in sections 35 and 26, township 140, range 46, the eroded western border of the delta of the Buffalo River marks the shore of Lake Agassiz at the time of the Norcross beach.

In the west part of section 24, township 140, range 46, and for 4 miles northward, the Norcross beach lies only 1 mile to a half mile west of the Herman beach, and is about 50 feet lower. The terrace-like area between these beaches is strewn with occasional bowlders up to 6, 8, or 10 feet in diameter and rarely of larger size, much more abundant than upon the average surface of the till in this region, indicating that the surface there has been considerably eroded by the waves of the lake.

The elevation of the foot of the western slope of the upper or Herman beach along the north part of the east line of township 140, range 46, is 1,095 to 1,100 feet. Crest of the Norcross beach in section 12 of this township, 6 miles north of Muskoda, 1,080 feet, and along the distance of 3 miles through sections 13, 12, and 1 it varies from 1,075 to 1,085 feet. In section 31, Keene, its height is 1,085 feet. Like the Herman beach, it is a low, smoothly rounded ridge of gravel and sand, usually having a depression of 3 to 5 feet or more at its east side.

Through the west part of Keene the Norcross beach is 1 to 1½ miles west of the upper beach. Thence it crosses Hagen in a north-northeast course, lying 2 to 3 miles northwest and west of the upper beach. Its height in these townships is approximately 1,080 feet.

Both the Herman and Norcross beaches in this northern part of Clay County, between the Buffalo River and the South Branch of the Wild Rice, have an altitude notably higher than would coincide with a uniform ascent of these shores from Lake Traverse to Maple Lake. The normal height of the Herman beach on this tract would be 15 to 20 feet below where that beach is found; and the Norcross beach lies fully 10 feet above where it would be expected. The uplift of the earth's crust here was disproportionate by these amounts with its upward movement along the other explored portions of the eastern shore of this glacial lake.

Proceeding onward through Norman County, the position of the Norcross beach is shown approximately on Pl. XXV, but its course has not been exactly mapped. Two small beach ridges, having nearly the same height, probably belonging to the Norcross stages of this lake, were noted, running nearly from south to north, in the east half of section 8, Wild Rice Township. Again, on the north line of Norman County, in leveling from Rolette eastward, a well-marked beach ridge, 10 to 15 rods wide, with a depression of 4 to 5 feet on its east side, was crossed on the western edge of the delta of the Sand Hill River, near the northeast corner of

Spring Creek Township. This beach, which appears to be one of the upper Tintah shore-lines, has a height of 1,060 feet above the sea. About a quarter of a mile farther east beach gravel and sand are spread in a somewhat flattened, broad ridge, at a height of 1,070 to 1,073 feet, bounded by a hollow 2 or 3 feet lower on the east. This probably belonged to a slightly higher Tintah beach of Lake Agassiz. The Norcross shore-lines are not distinctly exhibited here on the very gradual ascent of the delta sand deposit, which extends eastward across the next mile or more to tracts of dunes.

On the Fosston branch of the Great Northern Railway, about 14 miles north of the last described locality and on the same latitude with the eastwardly curving Herman beaches north of Maple Lake, three small beach ridges are crossed about 2½ miles east of Benoit, the elevation of their crests being successively 1,062, 1,069, and 1,069 feet in their order from west to east. These probably represent the upper Tintah beach. One and a quarter miles farther east a more massive beach is crossed, with its crest at 1,092 feet, which is probably the lowest Norcross shore-line. Other beach ridges crossed 1½ miles and 1¾ miles east of the last, with crests respectively at 1,114 and 1,120 feet, are apparently referable to upper Norcross stages of the lake. The next beach noted on this railroad, three-quarters of a mile farther east, at the height of 1,142 feet, belongs to the lower portion of the Herman series.

In the southeast part of Lake Pleasant Township the lower Norcross shore is marked by a belt of gravel and sand about half a mile wide, extending from the southwest to the northeast and east, having an elevation in section 27 of 1,083 to 1,095 feet.

My only further observation of shore-lines referable to the Norcross stages of the eastern border of Lake Agassiz is within 1 to 2 miles west of St. Hilaire, where indistinct lower Norcross beaches, at a height of about 1,090 feet, are crossed by the St. Hilaire branch of the Great Northern Railway.

Thence northward the Norcross shores lie in a wooded country where they can not practicably be traced. From the altitudes of the region it is known that, after passing northward and then eastward around the higher district of the Beltrami Island, they curve east-southeasterly to the valley of the Rainy River and the vicinity of Rainy Lake, and thence sweep back to the northwest and north across the hilly Archean region east of the Lake of the Woods.

THROUGH NORTH DAKOTA, FROM LAKE TRAVERSE TO THE INTERNATIONAL BOUNDARY.

(PLATES XXIII AND XXVII–XXX.)

On and near the line between South and North Dakota, at a distance of 3 to 7 miles west of White Rock and the Bois des Sioux, the Norcross stages of Lake Agassiz formed no less than four separate and parallel beach ridges of gravel and sand, 3 to 8 feet high, lying on a surface of till. In section 1, township 128, range 48, South Dakota, where these small ridges run to the northwest and north-northwest, the elevations of their crests in order from west to east are, first, 1,045 to 1,048 feet above the sea; second, 1,043 to 1,045 feet; third, 1,033 feet; and, fourth, 1,030 feet. The highest beach of this series passes about a half mile west of Mr. L. H. Foote's house, which is in the southeast corner of this section; the second runs about 40 rods west of this house; and the third and fourth lie about a third of a mile and a half mile east of it, passing thence northward through the northeast corner of this section 1. Following these beach ridges in their curving course to the northwest and west-northwest into section 28, township 129, range 48, the higher two are found to rise to 1,050 feet, and the height of each of the lower two is increased by 10 feet. The continuations of these shore-lines northwestward to the east side of the Lightnings Nest and to the delta of the Sheyenne River have not been exactly traced. No other tract of the Norcross shore of this southern part of Lake Agassiz, so far as observed by this survey, is thus marked by several beach ridges. The multiplication of their number here, which elsewhere is commonly single along all the southern part of the lake, probably was due to a slight intermittent elevation of this tract while the adjacent country was at rest, until an uplift of the whole area about Lake Traverse led to the formation of the Tintah beaches, the next lower in the descending series.

The next definite observations of the Norcross shore were on the northern part of the Sheyenne delta. In the southwest corner of section 20, Helendale (the most northwestern township of Richland County), this shore is marked by a low beach ridge, which runs to the north-northwest, passing about 20 rods west of Mr. R. L. Porter's house. The crest of the ridge rises 5 to 8 feet above the general surface of this sand delta, from which it is distinguished by being somewhat more channeled and heaped up by the winds into low dunes, 5 to 10 feet in height. Scattered cottonwoods, growing either alone or in clumps of a few trees, are more frequent along the course of the beach than on the adjoining tracts. About 5 miles farther north, where this shore is crossed by the Fargo and Southwestern Railroad, 3 to 4 miles west of Leonard, it bears three small beach ridges, with crests at 1,062 to 1,065 feet. The most westerly and highest is about 18 rods wide, with a depression of 6 feet on the east and 5 feet on the west.

Thence northward across Cass County the contour of the western border of Lake Agassiz shows that the Norcross shore-line runs nearly parallel with the Herman beach, from which it is distant 1 to 3 miles eastward; but only small fragments of its course have been mapped.

Beginning in southwestern Traill County, near Clifford, the Norcross shore has been traced nearly continuously more than 100 miles north to the international boundary. About a mile northwest from Clifford it is marked by a broad swell or ridge of sand and gravel, 1 to 2 feet above the surface of till on the west. Its elevation is 1,072 feet above the sea. One to 1½ miles farther north, in the south half of section 9, Norman, the shore deposit becomes a typical beach ridge, with crest at 1,075 to 1,077 feet, having a hollow of 2 to 4 feet on the west and a descending slope on the east which falls 30 feet in a third of a mile. Thence northward in section 4 of this township the shore forms an eroded cliff of till, 10 to 15 feet high, with its base at 1,075 feet. In the next mile to the north, through section 33, township 146, range 53, the line of erosion is continued, crossing an area of gravel and sand. The escarpment rises about 10 feet in 4 to 6 rods from east to west, its base being at 1,073 to 1,075 feet, from which a smooth slope of sand and fine gravel falls about 25 feet in two-thirds of a mile eastward. In the north part of section 20 two wells on this tract of modified drift are respectively 22 feet and 31 feet deep, wholly in loose and caving sand and gravel. Here and through the west half of section 17 the Norcross beach is a very finely developed ridge, rising 15 feet above its east base and descending 4 or 5 feet on the west. The elevation of its crest is 1,087 to 1,091 feet. In the southeast part of section 7 an aboriginal mound, 5 feet high and 60 feet in diameter, is situated on the top of the beach ridge; and two others of similar size were seen within a half mile to the southwest.

Thence the lake shore turns to a northwestward course for the next 5 miles, passing through the northeast corner of Primrose to the Middle Branch of Goose River, which it crosses in the southwest part of section 27, Enger. In the south half of section 2, Primrose, the crest of the beach, there unusually massive, is 1,094 feet above the sea, with a descent of 10 feet in 20 to 30 rods eastward and of 5 feet in a shorter distance to the west. Passing northward through Enger Township, this shore bears a typical beach ridge in sections 22, 15, 9, and 3, with crest at 1,080 to 1,085 feet.

Across the large delta of sand and silt which extends from McCanna and Larimore southward beyond Hatton, the Norcross shore is indistinct in portions of its course, but elsewhere has a well-defined beach ridge. Through sections 8 and 5, Garfield, close northeast of Hatton, the crest of the beach is 1,078 feet above the sea, with descent of 6 or 7 feet in 15 rods east and 2 to 3 feet in 10 rods west. In the west part of section 15, Washington, the beach has an elevation 1,083 feet, from which its eastern slope falls 5 feet in 20 rods, and its western slope 3 feet to a slough 10 to 30 rods wide, which is mown for hay. The material of the beach ridge is fine sand. Three to 4 miles farther north, in sections 33 and 29, Pleasant View, the irregular deposits of the Norcross beach are about 1,085 feet above the sea. In the northwest corner of this township, passing through sections 7 and 6, this shore has a finely developed beach ridge of sand and gravel, with crest at 1,090 to 1,095 feet above the sea.

On the Devils Lake and Great Falls line of the Great Northern Railway two Norcross beaches are crossed, about 3 and 3½ miles east of Larimore, with their crests respectively at 1,092 and 1,080 feet. Through the next 4 miles northward these beach ridges appear to have lain on opposite sides of the Turtle River and of its North Branch, causing these streams to take their southerly course instead of passing eastward in the direction of the slope of the surface. Originally confined between the low beach ridges, they have since eroded channels 50 to 75 feet deep in the general sheet of till. In section 29, Hegton, the elevation of the upper Norcross beach, lying west of the North Branch, is 1,106 feet. Along the next 2 miles northward in sections 20 and 17 the crest of this beach varies from 1,100 to 1,105 feet. It is intersected by the North Branch in the southwest quarter of section 20. Remnants of the lower Norcross beach on the east side of this stream in section 29 have an average height of 1,090 feet, above which they are partly heaped 10 to 15 feet in dunes.

The Norcross shore-line runs northward through the east part of Agnes and Inkster townships. In sections 11 and 2, Agnes, the upper beach, a fine ridge of gravel and sand, passes about 25 rods west of Orr's station, on the Park River and Langdon branch of the Great Northern Railway. Its crest here has a height of 1,102 to 1,105 feet. In sections 23 and 14, Inkster, about a mile west of Inkster village, two Norcross beaches are distinctly developed, crossing a tract of gravel and sand. The crest of the western ridge is at 1,092 to 1,097 feet and that of the eastern at 1,090 to 1,092 feet. Depressions 4 or 5 feet deep lie on the west side of each of these ridges, which are about 50 rods apart. A half mile and 1¼ miles farther west, two other well-marked beach ridges, running northward parallel with the foregoing, belong to the lowest part of the Herman series. The crest of the eastern one is at 1,113 to 1,122 feet, and of the western at 1,127 to 1,130 feet. It is to be remarked, however, that the Herman and Norcross series of beaches here lie very near together, being less distinctly separated than farther south and in general on most other parts of the borders of the lake area.

In the east edge of section 10, Inkster, on the north side of the Forest River, the upper Norcross beach is well developed, attaining a height of 1,100 to 1,102 feet. About 3 miles farther northwest it crosses the south line of section 28, Eden, with an elevation of 1,107 feet. In sections 5 and 6 of this township it is marked only by a slightly more rapid descent of the eroded surface of till, which is strewn with frequent bowlders. Through Eden and the next 15 miles northward to the vicinity of Edinburg, the Norcross shores on the eastern side of "the mountains" lie mostly within a half mile to 1 mile distant from the highest Herman shore. Upon this somewhat steep slope, intersected by numerous ravines, neither the Herman shores nor the Norcross shores are so distinctly traceable as usual, either by beach deposits or by lines of erosion.

From the northern end of "the mountains," near Edinburg, the Norcross shore-lines run north-northwestward, passing about 2 miles east of Gardar, less than a mile west of the little village of Mountain, and about 1½ miles east of Young post-office. At the locality last named the upper Norcross shore lies about a third of a mile east of the lowest Herman beach, and is marked by a ridge of gravel and sand 10 to 20 rods wide, with a depression of 1 to 4 feet on its west side and a descent of about 6 feet in a few rods to the east. Its crest has an elevation of 1,143 to 1,145 feet, being 30 feet lower than the adjacent Herman ridge.

The outer border of the plateau of the Pembina delta, forming the "first Pembina Mountain," was the Norcross shore of Lake Agassiz. After the Herman stages of this lake all its lower levels with southward outflow washed the front of the Pembina delta, carrying away much of this deposit southward and eastward, and producing the steep escarpment, mostly 100 to 175 feet high, by which it is bounded on the east.

On the more gradually sloping northern edge of this delta, 2 to 4 miles west of Walhalla, a beach formed during the lower Norcross stage passes from east-southeast to west-northwest. In the north half of section 23, township 163, range 57, where its crest has an elevation of 1,135 to 1,140 feet, it is a broad, low ridge, chiefly of sand, with fine gravel, containing pebbles up to 1 or 2 inches in diameter. Most of the gravel is derived from the Cretaceous shale of the Pembina Mountain, but a part is of limestone and crystalline Archean rocks. A depression of 5 or 6 feet, 15 to 20 rods wide, lies on the southern side of the beach, away from the lake; and its northern side falls off into the lacustrine area with a gentle slope.

Two miles farther northwest the Norcross shore-lines, with the entire Herman series, leaving the Pembina delta, sweep into the great Cretaceous escarpment of the second Pembina Mountain, with which they coincide through several miles northward, crossing the international boundary.

WESTERN NORCROSS SHORES IN MANITOBA.

(PLATES XXX–XXXIII.)

Through township 1, range 5, the Norcross shores of Lake Agassiz lie on the escarpment of the Pembina Mountain, and the first observations of their beaches were in sections 7, 18, and 19, township 2, range 5, where the mountain wall is reduced to a gradual ascent in the vicinity of Mountain City and Thornhill. About a half mile southeast of Mountain City the upper Norcross beach is well displayed at John Borthwick's house, which is built on its crest, 1,167 feet above the sea, in the southwest corner of section 19. Digging for wells here shows that the gravel and sand of the beach extend only to a depth of 6 or 8 feet, there resting on the Fort Pierre shale. From the crest of this beach ridge its slopes fall 8 or 10 feet within a few rods on the east and about 4 feet on the west. It is bordered on the west at this locality by a surface strewn with very abundant bowlders up to 5 feet or rarely more in diameter, nearly all being Archean granites, with perhaps a third of 1 per cent of magnesian limestone. Generally, however, the surface in this vicinity has few or no bowlders; and a shallow depth of ordinary till or of lacustrine deposits overlies the Cretaceous shale. The second Norcross beach, also forming a distinct ridge, lies a third of a mile farther east, with its crest about 1,150 feet above the sea. A large excavation for sand to be used in plastering has been made in this ridge in the south edge of this section 19. A mile farther south John W. Stodders's house is built on it at an elevation of 1,148 feet. His well, 12 feet deep, passes through gravel and sand, 11 feet, and then enters the shale, the top of which, to a depth of 6 to 12 inches, is a hard, calcareous layer, including nodules and veins of calc spar. Pieces of the hard surface of this layer thrown out of the well were plainly marked with glacial striæ. The continuation of these beaches is traceable through the next 7 miles northward across the Southwestern Branch of the Canadian Pacific Railway, passing about 3 miles east of Thornhill to Bradshaw's Creek, beyond which to near Treherne they again coincide with the Pembina Mountain escarpment.

About 1½ miles east of the Little Boyne River, near Treherne, the Manitoba and Southwestern Railway cuts the upper Norcross beach ridge, the crest of which is 1,195 feet above the sea, with a descent of about 5 feet on the west and 10 feet on the east. A half mile farther east it cuts the lower Norcross beach, with its crest at 1,167 feet, from which there is a descent of 10 feet to the west and 15 feet to the east. This beach has been extensively excavated for ballast, a spur track being run along its course a quarter of a mile northwestward from the railway. The excavation, varying along this distance from 6 to 8 rods in width and from 5 to 15 feet in depth, shows that the ridge is composed of interbedded sand and gravel, the layers of sand constituting about half of the entire deposit. The gravel layers differ in coarseness from those that contain no pebbles more than 1 or 2 inches in diameter to others containing waterworn masses of shale a foot across and Archean cobbles 6 inches in diameter. By estimate, nearly nine-tenths of the gravel is the hard Fort Pierre shale which makes up the principal mass of the Pembina Mountain, the Tiger Hills, and Riding Mountain, this shale gravel being often almost unmixed with other material; about a twentieth part consists of two classes of limestones, derived in nearly equal proportions from the yellowish-gray arenaceous limestone of Niobrara age, plentifully fossiliferous, which outcrops beneath this shale on the Boyne and Assiniboine rivers, and from the Paleozoic limestones of the flat country about Lakes Manitoba and Winnipeg; and the remaining twentieth is from the Archean rocks that lie east and north of Lake Winnipeg. Continuing northwesterly and northerly, this massive beach ridge crosses sections 8 and 17 and the eastern edge of section 19, township 8, range 9, beyond which it is lost sight of on the undulating and partly wind-blown surface of the Assiniboine delta.

The next definite observations of the Norcross shores of this lake are near Neepawa, where the Manitoba and Northwestern Railway, a half mile west of this station, crosses small beach ridges referable to the upper Norcross stage, with their crests 1,223 to 1,225 feet above the sea. Close to the west is an eroded escarpment of till 15 feet high, rising from 1,225 to 1,240 feet. On the other side of the station, between a half mile and 1 mile east from it, the railway crosses a surface of wind-blown sand with hollows 2 to 4 feet deep, the crests of its low dunes being at 1,193 to 1,192 feet. These occupy the level belonging to the lower Norcross beach. The bed of the railway here, formed of the sand of the Assiniboine delta, further worn and redeposited by the lake waves, proves somewhat insecure because of its liability to be channeled by the wind. The road leading northward from Neepawa to Eden and Riding Mountain runs on the crest of the upper Norcross beach ridge through the east part of sections 21 and 28, township 15, range 15, 3 to 5 miles north of the railway, its crest there having a nearly constant height of 1,223 feet, with a descent of 5 or 6 feet from it to the east and half as much to the west. Thence this beach ridge continues north-northeasterly to the east part of section 23, township 16, range 15, where it has an elevation of 1,225 to 1,230 feet, with width of about 30 rods and descent of 10 to 15 feet on its east side. It next runs north or slightly west of north to Thunder Creek, in the south part of township 17, beyond which its course, with that of the lower Norcross shore, is along the steep ascent of Riding Mountain. In the journey from Eden post-office (southwest quarter of section 22, township 16, range 15) to Orange Ridge post-office (northwest quarter of section 32, township 16, range 14) a nearly flat surface of till with frequent bowlders is crossed upon the width of 3 miles between this beach and the upper Campbell beach, descending in that distance from 1,200 to 1,100 feet, approximately. Bowlders are especially abundant within the first mile from the upper Norcross beach, whence the erosion of the lake bed supplied its gravel and sand. This even tract of till would seem most favorable for the accumulation of the beaches belonging to stages of Lake Agassiz between its upper Norcross and upper Campbell levels; but no beach ridge nor other deposit of gravel and sand, nor line of erosion which sometimes takes the place of these to mark a shore-line, was seen in the intervening distance. It seems probable that not far south and north from this route of observation the lower Norcross and the two Tintah beaches will be found.

My study of the beaches of Lake Agassiz mapped by Mr. J. B. Tyrrell[1] on the eastern flanks of Riding and Duck mountains leads me to correlate the two highest gravel ridges near the Valley River, having elevations of 1,280 and 1,260 feet above the sea, with the upper and lower Norcross beaches traced by me in North Dakota and southwestern Manitoba. The

[1] Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. III, for 1887–88, Part E.

ascent of these beaches in the 70 miles northward from the latitude of Gladstone and Neepawa to the Valley River is about 75 feet, or very closely 1 foot per mile, being slightly more than from the international boundary to Neepawa.

On Shanty Creek, 20 miles farther north, these beaches, according to Mr. Tyrrell, are 1,365 and 1,319 feet above the sea, showing the very remarkable northward ascents, respectively, of 85 and 59 feet, or about 4 and 3 feet per mile.

Along the next 25 miles north to the Pine River, where, according to my correlation, the upper Norcross beach has a height of 1,440 feet,[1] its ascent continues at the rate of 3 feet per mile. This is the highest altitude at which any beach of Lake Agassiz has been recorded. Its latitude is 51° 52″ north, being 200 miles north of the international boundary. It is 422 miles north of Lake Traverse and the mouth of Lake Agassiz, in which distance this shore has a total ascent of about 400 feet.

The significance of the more rapid northward rise of these shore-lines and others below them in the district of Riding and Duck mountains than along all the portion of the lake border explored by me farther south has been partly discussed in Chapter V, on the history of this lake, and will be again considered in Chapter IX, on the changes in the levels of its beaches.

BEACHES OF THE TINTAH STAGES.

EASTERN TINTAH SHORES FROM LAKE TRAVERSE TO TINTAH AND NORTHWARD IN MINNESOTA.

(PLATES XXIII–XXVI.)

The plateau, 3 to 4 miles across, which formed an island in Lake Agassiz, situated between Wheaton and the Mustinka River, on the southeast, and the Bois des Sioux River and White Rock station, on the northwest, rising to an altitude of 1,040 to 1,055 feet, is encircled by the Herman, Norcross, and Tintah shore-lines. This high tract has a base of till, but the plain forming its top consists, to a depth of 10 to 20 feet or more, of

[1] Stated to be 1,460 feet by Mr. Tyrrell, in the Bulletin of the Geological Society of America, Vol. I, 1890, p. 406; but later published by him as 1,440 feet in the Am. Geologist, Vol. VIII, p. 23, July, 1891.

delta sand and gravel, brought by the glacial representative of the Sheyenne River, apparently at the time of formation of the Dovre moraine, when the retiring ice-sheet began to uncover the edge of the area of Lake Agassiz (p. 150). Previous to the lower Tintah stage of the lake, the River Warren, outflowing by two broad channels, one south and the other west of this plateau, had eroded the upper portion of the valleys, respectively 2 and 4 miles wide, which are occupied by the Mustinka and the Bois des Sioux. At the time of the lower Tintah beach and during the later Campbell and McCauleyville stages the River Warren outflowed wholly west of this tract, completing the erosion of the valley of the Bois des Sioux from White Rock south to Lake Traverse, where it now contains a great marsh with numerous permanent areas of water 1 to 3 miles in length.

In the south half of section 2, township 128, range 47, at a distance of about 1½ miles east of White Rock, the upper Tintah shore bears a well-defined beach ridge of sand and gravel, lying on a surface of till. This ridge is 15 to 20 rods wide, rising 3 feet above the surface on each side, with its crest about 1,015 feet above the sea. Thence it was traced nearly 4 miles in a curving course to the northeast and east, passing through sections 31 and 32, Taylor. At the center of section 31, Mr. David Wariner's farm buildings are situated on its top, which has a height of 5 to 8 feet above the surface of till at the south and north. His well shows that the beach gravel and sand reach to a depth of 10 feet. In this vicinity the beach is somewhat irregular in its development and varies from 10 to 30 rods in width. Other irregular sand and gravel deposits belonging to this shore-line were found extending from south to north in sections 21 and 16, Taylor, lying on a tract of till slightly elevated above long sloughs on the south and east.

Two very small beach ridges, from 1 to 3 feet high, consisting of sand and gravel on a nearly flat surface of till, are crossed by the Evansville and Tintah line of the Great Northern Railway, about 1¼ miles and 1 mile east of Tintah.[1] The heights of their crests are respectively 1,010 and 1,007 feet above the sea. On the Minneapolis and Pacific Railway, 2 miles

[1] A Dakota name meaning *prairie* (A. W. Williamson in Thirteenth Annual Report, Geol. and Nat. Hist. Survey of Minnesota, for 1884, p. 110).

farther north, these inconspicuous beach ridges pass about 1 mile and a half mile east of Nash, their elevations being 1,012 and 1,010 feet. One to 2 miles onward, in sections 25 and 26, Champion, both ridges are somewhat more distinctly developed at 1,012 and 1,008 feet, each being 3 to 4 feet high above the till on each side.

Thence northward between the Rabbit and Red Rivers the level of these beaches was carefully followed with leveling across a very smooth and flat expanse of till; but no distinct shore marks, either of ridged beach deposits or of any noticeable erosion, were found. The shore passes almost due north, lying from a half mile to 1 mile west of the east side of Bradford, and crosses the Red River in the southeast part of township 132, range 45, between 2 and 3 miles above its most southern bend.

Within a half mile to 1½ miles north of the Red River two Tintah beach ridges are well developed, consisting of gravel and sand which lie on till. The eastern and higher ridge in the northwest quarter of section 26 and southwest quarter of section 23, township 132, range 45, varies in width from 10 to 25 rods; its crest is 1,019 to 1,023 feet above the sea, and both its eastern and western slopes fall 3 to 7 feet. Three-quarters of a mile to the west the crest of the lower ridge, which is of similar size, has a height of 1,012 to 1,015 feet. Through the next 2 miles these beaches are not distinctly traceable, and the surface consists of slightly undulating till. In the east edge of section 4, this township, the upper shore-line again bears a conspicuous gravel ridge, with crest at 1,020 to 1,022 feet, from which within 10 rods there is a descent of 5 feet eastward and 6 to 8 feet westward.

In the northeast corner of section 28, Andrea, the upper Tintah beach, a typical gravel and sand ridge, has an elevation of 1,017 to 1,018 feet above the sea. Along the next 2 miles northward, in sections 21 and 16, its crest holds a nearly uniform height of 1,017 to 1,019 feet, being 3 to 4 feet above the hollow east of the beach, and 6 to 7 feet above the adjoining surface on the west. Through the west half of section 9 and the southwest quarter of section 4 this beach is not distinctly a ridge, but is represented by a somewhat broad tract of gravel and sand. In the east edge of section 6, Andrea, about a mile west of the foregoing, the lower Tintah beach forms a massive gravel and sand ridge, with crest at 1,015 to 1,017 feet, rising 10 feet above the adjoining area of till on each side; and it continues north with the same conspicuous development through the east edge of section 31 and the southeast quarter of section 30, Akron.

Across the next 3 miles both these beaches fail, and the surface in their course is nearly flat till, with a thin covering of lacustrine silt, which is apparently due to the action of the lake during the deposition of the englacial till from the melting and receding ice-sheet.

Again, the upper Tintah beach has a very massive and higher development in the southwest corner of section 8, Akron, and extends with a width of 30 to 40 rods and an elevation of 1,024 to 1,029 feet above the sea along the east side of sections 7 and 6, the top of its ridge coinciding nearly with the south-to-north section line. Its maximum width and height are attained at the quarter-section stake between sections 7 and 8. On the east the descent from its crest is 3 to 6 feet, and on the west 10 to 15 feet within 20 rods. This gravel and sand beach passes onward, less massive, but having a distinctly ridged form, through the western tier of sections in Tanberg. In the east edge of sections 31 and 30 its elevation is approximately 1,028 feet. In section 19 it is offset a quarter of a mile to the west, and thence runs nearly due north 3 miles, being lost near the center of section 6 in a marshy tract.

The lower Tintah beach also forms a conspicuous gravel ridge, nearly parallel with the foregoing, at a distance of 1 mile to a half mile west, beginning in the northeast quarter of section 12, township 134, range 46, and running slightly west of north, with an elevation of 1,015 to 1,017 feet, about 3 miles to the east part of section 25, Manston. There it is offset a quarter of a mile to the east, and thence runs due north along the west line of Tanberg, having a height of 1,016 to 1,018 feet, to the marshes in which, like the upper Tintah beach, it is lost near the northwest corner of this township.

Both the Tintah beaches were next identified in the vicinity of Barnesville. On the northern border of a bowlder-strewn higher tract of till the upper Tintah shore-line is marked in the south part of section 36, Barnesville, at a distance of about a quarter of a mile east of the railway line to

Breckenridge, by a sand and gravel deposit several feet deep, which runs from west to east. Thence this beach, having a height of 1,030 to 1,035 feet above the sea, curves to the northeast and north, passing through the city of Barnesville not far east of the railway station, and onward a little east of north to section 7, Humboldt, where it bends northwestward. The lower Tintah beach in Barnesville is a shallow, slightly ridged tract of gravel and sand, resting on the general slope of till, above which it rises 1 to 2 feet on the east, while its western side falls 10 or 15 feet within 20 or 25 rods. It lies close west of the street which runs north from the railway station for a third of a mile to the bridge crossing the Willow River (also called Whiskey Creek), beyond which the street itself occupies the beach. Its height in the city is 1,015 to 1,018 feet. This shore, mostly marked by a well-defined gravel ridge, runs north the next 2 miles, lying in the west edge of sections 19 and 18, Humboldt, and then turns to the north-northwest, passing through sections 12 and 1, Barnesville.

Thence northward the Tintah shore-lines in Minnesota have been traced in only a few localities. Through Clay and Norman counties, however, to the Sand Hill River, their position is shown approximately on Pl. XXV, in accordance with the general westward slope of the east border of this lacustrine area.

As already noted in the description of the Norcross shore-lines (p. 387), two beaches observed on the western margin of the Sand Hill delta deposit, at the heights of 1,060 and 1,070 to 1,073 feet, seem referable to the upper Tintah stages of the glacial lake; and the continuations of these beaches are crossed by the Fosston Railway line at the elevations of 1,062 and 1,069 feet above the sea. Three-fourths of a mile to 1 mile west of these, and at a distance of nearly 2 miles east of Benoit, this railway intersects two less conspicuous beach ridges, with crests at 1,047 and 1,044 feet, which are believed to mark the lower Tintah stage.

These shore-lines are inconspicuous on the St. Hilaire railway branch, but 3 to 5 miles northward several beach ridges were noted by Mr. E. C. Davis in leveling for a proposed canal from the Red Lake River at Crookston to its southward bend at the mouth of the Thief River. A gravel ridge probably belonging to the lower Tintah level of Lake Agassiz lies about 3 miles east of the Black River and has an elevation of 1,050 feet. The upper Tintah shore was not recognized, but three gravel ridges, successively crossed at 2 miles, $2\frac{1}{2}$ miles, and $4\frac{1}{2}$ miles northeast from the 1,050-foot beach, with their crests respectively at 1,086, 1,088, and 1,092 feet, appear to be lower Norcross beaches.

Farther to the north the Campbell shore-lines are the highest that have been observed by me on the east side of Lake Agassiz; but information from others gives approximately the course of the Tintah shores to the international boundary and the south and west sides of the Lake of the Woods.

According to Mr. Charles Hallock, the road from Stephen to Roseau Lake runs on a gravel ridge, apparently one of the Tintah beaches, in townships 159 and 160, range 45, passing close along the northwest side of two lakes Crossing the South Fork of Two Rivers about 2 miles northeast of these lakes, the road is described as continuing for the next 15 miles upon this beach ridge or another closely associated with it, lying 5 to 8 miles southeast of the Great Roseau Swamp The beach forms a massive, smoothly rounded ridge of sand and gravel, with pebbles and cobbles up to 4 inches or more in diameter. Its width is 20 to 40 rods, with crest 5 to 10 feet above the adjoining surface of till, and it is in many places bordered on the side that was away from the lake by narrow swampy tracts. A trail which leaves this road before reaching Roseau Lake and passes east to the Lake of the Woods at the mouth of War Road River is said to lie for considerable portions of its extent on a beach ridge. This also doubtless belongs to one of the Tintah stages, and is, indeed, quite likely the direct continuation of the beach occupied by the Roseau road.

Dr. George M. Dawson has kindly supplied a manuscript profile of the international boundary from the Lake of the Woods to the Red River, as surveyed by the British Boundary Commission, which shows four low ridges, probably Tintah beaches. They are crossed successively at 12 miles, 22 miles, 24 miles, and 32 miles west of the Lake of the Woods, their crests being, in the same order, 1,088 feet, 1,081 feet, again 1,081 feet, and 1,070 feet above the sea. The first and second of these ridges are respectively about 5 miles east and 5 miles west of the crossing of the North Branch of the Roseau River, and the fourth is 3 miles west of Pine River. The elevation of the Lake of the Woods, varying at its stages of low and high water from 1,057 to 1,063 feet above the sea, shows that this large lake was first separated from the diminishing expanse of the glacial Lake Agassiz between the times of formation of the Tintah and Campbell beaches.

WESTERN TINTAH SHORES IN NORTH DAKOTA.

(PLATES XXVII–XXX.)

In the northeast corner of South Dakota, two beach ridges, belonging to the upper Tintah shore of this glacial lake, run north-northwestward across the northeast part of section 6, township 128, range 47. The eastern ridge is 20 to 30 rods wide, consisting of gravel and sand on the westwardly ascending surface of till. It has a height of 1,014 to 1,018 feet above the sea, with a descent of about 15 feet on the east and of 3 to 6 feet on the west. A smaller parallel gravel ridge, rising 5 feet from its eastern base and falling 1 to 3 feet toward the west, with crest at 1,015 to 1,021 feet, lies a quarter of a mile farther west. The eastern beach, curving northwestward, was traced several miles into North Dakota, to the northeast quarter of section 22, township 129, range 48, where its elevation is 1,015 to 1,018 feet. Thence it is probably continuous to two small beach ridges that were observed, without determination of their height (known, however, to be approximately 1,015 feet), in or near the north edge of section 34, township 130, range 49, on the south side of a little creek which there emerges from the sand area of the Sheyenne delta.

The Tintah shore-lines cross the eastern portion of this delta, but are seldom traceable, even on its smooth areas, and still less among its frequent tracts of dunes. The altitudes of the Northern Pacific, Fergus Falls and Black Hills Railroad show that they cross this line 1 to 2 miles east of Barney. Along the northern border of the delta they coincide with the escarpment and slope descending from its plateau, which pass close north of Leonard and thence extend 8 miles westward to the Maple River. On the Fargo and Southwestern Railroad the upper Tintah level of Lake Agassiz eroded an escarpment in the delta sand and gravel whose top has an altitude of 1,034 feet above the sea; and the lower Tintah shore bears three beach ridges, 5 to 7 feet above the intervening hollows, with their crests at 1,017, 1,016, and 1,014 feet.

Across an extent of nearly 60 miles next northward we have only scanty observations of the Tintah shores, the most important being $1\frac{1}{4}$ miles east of Clifford, where a well-defined gravel ridge upon an area of till was seen along a distance of 2 miles from south to north. Its crest has an elevation of 1,040 to 1,045 feet above the sea, with descent of a few feet on its west side and of 15 to 25 feet within 30 or 40 rods eastward.

From the South Branch of the Goose River, 10 miles north of Clifford, a Tintah shore-line, marked in portions of its course by an eroded slope and in other portions by a ridged beach deposit, passes to the north and northeast through township 147, range 53, crossing the railway line from Portland and Mayville to Larimore near the southwest corner of section 2 and the North Branch of Goose River near the center of this section. Here and onward to the north through the eastern tier of sections in township 148, range 53, and to the north-northwest through the next two townships of the same range, and onward to the Devils Lake line of the Great Northern Railway and to the Turtle River, this shore lies mostly on the eastern slope and near the border of the extensive delta of sand and fine clayey silt brought into Lake Agassiz by the glacial river of the Elk Valley. In section 14, Washington, and through several miles northward, the shore bears a well-defined beach ridge, which in the southeast quarter of section 34, Pleasant View, has been excavated to obtain sand for plastering. In portions of sections 8 and 5, Pleasant View, and in section 31, Chester, the beach deposit, with crest at 1,050 to 1,055 feet above the sea, changes to a low, eroded escarpment of till 10 to 20 feet high, with its top 5 to 15 feet above the beach. The delta here extends nearly or quite to the Tintah shore, which divides it from an eroded tract of till on the east.

North of the Turtle River, which is crossed by this shore-line 2 miles west of Arvilla, it continues in the same north-northwestward course, crossing an area of till. One mile east of Orr's station it is a distinct gravel and sand ridge, and about three-quarters of a mile west of Inkster it has two beach ridges, the crest of the western one being 1,070 to 1,072 feet above the sea, and that of the lower and less massive eastern ridge 1,060 feet. In the east edge of section 28, Eden, the Tintah levels of Lake Agassiz are shown by erosion upon the eastwardly sinking till slope. The upper limit of the steeper eroded belt is at 1,062 to 1,070 feet, being about 20 feet above its base. Beyond this township, northward to the Pembina delta, the courses of the Tintah shores, though not exactly traced, are known very nearly from the rate of eastward descent of the land and from the mapped course of the next succeeding Campbell beach. At one locality a Tintah beach ridge was noted, near the middle of the line between sections 19 and 18, Kensington, about 2 miles northwest from the town of Park River; but the next two miles or more northward have a rather irregularly rolling surface, with no definite beach observable.

The Tintah shores are only a short distance below those of the Norcross stages on the flanks of the Pembina delta and on the lower part of the Pembina Mountain escarpment for several miles thence northward.

WESTERN TINTAH SHORES IN MANITOBA.

(PLATES XXX–XXXIII.)

In proceeding northward from the international boundary, the Tintah beaches were first observed near the line between townships 1 and 2, range 5, lying on a terrace which forms the lower part of the Pembina Mountain. On the boundary this terrace is about three-fourths of a mile wide, its eastern margin being an escarpment that rises from 1,040 to 1,090 or 1,095 feet; and from its verge it gradually rises 25 to 35 feet in its width, so that its western limit at the base of the main escarpment has a height of 1,120 to 1,125 feet. Its surface is till with plentiful bowlders, nearly all Archean, up to 5 feet in diameter, mostly embedded or only projecting a foot or less; but the slope on its east side consists of weathering and pulverized Cretaceous shale, which is thus shown to form the principal mass of the terrace, beneath a thin mantle of till. In the distance of 6 miles northward across township 1 this terrace widens to 2 miles, and its eastern verge sinks to 1,055 feet; but it is bordered by only a slight escarpment, about 15 feet high, the base of which is thus at the same level as on the international boundary. In its width of 2 miles it there rises about 90 feet to the base of the mountain escarpment, at 1,140 to 1,150 feet. A quarter to a third of a mile east of this escarpment a line of erosion rises from 1,110 to 1,125 feet, approximately, marking the upper Tintah shore. In the southeast quarter of section 5, township 2, this shore bears scanty deposits of beach gravel and sand, with their crest at 1,110 to 1,115 feet. The lower Tintah beach lies a third of a mile farther east, and is a distinct ridge of gravel and sand with its crest at 1,083 to 1,085 feet, bordered on each side by till, the surface of which is 5 feet lower on the east and 3 feet lower on the west. Thomas Kennedy's well, 14 feet deep, in the northeast quarter of section 5, township 2, range 5, found the till only 4 feet deep, underlain by the Fort Pierre shale. This terrace doubtless owes its form, like the far more prominent Pembina Mountain, to preglacial erosion of these Cretaceous beds. It continues along the foot of the mountain, with a width of 1½ to 2 miles, at least to the South Branch of Tobacco Creek, which crosses it near Miami post-office, 25 miles north of the international boundary. Throughout its whole extent it has a considerable ascent upon its width from east to west, as in the localities noted. Much of its surface is till with many bowlders, but some portions have no bowlders, such tracts being overspread with lacustrine gravel and sand, or perhaps occasionally consisting of Cretaceous shale next below the soil, with no drift or lacustrine deposit.

A mile west of Morden the escarpment bordering this terrace has an ascent of about 40 feet, with its top approximately 1,070 feet above the sea. Within an eighth of a mile to the west is the lower Tintah beach, a small ridge of gravel and sand which has been excavated for use in plastering, its crest being at 1,085 feet, nearly, with a descent of 5 or 6 feet from it to the east and 2 or 3 feet to the west. It extends a considerable distance nearly parallel with the verge of the terrace. The road thence to Thornhill ascends slowly in the next 2 miles across a somewhat uneven surface on which eight or ten beach ridges are discernible, belonging to the upper Tintah, Norcross, and Herman stages.

The most remarkable feature of this tract is its extraordinary abundance of bowlders, nearly all Archean, usually less than 5 feet in diameter, but in many places ranging in size to 10 feet or more. Upon an area that extends at least 1 to 2 miles both south and north of the road and railway the surface is as thickly strewn with bowlders as are the most typical terminal moraines seen by me in Minnesota and South and North Dakota. Many of these rock masses, instead of being embedded in the drift, as is generally the case in this region, project 2 to 3 or 4 feet above the surface, or lie wholly on it with no portion concealed. Here the ice-sheet probably terminated, depositing these bowlders in the west margin of Lake Agassiz, during the time of its accumulation of the terminal moraine that forms the west part of the Tiger Hills and the Brandon and Arrow hills.

About a mile south and west of Nelson, the lower Tintah beach ridge, having an elevation of 1,085 feet, approximately, lies an eighth of a mile west from the margin of the terrace; and the upper Tintah beach probably extends along its west side, close to the base of the Pembina Mountain, where the elevation is about 1,100 to 1,120 feet. The width of the terrace here is about $1\frac{1}{4}$ miles.

A half mile east of the lower Norcross beach, near Treherne, the upper Tintah shore seems to be indicated where it crosses the railway by a line of erosion in the Assiniboine delta, with descent approximately from 1,140 to 1,120 feet.

On the profile of the Manitoba and Northwestern Railway the upper and lower Tintah beaches are apparently shown about 3 miles and $5\frac{1}{2}$ miles east-northeast of Neepawa, with their crests respectively at 1,158 feet and in two ridges at 1,116 and 1,111 feet above the sea. Within its next 3 miles northward the upper beach is represented by a tract of low dunes extending through the east edge of township 15, range 15, to Snake Creek. Thence the course of these shore-lines, as shown by the contour, is nearly due north to the foot of the escarpment of Riding Mountain, in township 17.

Along the eastern base of Duck Mountain the Tintah shores of Lake Agassiz have been observed by Mr. Tyrrell, according to my correlation of the beaches shown on his map (see p. 395), as follows: The upper Tintah beach, close north of the Valley River, at an elevation of 1,220 feet above the sea; both the upper and lower Tintah beaches on Shanty Creek, respectively, at 1,287 feet and 1,235 feet; and the upper of these beaches, extending several miles between the Pine and Duck rivers, at 1,365 feet. In proportion with the northward ascent of the upper Tintah beach thus indicated, its height on the Pine River would be about 1,335 feet, and on the Duck River, a dozen miles farther north, at latitude 52°, about 1,375 feet.

BEACHES OF THE CAMPBELL STAGES.

The Campbell shore-lines have in general somewhat the most conspicuous development of all below the Herman series. They belong to stages of Lake Agassiz much below its highest level, and furnish a very useful record of the boundary and depth of this body of water, as shown on Pl. XXXIV, near the time when it ceased to outflow to the south at Lake Traverse. Considerable portions of the lower and principal Campbell shore are marked by a low, eroded escarpment in the general sheet of till; and the aggregate length of such terracing by this one level of the lake is probably equal to that of the numerous shorter lines of escarpment formed during all its other levels, both above and below. Probably the land reposed without upward movement longer at this stage than at any other in the history of the lake, unless the earliest and highest stage of the Herman series must be excepted. It is also to be remarked that no other shore of Lake Agassiz bears at any place so extensive an embankment of beach gravel and sand, transported a long distance by the action of waves and coastal currents, as that swept southward from the Pembina delta during the Campbell stages.

Between the rate of northward ascent of the uppermost Herman beach and that of the Campbell beach there is a remarkable contrast. Along the 300 miles from the mouth of Lake Agassiz to Gladstone explored by me the land had been considerably uplifted after the formation of the Herman beach; but its level in all this extent has been only slightly changed since the old lake shore was at the present site of the town of Campbell, in Minnesota. Farther to the north, however, on the east side of Duck Mountain, a large amount of differential northward uplifting took place after the Campbell stages of the lake. The rate per mile of northward ascent of the Campbell beaches there exceeds that of the first and highest Herman beach upon all the country south of Gladstone.

Unusual interest, therefore, appertains to the Campbell shores, and they have been more fully mapped, especially in North Dakota, with leveling to ascertain their height continuously, than any other of the successive boundaries of this glacial lake, whether belonging to its stages of southward or of northeastward outflow, excepting only the Herman beaches.

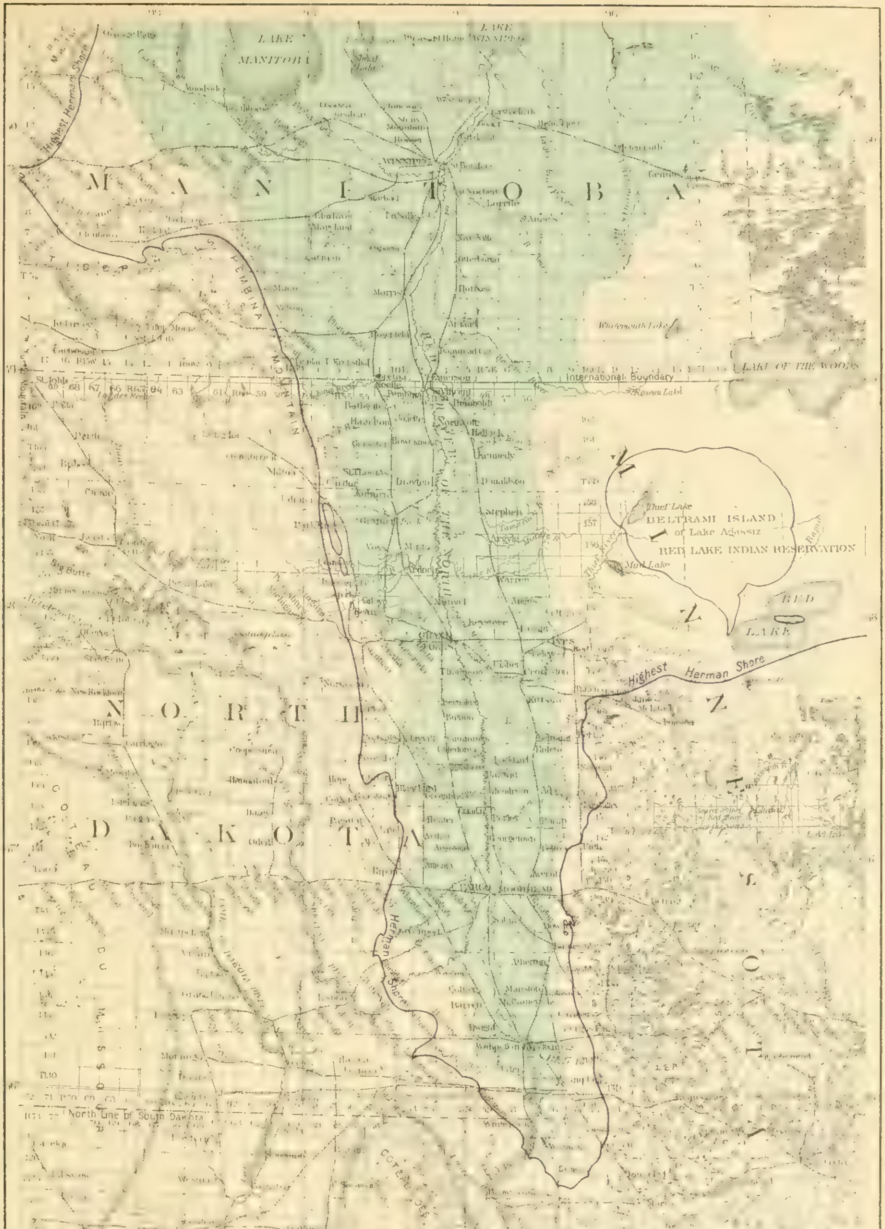
FROM LAKE TRAVERSE AND CAMPBELL NORTH TO THE TAMARACK RIVER, IN MINNESOTA.

(PLATES XXIII–XXVI.)

For a distance of about 18 miles north from the mouth of Lake Agassiz the Campbell shore-line is within a half mile to 1 mile east of the marsh with lakelets and of the Bois des Sioux River, through which Lake Traverse outflows. Perhaps, however, it would be better, at this stage of the decrease of Lake Agassiz in area and depth, to regard its mouth and the beginning of the River Warren as transferred from Lake Traverse 12 miles north to the vicinity of White Rock.

Parting company with the Bois des Sioux 5 or 6 miles north of White Rock, the Campbell shore runs northeastward across Campbell Township, passing less than a mile north of Tenney station, on the Minneapolis and Pacific Railway, and crossing the Breckenridge line of the Great Northern Railway at Campbell. Near the center of section 31, Campbell, it is recognized by a beach ridge which has been excavated for masons' sand. On the Minneapolis and Pacific Railway the crests of its scanty gravel and sand deposits are 980 to 983 feet above the sea; and on the Aberdeen Branch of the Great Northern Railway the top of the beach is at 989 feet, with adjoining land on the northwest 5 feet lower. The vicinity of the town of Campbell, however, has no definite ridge. A half mile to 1 mile north of Campbell the beach is dimly traceable, with crest at 984 to 986 feet, rising only 2 to 3 feet above the general surface; and it has the same inconspicuous development in its course thence nearly due north to the Red River.

In the northeast part of Richardson this shore bears a well-defined ridge of gravel and sand, which runs through the center of section 14 and the east part of sections 11 and 2. It has been excavated in the southeast quarter of section 11, showing pebbles up to 1½ inches in diameter. The crest of the beach ranges in height from 987 to 995 feet, from which there is commonly a descent of 2 to 5 feet on the east and twice as much on the west to the general surface of till. This beach, about 30 rods wide and 5 feet high, with its top at 992 to 995 feet, is crossed by the Northern Pacific,



MAP OF THE SOUTHERN PORTION OF LAKE AGASSIZ, SHOWING ITS EXTENT IN THE LOWER CAMPBELL STAGE.

Scale, about 42 miles to an inch.

Fergus Falls and Black Hills Railroad a quarter of a mile west of Everdell station. Thence for the next 15 miles its course is a few degrees west of north to the vicinity of Manston.

Through sections 15, 10, and 3, township 134, range 46, and northward in Manston, the Campbell shore-line is mostly marked by a definite gravel ridge, the land on each side being till. The ridge varies in elevation from 987 to 992 feet, attaining the latter height 1½ miles southeast of the village of Manston, where it rises 6 or 7 feet from its east base and has a descent of about 10 feet toward the west.

In Atherton this shore is intersected three times by the railway from Breckenridge to Barnesville. A beach ridge, for the greater part scantily and irregularly developed, passes northwestward across section 34 and the railway. Thence curving to the north and northeast, it lies close west of the railway for 2 miles, nearly to the Deerhorn Creek. About a quarter of a mile south of this creek it again crosses the railway, from which a spur track turns off to take gravel ballast from the ridge, its excavation being 6 to 10 feet deep. For the next 2 miles this upper Campbell beach runs nearly parallel with the railway and close on its east side to the south part of section 10; and thence, after its third crossing of the railway, it extends 3 miles nearly due north to a cemetery about 1½ miles west of Barnesville. The elevation of the beach crest in sections 15, 10, and 3, Atherton, and also in the cemetery, is 990 to 992 feet above the sea, with a descent of 3 or 4 feet on the east and of 6 to 10 feet on the west.

A second beach ridge, of smaller size, a tenth to a quarter of a mile west of this, with its crest 5 to 7 feet lower, about 985 feet, begins near Atherton Station and is continuous, or nearly so, through section 15 and the south part of section 10. The foot of the western slope of the lower ridge, at 980 feet, indicates approximately the level of Lake Agassiz when it was formed. A slight elevation of the land, probably amounting to 5 feet, had apparently taken place between the times of formation of these two beaches.

Both the upper and the lower Campbell beaches are also well exhibited 2 to 3 miles north of Barnesville, near the railway bridge over Siebers Creek. In the northwest corner of section 13, Barnesville, less than a quarter of a mile south of this creek, the upper beach, forming an irregular belt of gravel and sand from 992 to 980 feet on the descending slope of till, is crossed by the railway, and thence runs northward as a more definite ridge, with crest at 992 to 995 feet, through the west half of section 12. The top of the lower beach ridge, which lies an eighth of a mile to the west, running nearly along the west line of this section, is at 985 feet, with descent of 2 or 3 feet eastward and about 10 feet westward.

Through the next four townships to the north, extending 24 miles, the Campbell shore-lines have not been exactly mapped, but their position is known very nearly by the general westward descent of the border of the lacustrine area toward the flat Red River Valley plain which forms its central part. Near the middle of this distance, however, on the Northern Pacific Railroad, two beach ridges, belonging to the Campbell stages, lie between 3 and 3½ miles west of Muskoda. The railroad profile shows that the elevation of the eastern one of these ridges is 1,004 feet above the sea, with descent of 4 feet east and 11 feet west in its width of 30 rods, and that the crest of the second ridge is at 1,000 feet, 7 feet above its east base, while its west slope falls almost 20 feet, the whole width of this beach being about 50 rods. The unusually massive development of the Campbell beaches here, and of the closely associated McCauleyville beach, is due to their derivation partly from the delta of the Buffalo River, and in larger part from exceptional erosion in the slope of till that formed the lake shore northward. This slope is strewn with many bowlders, the remnants from a considerable depth of till worn away by the lake waves.

In Hagen the Campbell shore is mainly traced by a line of erosion forming a somewhat steep escarpment, from 5 or 10 to 25 feet in height, near the foot of the slope of till which thence rises gradually toward the east; but beach gravel and sand deposits mark its course where it crosses the depression occupied by the South Branch of the Wild Rice River. Likewise through Rockwell this lake margin is an eroded till escarpment.

The shore again bears a well-defined gravel ridge in Lake Ida Township, passing from the southeast quarter of section 34 north-northeastward across section 26 to the Wild Rice River, and thence nearly due north through the west edge of sections 13, 12, and 1, there rising 6 to 8 feet from its eastern base and descending 20 feet toward the west. The height above the sea was not exactly determined here, nor along the next 12 miles of this shore northward, mostly marked by a low escarpment of till, in Green Meadow and Spring Creek townships.

Close south of the Sand Hill River, in section 34, Liberty, the top of this Campbell escarpment is 1,010 feet above the sea, being probably 10 feet higher than the lake level when it was made. It runs in a nearly due-north course, parallel with the well-developed McCauleyville beaches which lie a half to two-thirds of a mile farther west. Continuing northward through Liberty and Onstead townships and the southern two-thirds of Kretchmarville, this shore-line is almost continuously a terrace cut in the till, having a descent of 10 to 30 feet within as many rods. Numerous residual bowlders are strewn upon a narrow belt below the terrace. Erosion was in progress along the greater part of this terrace during both the upper and lower Campbell stages of the lake; but a beach ridge of gravel and sand, which was accumulated along its base during the lower stage, extends through section 5, Onstead, and into the adjoining sections.

From the southeast part of section 9, Kretchmarville, the Campbell shore takes a north-northeastward course for the next 10 miles to the southwest corner of the township of Red Lake Falls and to the Red Lake River Along this extent it bears a conspicuous beach deposit, on which several farmhouses are built, their cellars being dug to the depth of 6 or 8 feet in gravel and sand, while the surface on each side of the shore-line is till. For the greater part of this distance there are two parallel beach ridges, usually occupying together a width of about 50 rods. The crest of the eastern and higher beach is 1,012 to 1,015 feet above the sea, and that of the lower beach about 1,000 feet, varying from this only 1 or 2 feet. Each ridge has a descent of 4 to 6 feet toward the east, and their western bases are respectively at 995 and 985 feet, approximately. The upper and lower Campbell levels of Lake Agassiz, which heaped up these beaches by their waves, were very nearly at 1,000 and 990 feet.

In the west edge of section 30, Red Lake Falls, only the upper beach ridge is present. Its width is about 30 rods, and its elevation varies from 1,013 to 1,020 feet, with descent of several feet eastward and 15 to 20 feet to its western base. On the top of this prominent sand and gravel ridge, about a quarter of a mile south from the Red Lake River and the northwest corner of this section, lie five dome-shaped artificial mounds, of gradually increasing size in their order from south to north. The southernmost is about 30 feet in diameter and 2 feet high; the second measures 50 feet across and is 3 feet high; the third is slightly larger, with a height of 4 feet; the fourth is 70 feet in diameter and rises 6 feet above the beach; and the most northern has a diameter of 80 feet and a height of about 8 feet. These mounds, which were undoubtedly used for burial, overlook a broad prospect, especially toward the west, including many miles of the well-wooded river valley.

The St. Hilaire Branch of the Great Northern Railway crosses the Campbell beach a half mile east of Black River, the crest of its gravel ridge being 1,019 feet above the sea, with a descent of 6 feet toward the east and about 10 feet westward. Within a few miles farther north the line of the survey by Mr. Davis, mentioned on page 400, found the elevation of this beach 1,022 feet, from which its slopes fall 6 or 7 feet on each side. Farther northward its elevation has not been determined, but its position has been accurately mapped. In townships 153, Bray, and 154, range 45, it runs nearly due north as a prominent gravel ridge, passing close west of the centers of these townships, and lying from 2 miles to 1 mile east of the old Pembina trail, which follows the McCauleyville beach. But near the south line of Viking the Campbell beach turns slightly, thence bearing north-northwestward, and for a few miles in the central and northwest portions of Viking the trail runs on its top.

Along the greater part of its explored extent north of the Red Lake River this shore is marked by a single large gravel ridge, 20 to 30 rods wide, 5 feet or more above the adjoining surface of till on the east and 10 to 20 feet above its western edge; but in the northwest part of Viking two Campbell beaches, a quarter to a half mile apart, run from section 17 to section 6, the western being less typically ridged and mostly 10 to 15 feet lower than the eastern. On the top of the western beach, near the middle of the west half of section 6 and a quarter of a mile south of the Snake River, a conspicuous aboriginal mound was noted, having a diameter of 50 feet and a height of 6 feet. Only a few feet south from its edge a smaller mound, about 15 feet in diameter, rises $1\frac{1}{2}$ feet above the beach. No other earthworks were seen in this vicinity.

Snake River, where it intersects the Campbell and McCauleyville beaches, has only stagnant pools in hollows of its bed during dry summers, while the Middle and Tamarack rivers, next to the north, seldom or never fail to carry running water, although reduced nearly to the size of brooks. Just after crossing the Snake River the Pembina trail turns westward three-fourths of a mile to the McCauleyville beach, on which it runs nearly all the way for 15 miles northward. The Campbell shore, continuing in the line of its western beach before described, passes almost due north along the west side of Marsh Grove Township, and thence runs a little to the west of north, bearing a fine ridge of gravel and sand, underlain and bordered on each side by till. Its distance east from the Pembina trail is between 1 and 2 miles, to the Tamarack River. Beyond this stream the trail turns to the northwest, diverging from these beaches, which continue to the north and north-northwest.

Through Marshall County the Campbell shore lies nearly on the limits of the chiefly prairie country on the west and of the wooded region on the east. The beaches are mostly grassed, with no bushes or trees, but brush and small poplars occupy much of the adjoining land on the west and between these gravel ridges, and almost the entire area on the east bears a small growth of poplars, where they have not been lately burned. At a distance of 10 to 20 miles eastward a forest of many species begins, comprising the common poplar or aspen, the large-toothed poplar, the balsam poplar, cottonwood, canoe birch, black and bur oaks, white elm, white and black ash, red and sugar maple, basswood, and the white, red, and jack pines. In the swamps, and frequently on higher land, tamarack, black spruce, and balsam fir grow in abundance, often festooned with moss. Crossing Kittson County, the most northwestern in Minnesota, the Tintah shore-lines extend here and there into heavily timbered tracts, while the Campbell and McCauleyville beaches continue approximately along the somewhat definite boundary dividing the woods and the prairie.

CAMPBELL SHORES IN NORTH DAKOTA

(PLATES XXVII–XXX.)

On the west side of Lake Agassiz one of the Campbell shore-lines begins to be marked by a beach ridge in the northwest corner of section 5, township 128, range 47, South Dakota, where it lies about 15 rods east of L. H. Eldred's house, running in a north-northwesterly course and immediately passing into North Dakota. The crest of this gravel ridge is 988 to 990 feet above the sea, with slopes that fall 12 feet to the east and 3 to 6 feet to the west, the surface on each side being till.

The Minneapolis and Pacific Railway and the Aberdeen Branch of the Great Northern Railway cross three Campbell beaches west of the Bois des Sioux. Wider spaces separate the shore-lines here than elsewhere, because the land is very nearly level and the lake had only a slight depth to a distance of several miles offshore. When the district was uplifted or the level of the water fell away even 4 or 5 feet, the emerging belt varied from 1 to 3 miles in breadth. The most eastern of these beaches, lying within a half mile east of Fairmount, forms small, irregular ridges, with crests at 979 to 984 feet. The next, passing by De Villo station, has an elevation of 987 feet; and the third, which is the continuation of the ridge at Mr. Eldred's, runs northwestward nearly through the center of De Villo Township, rising 5 feet above the general level, with its crest at 993 feet. But probably the earliest Campbell stage of Lake Agassiz here is represented by a line of dunes only 3 to 5 feet in height, with crests at 995 to 997 feet, crossed by these railways about 2 miles west of Oswald and Sonora. The lake levels thus indicated range from 992 feet, very nearly, downward to 980 feet, or perhaps 2 or 3 feet lower.

Continuing northwestward, these shores converge, on account of the increasing rate of westward ascent of the surface, as they approach the Sheyenne delta. They cross the Northern Pacific, Fergus Falls and Black Hills Railroad on the very gentle southeastward slope of the delta about 2 miles west of Mooreton, but are not definitely traceable there. Eight miles farther north the Campbell and upper McCauleyville shores begin to be marked by the escarpment or steep slope, descending eastward 20 to 50 feet within about a mile, which forms the eastern border of the principal plateau-like mass of the Sheyenne delta, having been sculptured by wave erosion during these stages of the glacial lake. The same shore-lines continue near together along this frontal slope through a distance of 30 miles to the north and northwest, passing about 3 miles west of Barrett, 1 to 2 miles west of Colfax, a similar distance southwest of Walcott, about 3 miles southwest of Kindred, and 1 to 1½ miles north of Leonard. In many places, however, the eroded surface as it was shaped by the lake waves has been much changed since by the winds, which have heaped up its sand in dunes 10 to 30 feet high.

Beyond the northern limit of the Sheyenne delta, near Leonard, the border of the lacustrine area rises somewhat steeply from the Red River Valley plain, and the lower and best-defined Campbell shore-lines are mostly united or lie close together, whether marked by beaches or by an eroded escarpment. This very finely developed margin of the old glacial lake has been mapped, with determination of its height by leveling, through all the distance from Leonard to the international boundary, about 175 miles.

The Fargo and Southwestern Railroad crosses the Campbell shore close below the Tintah beaches and slightly more than a mile northeast of Leonard, but it is not distinctly marked there, lying near the foot of the northeastwardly declining slope of the Sheyenne delta. Its course is thence west-northwest about 8 miles, crossing the Maple River, to the southeast part of section 29, Walburg, where it turns to the north and holds mainly a north-northeast course through the next 25 miles to Wheatland and Arthur. About a quarter of a mile south of the Maple River the Campbell shore is marked by an exceptionally massive beach ridge which passes through a cemetery in the north part of section 3, Watson, its crest in the cemetery and close westward being 1,008 to 1,013 feet above the sea and some 75 feet above the river. This ridge consists of sand and fine gravel, largely derived from Cretaceous shales, with no pebbles exceeding 2 inches in diameter. North of the narrow valley cut by this river the beach ridge continues with an elevation of 1,006 to 1,009 feet for nearly 2 miles to its northward bend, beyond which the shore along its next 2 or 3 miles, having left the thinned margin of the delta sand brought into Lake Agassiz by the

Sheyenne, is traced as a low, eroded escarpment of till, 10 to 15 feet in height, with base at 995 feet.

Four to 6 miles north of its bend the Campbell shore is compound and irregularly developed, bearing three beach ridges of gravel and sand, which rise 5 to 10 feet above the adjoining surface of till and range from 986 to 1,000 feet above the sea. The uppermost forms a northwardly projecting spit in the southwest quarter of section 4, Walburg, on which Mr. Luther Wyckoff's well found sand and gravel to the depth of 10 feet and till beneath. Along its course of 6 miles onward to Wheatland some portions of this shore are marked by beach gravel, with crest at 992 to 995 feet; but commonly there is no beach deposit, its place being occupied by a somewhat steep descent toward the east, falling from 990 or 995 feet to about 975 feet, eroded in the general sheet of till. Below this a tract a half mile or more in width is fine lacustrine silt, descending eastward with less slope.

In the east part of Wheatland village the Northern Pacific Railroad intersects the Campbell beach a quarter of a mile from the station. A massive gravel and sand ridge here occupies a width of about 60 rods, including its slopes, and rises 15 feet above the nearly level expanse thence eastward. Its crest, at 994 feet, is 10 feet above the hollow, 40 rods wide, on its west side. This ridge appears to have been formed during the lower and more important of the Campbell stages of the glacial lake, when its level was about 990 to 985 feet. The accompanying upper shore-line, which should be looked for 10 to 15 feet higher, crosses section 15 between 2 and 3 miles north of Wheatland, where Mr. Joseph Fuller's house is built on the top of its beach ridge, about 1,012 feet above the sea. His well was dug 15 feet in sand and gravel, then passing into till.

North-northeastward from Wheatland the crest of the lower and principal beach holds a nearly constant elevation, varying in the first 3 miles, to Swan Creek, from 993 to 996 feet, with descent of 12 to 15 feet in 20 rods east, and usually 3 to 5 feet in 10 rods west. About two-thirds of its gravel, which has pebbles and cobbles up to 4 inches in diameter, are limestone; three-tenths, by estimate, are granite and other crystalline rocks; while about a thirtieth part is Cretaceous shale. Looking east from this beach, one sees a very flat country, originally a monotonous prairie, which is in view to a distance of about 10 miles, and is hidden beyond only by the curvature of the earth's surface. In the summer nearly all this expanse is occupied by vast fields of wheat and oats, with frequent groups of substantial farm buildings, some of them surrounded by trees. The thriving towns of Everest, Casselton, and Amenia are seen in their order from south to north; and at these and many smaller stations of both the Northern Pacific and Great Northern Railways, also on some of the large farms, elevators tower above the flat lands, waiting to be filled with their grain. It is a most beautiful prospect, completely characteristic of the Red River Valley.

Through the next 5 miles to the Rush River the same features of the beach ridge continue, with elevation varying from 990 to 996 feet, except that occasionally the gravel and sand deposit is replaced by an escarpment of till, with crest at the same height as that of the beach, and having a steep descent of 10 to 15 feet from west to east. For nearly 4 miles onward after crossing this river (a puny stream, which is reduced to a series of stagnant pools during summer droughts) the Campbell shore is a till escarpment, as just described. Thence through the next 3 miles, to the town of Arthur, it is again a massive gravel and sand ridge, with elevation of 994 to 998 feet. Along the middle part of this distance, in section 32, Arthur, the descent from its crest westward, away from the lake area, is 3 to 5 feet, and its eastern slope falls 10 to 15 feet to a slough or moist tract, wholly mowing land, beyond which, at a distance of an eighth to a quarter of a mile from this beach, there is a lower beach ridge, probably representing the highest of the McCauleyville stages, with crest at about 985 feet.

At Arthur the Campbell beach curves to a north and almost north-northwestward course. It passes about an eighth of a mile east of the railway station, where its elevation is 994 to 997 feet above the sea, with slopes descending 3 or 4 feet to the west and about 10 feet eastward. Thence through 3 miles north the top of this gravel ridge varies from 996 to 1,002 feet. For the next 20 miles north-northwest, crossing the South and North branches of the Elm River (very small streams, wholly dry or chains of pools in summer), the Campbell shore is almost continuously an escarpment of till, as shown by fig. 7 on page 26, with its crest and the level of the surface westward at 995 to 1,005 feet, from which a somewhat steep slope falls 10 to 20 feet eastward. It passes about three-fourths of a mile west of Hunter and 2 miles west of Greenfield. Along all this distance the nearly parallel McCauleyville shore, 20 to 30 feet below the top of the Campbell escarpment, lies about a mile, or in part only a half mile, farther east.

From a mile east of Roseville the Campbell shore runs nearly due north 4 miles to the west edge of the town of Portland, where it is an escarpment 12 to 15 feet high, with its crest and base respectively about 1,000 feet and 985 feet above the sea. The escarpment is eroded in the southern extremity of the sand and silt delta which reaches from McCanna to Portland, deposited by a river flowing into Lake Agassiz from the Elk Valley while lobes of the melting and retreating ice-sheet lay on each side. For its next 8 miles this shore-line passes northeastward to Morgan Township, in which it curves to the north and north-northwest; and thence it holds the latter course, with only deviations of a few degrees, through a distance of 75 miles north to the Pembina delta. Between Portland and Arvilla it is mostly marked by a well-defined beach ridge of gravel and sand, lying on till, at a distance of 2 to 3 miles east from the margin of the delta, which coincides nearly with the Tintah shore-lines.

The Great Northern Railway crosses this ridge three-fourths of a mile east of Arvilla, where it occupies a width of about 60 rods. Its crest has an elevation of 1,014 feet, from which there is a descent of 23 feet to the east and 9 feet to the west. Close south of the Turtle River, nearly 2 miles farther north, its top is at 1,011 to 1,013 feet; and within the next mile north of this stream its elevation is 1,007 to 1,010 feet. In the vicinity of Arvilla and through nearly 15 miles onward, passing through townships 152, Hegton, and 153, range 54, both the Campbell and McCauleyville shores bear conspicuous beach ridges, which are nearly parallel at a distance of about a half mile apart.

In section 5, township 153, range 54, and for 6 miles thence northward in Strabane and Inkster, passing a third of a mile east of Inkster station, the Campbell shore is a low escarpment in the general surface of till, with crest at 1,018 to 1,026 feet, from which there is a somewhat steep descent of 15 to 25 feet. A few miles farther north, however, this is changed to a massive beach ridge of gravel and sand, which lies about a half mile west of Conway station.

Beyond Conway, along a distance of about 35 miles of very direct north-northwest course, this shore-line, passing through the west edge of the town of Park River and close by the east side of the village of Mountain, is almost uninterruptedly an eroded escarpment of till, with eastward descent of 20 to 30 feet, or rarely 40 feet, within an eighth of a mile, or often a less distance. At Park River the Campbell escarpment falls rather abruptly from 1,035 feet to 1,015 feet above the sea; and thence a gentle slope of till sinks about 15 feet lower in a half mile east to the McCauleyville beach and railway line. In the northwest corner of Dundee, 10 miles

FIG. 17.—Profile of the Campbell escarpment in section 6, Dundee. Scale, 100 feet to an inch.

north of Park River, the escarpment falls from 1,045 to 1,015 feet, being steep for the upper half, which consists of till; then it descends more slowly a few feet, also in till, with frequent bowlders; and its lower third is a somewhat steep slope of beach sand and coarse gravel (fig. 17).

From its foot a smoothed surface of till sinks gradually eastward, having an estimated descent of 100 feet within 3 miles. In section 2, Gardar, the crest of the escarpment, at 1,045 feet, bears a slight ridge of beach gravel and sand, 2 to 3 feet high above the surface of till on the west; but the face of the escarpment, here falling 25 feet within 30 rods to the east, is till inclosing plentiful bowlders of granite and gneiss. A few miles farther north, at a distance of about 1 mile south of Mountain village, the steep slope falls from 1,040 to 1,000 feet, and is covered with a beach deposit of gravel and sand from 1,030 to 1,020 feet, while its higher portion and a broader belt forming its foot, like the lower land extending eastward, are till (fig. 18). At Mountain this shore descends 30 feet, from 1,045 to 1,015 feet, within a distance of about 25 rods. It is wholly till, with no associated beach formation, as also are the more gentle slopes on both sides, sinking toward the east and rising westward. During all the Campbell stages of Lake Agassiz erosion was in progress upon this long escarpment; but in some localities the action of the waves in cutting away and removing the till was temporarily changed, alternating with accumulation of shore deposits of wave-brought gravel and sand.

Erosion of the base of the "first Pembina Mountain"—that is, the front of the Pembina delta, along a distance of 6 miles to the southeast from Walhalla—supplied an extraordinarily massive Campbell beach or embankment, varying from a quarter of a mile to nearly 1 mile in width, which extends 8 or 9 miles in a curving course, convex to the southeast, through sections 5, 8, 17, 20, 29, and 30, township 161, range 55, and the south half

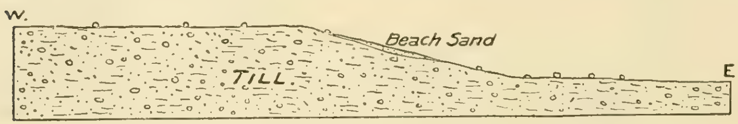


FIG. 18.—Profile of the Campbell escarpment 1 mile south of Mountain. Scale, 100 feet to an inch.

of section 25, the southeast quarter of section 26, and the west half of section 35, township 161, range 56. This broad belt consists of gravel and sand, 15 to 40 feet or more in depth, which were carried southward by the shore currents of Lake Agassiz in its Campbell stages, the greater portion being transported 6 to 12 or 15 miles. A section crossing this deposit is shown in fig. 19. The crest or somewhat plateau-like top of the embankment in its course of 6 miles south of the Tongue River has an elevation of 1,020 to 1,030 feet above the sea. In its narrower part, north of this river, its crest ranges from 1,028 to 1,033 feet along the first mile from the river; 1,030 to 1,035 feet along the next mile; and 1,035 to 1,045 feet, averaging 1,040 feet, in its third and most northern mile, passing through the southwest edge of section 29, township 162, range 55, where it becomes an ordinary beach ridge only 20 to 30 rods wide, with descent of 15 feet to the east and 5 feet to the west. The process of accumulation of the extensive embankment was by transportation of its material along the shore that is marked by this beach ridge, and by building it thence out into the lake in this long hook bent to the west, which grew gradually in length and in height until it rose to the lake level, its growth afterward being by additions to its width. From its eastern verge a slope of the same gravel and sand falls 30 to 40 feet in a third or half of a mile, to a south-to-north belt of dunes and sand ridges, 10 to 15 feet high, which appears to represent the McCauleyville beaches. West of this embankment a basin 15 to 40 feet below it, mostly consisting of fertile wheat land, well drained by the Tongue River, extends 6 miles from south to north, with a maximum width of about 3 miles, lying between the embankment and the southeastern border of the Pembina delta, which was the lake shore during the Norcross and Tintah stages. The prevailing course of the coastal currents of Lake

FIG. 19.—Section across the Campbell embankment in sections 20 and 21, township 161, range 55. Horizontal scale, one-third of a mile to an inch; vertical scale, 100 feet to an inch.

Agassiz, and of the transportation of its beach material here and elsewhere, on both its western and eastern sides, was from north to south, as now on Lake Michigan, due then and now to the prevailing directions of the winds, and especially of gales in severe storms, when the broader and higher portions of the beaches were chiefly amassed.

At Walhalla and northwestward the Campbell shore-lines run along the base of the escarpment of the Pembina delta, where its steep descent is succeeded by a more gentle slope. Rev. John Scott's house, a half mile west of Walhalla, and the houses of H. A. Mayo and John Harvey, respectively about a half mile and 2 miles farther northwest, are on the principal lower Campbell shore, which in part is a well-developed beach ridge, with crest 1,030 to 1,035 feet above the sea, but mostly is a terrace eroded in the delta deposit, falling from 1,040 to 1,020 feet, approximately. In the northeast part of section 14, township 163, range 57, about 3 miles northwest of Walhalla, the upper Campbell shores form such a terrace, which falls from 1,075 to 1,035 feet; while a more moderate slope of sand and fine gravel below, to 1,025 feet at the road running northwest from Walhalla, probably represents the lower Campbell stage.

Three miles farther northwest and about 1 mile south of the international boundary a terrace of gravel and sand in the west part of section 34, township 164, range 57, marks the Campbell levels of the lake. The front of the terrace rises steeply from 1,015 to 1,035 feet above the sea, and its top has a further gentle ascent of 10 or 15 feet in its width of about 50 rods to where it abuts on the base of the lowest escarpment of the Pembina Mountain, which rises from 1,050 to 1,100 feet. From the top of this escarpment a terrace or plateau of till and underlying Cretaceous shale extends across a width of three-fourths of a mile west to the principal Pembina escarpment. The upper Campbell level probably passed along the top of the sand and gravel terrace, near the elevation of 1,045 feet; the second level of the series was near the verge of this terrace, approximately 1,035 feet; and the third and lowest stage coincided with the lowest third of its steep front.

CAMPBELL SHORES IN WESTERN MANITOBA.

(PLATES XXX–XXXIII.)

Along the course of the Cretaceous terrace, thinly covered with till, which borders the base of the Pembina Mountain for at least 25 miles northward from the international boundary, as described in connection with the Tintah beaches, the upper Campbell shore-line, there having an elevation of 1,045 to 1,050 feet, coincides generally with the low escarpment which forms the east margin of this terrace. A portion of the sculpturing of this escarpment was doubtless done by the waves of the lake; but the main outlines of the terrace as a bench intermediate between the expanse of the Red River Valley and the high Pembina escarpment seem clearly attributable to subaerial erosion before the Ice age. The first locality where I observed a distinct beach ridge of gravel and sand referable to this stage is in section 3, township 4, range 6, a half mile west of Nelson, and thence through a distance of a mile or more north-northwestward. It lies close east of the terrace escarpment, and has an estimated elevation at its crest of 1,055 feet. In township 7, range 8, this shore is marked by a conspicuous beach ridge, passing through sections 22, 27, and the east edge of 33, lying an eighth to a half of a mile west of the Boyne River, with its crest about 1,055 to 1,060 feet above the sea. The descent from the crest is 10 to 15 feet on the east and 5 to 8 feet on the west. The lake at this stage, or at a slightly higher level, also cut an escarpment 15 to 20 feet high, with its top at 1,075 feet, approximately, which passes northwestward across sections 28 and 29 of this township and northward through the east part of sections 6 and 7, township 8, crossing the railway about 7 miles east of Treherne.

The lower Campbell beach, in its course northward from the international boundary, lies close east of the terrace face which was the upper Campbell shore. In sections 2 and 11, township 1, range 5, the elevation of its crest is 1,036 to 1,040 feet. On the west a nearly level surface extends an eighth of a mile to the terrace. On the east a slope of beach gravel and sand sinks to 1,028 feet in about 25 rods; and a similarly descending surface of till continues to 1,015 feet in the next 25 rods, beyond which there is a much slower descent eastward. The road on the line between townships 1 and 2, range 5, crosses this shore about three-eighths of a mile west of the northeast corner of section 34, township 1, where it is marked by a typical beach ridge, with its crest at 1,034 feet, from which there is a descent of 10 feet in 10 rods to the east and 3 or 4 feet in 10 rods to the west. This ridge was seen to hold nearly the same outline and height through a distance of 1 mile or more to the south and a half mile north to a small creek. About a half mile west of Morden, where it has been considerably excavated for plastering sand, it has a nearly flat top 10 to 20 rods wide, with ascent on this width from 1,030 to 1,040 feet, approximately, resting on the base of the terrace escarpment. Five to 6 miles farther north the road from Nelson to Miami runs along the top of this beach through the north half of section 3 and the southwest quarter of section 10, township 4, range 6. It is there a broad, low ridge of sand and gravel, 20 to 30 rods wide, the elevation of its crest being about 1,035 feet, or 10 feet above Nelson. Continuing northward, it crosses the north-east quarter of section 6, township 5, range 6, a mile west of Miami.

The course of these shore-lines was not traced across the Assiniboine delta, but their elevation shows that they lie on its eastward slope, where they are intersected by numerous ravines, and are doubtless obscured in many places among its dunes. On the Canadian Pacific Railway profile three massive beach ridges, the two higher referable to the upper Campbell stage and the third to the lower Campbell stage of the lake, are shown 3 miles to 2½ miles west of Austin, their crests being, respectively, 1,087, 1,081, and 1,066 feet above the sea. These beaches are each about 30 rods wide, with descents of 10 to 20 feet from their crests to their east bases and half as much to the west.

On the Manitoba and Northwestern Railway the upper Campbell beach is a very massive rounded ridge, 30 to 50 rods wide, along whose eastern slope the railway runs about 3 miles, from the south side of section 6, township 15, range 13, north-northwest to Arden. Before the railway was built, the old trail from Winnipeg to the Saskatchewan River passed along the top of this ridge the same distance and to a point about a mile north of Arden, there leaving it and turning to the west. This portion of the trail was a good dry road throughout the year, being thus remarkably contrasted with the deep mud along most of its extent during rainy seasons. Because of this character of the road and the beauty of the smooth beach, which is prairie, without tree or bush, but is bordered on each side by groves, this avenue-like tract received its widely known name, the Beautiful Plain. It is not flat, however, as the name seems to imply, for the crest of the beach ridge, at Arden, 1,090 feet above the sea, and not varying more than a few feet above or below this elevation in its course through several miles south and north, is 15 to 25 feet above the nearly straight margin of the woods an eighth to a quarter of a mile east, and 7 to 10 feet above the more irregular margin of bushes and woods on the west, commonly 10 to 30 rods distant. The barrier of this beach ridge was sufficient to turn the White Mud River southward 3 miles along its west side. In a section cut 6 feet deep close north of Arden, for the passage of the railway and in excavation of ballast, the material of this beach is mainly fine gravel, with pebbles only a quarter to a third of an inch in diameter, but also includes layers of sand and coarser gravel, with pebbles up to 2 inches in diameter, of which about three-fourths are from the Paleozoic formations of magnesian limestone that occupy the country eastward to Lake Winnipeg and northward to the Saskatchewan.

From Arden this beach extends north-northwest through the northeast part of township 15 and nearly through the center of township 16, range 14. In the north half of township 16 it has in several places a narrow, terrace-like secondary beach on its eastern slope 5 to 10 feet below the crest of the main beach; and it is closely bordered on the west by a low escarpment of till which rises 5 to 10 feet above the beach ridge and forms the margin of a flat or slightly uneven expanse of till that ascends slowly westward. A post-office situated close west of this beach and escarpment, in section 32, township 16, is named Orange Ridge, in allusion to the orange-red lilies (*Lilium philadelphicum* L.) which grow in abundance on the sandy and gravelly soil of the beach. The elevation of the Orange Ridge or Beautiful Plain beach on the north line of the northeast quarter of section 32, township 16, is approximately 1,080 feet above the sea; and of the escarpment on the west, which was eroded during the early part of this upper Campbell stage, 1,090 feet.

The lower Campbell beach is crossed by the railway near the southeast corner of section 6, township 15, range 13, where the elevation of its crest is 1,061 feet, with a descent of 8 feet in about 15 rods to the east and 5 feet in a few rods to the west. Through the next 15 miles northward it lies a half to two-thirds of a mile east of the Beautiful Plain and Orange Ridge. East of the latter, on the line between townships 16 and 17, range 14, the elevation of its crest is about 1,070 feet, with descent of 15 feet to the east and 10 feet to the west.

The northward continuations of the Campbell beaches pass through sections 5 and 8, township 17, range 14, to Thunder Creek, and thence a few degrees west of north to the Big Grass River, in section 31 of this township. Thence they traverse sections 6, 7, and 18, in township 18, range 14, and the northeast part of township 18, range 15, where a swamp on the west about 2 miles wide separates them from the base of Riding Mountain.

Mr. Tyrrell's observations and map of the beaches of Lake Agassiz adjacent to the northern part of Riding Mountain and on the eastern and northern sides of Duck Mountain, as correlated with my mapping from Lake Traverse to the southern end of Riding Mountain, show the principal Campbell shore, there probably the upper one, to be marked by a prominent gravel ridge, which Mr. Tyrrell has traced through distances of many miles.[1] The elevation of this beach ridge where it crosses the Ochre River, on latitude 50° 56′, is 1,115 feet above the sea. On the Valley River, about 30 miles farther northwest, its height is 1,135 feet. Twenty miles thence northward, on Shanty Creek, this shore has two beach ridges, respectively 1,180 and 1,190 feet above the sea. The lower one of these beaches has been followed continuously 15 miles to the north, attaining there an elevation of 1,225 feet. Nearly 20 miles farther north, the elevation of the Campbell beach at its most northern observed locality, on latitude 52°, is 1,290 feet, perhaps corresponding to its upper ridge on Shanty Creek.

This well-defined, massive gravel ridge, double in portions of its course, is doubtless the continuation of the similar beach which is called the Beautiful Plain and Orange Ridge, having at Arden an elevation of 1,090 feet above the sea. For the distance of about 70 miles north from Arden to the Ochre and Valley rivers its ascent continues somewhat as from the international boundary to Arden, averaging two-thirds of a foot per mile. But northward from Valley River to Duck River, in a distance of about 55 miles, between latitudes 51° 13′ and 52°, this beach rises 145 feet, or more than 2½ feet per mile. After the Campbell stages of Lake Agassiz, the southern part of the lacustrine area was only slightly uplifted; but the region of Duck Mountain subsequently experienced a greater differential uplift, increasing in amount from south to north, than that of the earliest Herman beach farther south, where nearly all of its inclination had taken place before the Campbell beaches were formed.

[1] Pages 395 and 406, this chapter. Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. III, for 1887–88, Part E; 16 pages, with map. Bulletin, G. S. A., Vol. I, 1890, pp. 395–410. Am. Geologist, Vol. VIII, pp. 19–28, July, 1891.

BEACHES OF THE M'CAULEYVILLE STAGES.

The channel of the River Warren, outflowing from Lake Agassiz, had been eroded below the level of Lakes Traverse and Big Stone when the McCauleyville beaches began to be accumulated. Portions of the bottom of the river-course are now the beds of these lakes, whose maximum depths are reported to be respectively about 15 and 30 feet. In the vicinity of White Rock the bottom of the River Warren, eroded in till, is 965 to 970 feet above the sea. Along the broad tract of marsh, with lakelets, between White Rock and Lake Traverse, the depth of the alluvial swampy deposit probably ranges from 10 to 15 feet, reaching down to the level of the deepest part of the bed of Lake Traverse, approximately 955 feet above the sea. This or a slightly greater depth of the channel continued between Lakes Traverse and Big Stone, where alluvium has since been brought in by the head stream of the Minnesota River to the depth of 25 feet or more. The bed of Big Stone Lake sinks to about 935 feet in its deepest part, and the alluvium of the Whetstone River, which is spread along the Minnesota Valley below this lake, has probably a corresponding thickness of at least 30 feet.

The southern portions of the McCauleyville shore-lines of Lake Agassiz coincide nearly with the levels of high and low water in Lake Traverse, which are approximately 976 and 970 feet above the sea. The highest yearly stage of the glacial lake attended the more rapid melting of the ice-sheet in summer, while its winter stages doubtless fluctuated so low at times as to reduce the depth of the River Warren to only a few feet. No appreciable epeirogenic movement of the south part of the lacustrine area appears to have taken place during the time of formation of the McCauleyville beaches; but northward, in Manitoba, the earth's crust was uplifted 15 to 50 feet within this time, as shown by its upper and lower shore-lines.

Along nearly all of their course the Campbell and McCauleyville shores lie nearly parallel, and are only a few miles or mainly less than 1 mile apart, permitting both to be mapped, with determination of their heights, from a single line of survey. The latter are 10 to 20 or 30 feet below the former in their southern portion, but the vertical range of the two series increases to 70 feet in southwestern Manitoba, while the highest

McCauleyville beach appears to be 90 feet below the highest Campbell beach at the northern end of Duck Mountain.

The McCauleyville shores are seldom marked by an eroded escarpment, like that which characterizes the principal Campbell shore through considerable distances. Instead, they are traced by beach deposits, which are generally well defined and often form a conspicuous ridge, vying in size with any other beach of this lake.

EASTERN M'CAULEYVILLE SHORES IN MINNESOTA.

(PLATES XXIII–XXVI.)

Through a distance of 47 miles, from Lake Traverse north to the southern edge of Mitchell, a few miles east of McCauleyville, the border of Lake Agassiz at its lowest level of southward outflow is mapped on Pls. XXIII and XXIV, the line being drawn on the second of these plates in accordance with the elevations determined at each quarter-section corner on east-to-west section lines by the Red River Valley Drainage Commission of Minnesota in 1886. It is not exactly horizontal, however, but has a descent from the known level of the lake at White Rock, about 970 feet above the sea, to the level indicated by the beaches between McCauleyville and Barnesville, which is approximately 960 feet. Thus there appears to have been a slight differential northward depression of this area, or else an increase of the height of the land at Lake Traverse as compared with the country northward, since Lake Agassiz ceased to outflow to the south. These changes in relative elevations were opposite to those which were intermittently in progress throughout all the explored portion of this glacial lake during its whole history, giving to the shores their present northward ascent. But the discordant movement reached no farther north, for beyond Barnesville these shores on both sides of the lake rise continuously, though very slowly, from 1 inch to 3 or 4 inches per mile, to the international boundary.

In the southwest part of Mitchell a broad, curved embankment, which may be called a hook, extends from the south part of section 21, 2 miles westward, and then about an equal distance southward, forming a plateau-like tract a quarter of a mile to nearly 1 mile wide. The narrowed southern end of the hook lies about 3 miles east-northeast of McCauleyville. It consists of gravel and sand that were borne from northeast to southwest by the currents and waves of Lake Agassiz and were accumulated in this broad deposit as a curved cape of its shore, which, on account of the prominence of this earliest portion observed by me, has been named for the neighboring pretty village of McCauleyville, on the Red River, opposite to Fort Abercrombie. The elevation of its top is 960 to 970 feet above the sea, being 5 to 10 feet or more above the general surface of till on the east, while westward a flat plain of stratified clay and fine silt, 25 to 35 feet below this beach, extends 3 miles to the Red River.

Following the McCauleyville shore northeastward 8 miles from the base of this hook to the Deerhorn Creek, which it crosses about $1\frac{1}{2}$ miles southwest of Atherton station, it is found to be marked chiefly by considerable

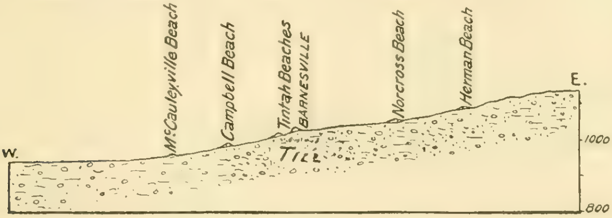


FIG. 20.—Profile across beaches at and near Barnesville, Minn. Horizontal scale, $2\frac{1}{2}$ miles to an inch.

erosion of the till, but not by a well-defined escarpment. At only two localities, in the southwest corner of section 11, Mitchell, and again in the southwest part of section 29, Atherton, short and inconspicuous beach ridges occur, their crests being in each place 965 feet above the sea.

Beyond the Deerhorn Creek the course of this shore is nearly due north for the next 10 miles, lying mostly about 1 mile west of the Campbell beach. It runs nearly through the middle of section 4, Atherton, where a small beach deposit has been dug for masons' sand; and in Barnesville it passes 2 miles west of the town. Fig. 20 shows a profile crossing the eastern border of Lake Agassiz from west to east through Barnesville. In the southwest part of section 2, Barnesville, it forms a rather broad gravel and sand ridge, rising to 966 feet above the sea, with springy and boggy ground about 10 feet lower on each side.

One to 4 miles farther north, in sections 34, 27, 22, 21, and 16, Elkton, two McCauleyville beach ridges are distinctly developed, extending north-northwesterly close alongside of the railway that runs from Barnesville to Glyndon. The upper beach has an elevation at its crest of 970 to 976 feet above the sea. It lies about an eighth of a mile east of the railway and was seen to be continuous at least 3 miles, attaining its most massive development and maximum height near Downer station, where its gravel, 8 to 10 feet in depth, has been largely excavated for railway ballast. The lower beach is smaller, and in part consists of a belt of sand and gravel, lying on the westwardly descending slope of till, without forming a definite ridge, while other parts are ridged up 1 to 2 feet above the east margin of the belt. Its gravel contains pebbles and cobbles up to 3 inches in diameter, and the depth of this deposit ranges from 3 to 5 feet. The elevation of its top is 964 to 966 feet, and its western base at 960 feet marks approximately the lake level when this second beach was formed, probably 8 or 10 feet lower than at the time of the higher beach.

About a mile north of Downer these shore-lines turn to a nearly due-north course, leaving this line of the Great Northern Railway. On the Northern Pacific Railroad they are united in a beach ridge that is crossed 5 miles east of Glyndon, having a width of about 20 rods, with descent of 3 feet to the east and 10 feet to the west from its crest, which is 983 feet above the sea. Thence through a distance of about 20 miles to the north the McCauleyville shore is not exactly traced, but is known to lie close west of the higher shore-lines, because the border of the lacustrine area rises steeply eastward.

In Rockwell and Lake Ida townships a well-marked McCauleyville beach ridge of gravel and sand, with till on each side, was traced several miles, lying about a half mile west of the Campbell escarpment and beach. Where it is crossed by the road on the north line of the northwest quarter of section 26, Lake Ida, its width is about 30 rods, and its east and west slopes fall respectively about 5 and 15 feet, its crest being 10 to 15 feet lower than that of the similarly massive Campbell ridge, which is a half mile distant to the east. The elevations of these ridges were not ascertained by leveling, but are probably about 985 and 1,000 feet above the sea.

My next observations of the McCauleyville beach are 10 to 15 miles farther north, in the townships of Spring Creek and Liberty. A large gravel and sand ridge, situated about two-thirds of a mile west of the Campbell escarpment, runs from south to north along the east edges of sections 9 and 4, Spring Creek, and sections 33 and 28, Liberty, to the Sand Hill River. Mr. Jacob Stambaugh's house is built on the top of this beach, in the northeast corner of section 33; and two aboriginal mounds, each about 3 feet high, were noted on the same ridge, one close north and the other a third of a mile south of this house, but no other Indian mounds are known in the vicinity.

The following notes of elevations describe a section (fig. 21) drawn from east to west, at Mr. Stambaugh's, across the Campbell and McCauleyville shore-lines. From the crest of the Campbell escarpment of till, 1,010 feet above the sea, there is a descent westward to a hollow of till a third

FIG. 21.—Section of the Campbell and McCauleyville beaches in sections 33 and 34, Liberty, Minn. Horizontal scale one-fourth mile to an inch.

of a mile wide, extending from south to north, at 980 to 975 feet; and west of this the McCauleyville beach ridge rises to 990 feet, holding this elevation, within 1 or 2 feet of variation above or below it, for a distance of at least 2 miles. Next westward the beach falls about 15 feet within 20 rods, and bears on its western border a secondary beach ridge, which in its most definite portions rises 4 or 5 feet from the east and falls about 10 feet on the west. The western base of this lower beach ridge is 970 feet above the sea, which represents very nearly the latest McCauleyville stage of Lake Agassiz, probably 10 to 12 feet below its earlier stage, when the higher principal beach was accumulated.

For nearly 25 miles between the Sand Hill and Red Lake rivers the McCauleyville shore has not been traced on the ground, but it is mapped approximately on Pl. XXVI, and is so shown by fig. 22, in accordance with the known westward descent of the surface. It lies mostly about a half mile west of the Campbell shore, but in the vicinity of the Red Lake River and for 10 miles northward their distance apart is 2 to 3 miles.

The Duluth and Manitoba Railroad crosses two McCauleyville beach ridges, and runs a considerable distance on the eastern one, between three-fourths of a mile and 2 miles west of the Black River. Their crests are about 995 feet and 990 feet above the sea. A quarter to a half of a mile farther north the St. Hilaire Branch of the Great Northern Railway crosses these gravel ridges, Ives station being on the course of the western ridge, into which the railway cuts to the depth of a few feet. The crest of this beach, which was followed by the old Pembina trail, is at 990 feet; and that of the eastern beach, a third of a mile distant, is at 997 feet. Within a mile or two farther north the profile of leveling by Mr. E. C. Davis

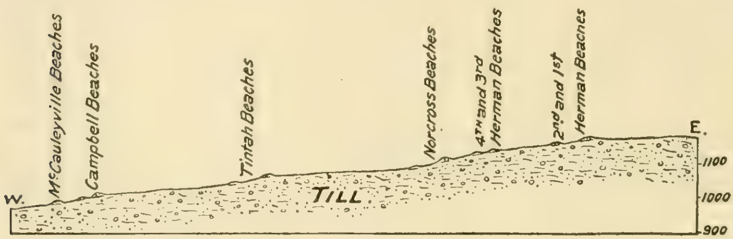


FIG. 22.—Profile across beaches on the north line of Onstead and Godfrey, Minn., west of Maple Lake. Horizontal scale, 2½ miles to an inch.

(p. 400) shows the McCauleyville beach at 996 feet. In this vicinity and along the next 15 miles northward this beach is a conspicuous gravel and sand ridge, mostly 20 to 30 rods wide, with slopes descending 5 feet or more to the east and 10 or 15 feet to the west. Throughout this distance it afforded an excellent roadway for the Pembina trail, on which during many years, until about 1870, long processions of Red River carts, drawn by oxen, traveled from St. Paul and St. Cloud to Fort Garry (now Winnipeg), carrying provisions and supplies for the Hudsons Bay Company, and returned laden with buffalo skins and furs.

Near the north line of section 20, Numedal, the McCauleyville beach ceases for the next few miles as a distinct ridge, and the Pembina trail thence passes to the Campbell beaches, on which it runs through Viking, the next township on the north. From the ford of the Snake River in the northwest corner of Viking the trail deviates three-fourths of a mile to the west, again taking its way along the crest of the McCauleyville ridge, which is finely developed through the next 18 miles, to the north part of Nelson Park Township. The farther course of this beach, however, was not followed, as it extends into the borders of a more wooded or bushy and swampy country.

The beach is intersected by the Middle and Tamarack rivers, respectively, in the southern and northern edges of township 157, range 46, Wright. Through the south half of Nelson Park, lying next north, the conspicuous beach ridge, rising 5 to 10 or 15 feet above the originally unchanneled surface on the east, was a sufficient barrier to turn the Tamarack River from its normal westward course to one a little east of south for 3 miles before it cut through the ridge. At the center of the township of Nelson Park, where this river first comes to the beach from the east, the Pembina trail departs from it to the northwest. In its extent of 25 miles thence to Hallock, descending about 200 feet, this trail crosses several shorelines of Lake Agassiz which elsewhere in certain portions of their course are very clearly defined; but no distinct beach ridge or eroded escarpment was seen on the trail or on either side, although the surface is mostly a gentle and regular slope of till, affording apparently very favorable conditions for the formation of shore marks.

Beyond Nelson Park the general course of the McCauleyville shore across Kittson County is to the north and north-northwest. It appears to be represented on the north line of Minnesota, according to the profile of the British Boundary Commission (p. 401), by a massive beach ridge with crest 1,016 feet above the sea and 20 feet above the land on each side, lying 20 miles east of the Red River. Within a short distance farther north, in Manitoba, this shore probably turns east-southeastward for a dozen miles or more, to cross the Roseau River near Pointe d'Orme (Elm Point), on the international boundary. Thence it passes northward and northeastward through the wooded region of southeastern Manitoba to the vicinity of Rennie station, on the Canadian Pacific Railway, and to the Winnipeg River, which it crosses not far above the mouth of the English River.

WESTERN M'CAULEYVILLE SHORES IN NORTH DAKOTA.

(PLATES XXVII–XXX.)

My most southern observations of the McCauleyville shore-lines in North Dakota are on the latitude of Wahpeton and northward, along the eastern border of the Sheyenne delta. Two levels of Lake Agassiz are indicated by the beaches and escarpments of these shores, the upper being now about 970 feet and the lower about 960 feet above the sea. A beach ridge formed by the lake at the upper level is crossed by the Northern Pacific, Fergus Falls and Black Hills Railroad, about a third of a mile west of Mooreton. Its width is about 30 rods, and the elevation of its crest is 974 feet, with descents of 8 feet to the east and 3 feet to the west. This shore continues north and northwest more than 30 miles along the base of the frontal steep slope of the Sheyenne delta, the erosion of which was completed by the lake waves during this stage. With the Campbell shores, which also run along this border of the delta plateau, it passes 1 to 2 miles west and southwest of Barrett, Colfax, Walcott, and Kindred, and about 1½ miles north of Leonard.

Sand and fine silt of the Sheyenne delta, however, extend to a distance of several miles east of this plateau, partly as spread originally in the deep central portion of the lake during the Herman stages, when the delta was formed, and partly as redeposited from the erosion of the delta front during the later and lower stages. On this nearly flat tract of silt, at a distance of 1½ to 2 miles from the plateau front, the lower McCauleyville shore is marked by a beach ridge, which through most of its observed extent of about 15 miles has become a narrow belt of dunes, occupying a width of 20 to 50 rods and rising 5 to 15 feet above the general level. This belt, running from south to north, is crossed by the railway 2½ miles south of Colfax. Thence it gradually curves northwestward, passing about a half mile east of Colfax and Walcott, and is again crossed by the railway 3 miles northwest of Walcott. The land on each side of the beach and its dunes has an elevation of 955 to 960 feet, which represents approximately the former water surface.

As on the opposite portion of the east side of the lake, this latest shore-line, formed during the time of southward outflow, now lies about 10 feet lower here than the present height of the Bois des Sioux Valley at White Rock, which then was the mouth of Lake Agassiz. The northward depression of the intervening area or its southward uplift, inharmonious with the epeirogenic movements of all other explored parts of the lake basin, was

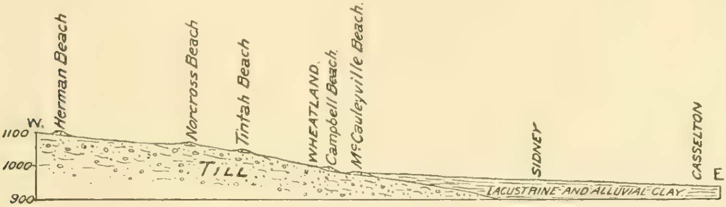


FIG. 23.—Profile across beaches at and near Wheatland, N. Dak. Horizontal scale, 2½ miles to an inch.

about 3 inches per mile along its extent of 40 miles, taking place after the flow of the River Warren ceased.

Northward from the Sheyenne delta, the McCauleyville shore through the next 30 miles lies within a mile, or mostly a half mile or less, to the east of the Campbell shore, both passing close east of Wheatland and Arthur. Fig. 23 presents a profile crossing the western beaches of Lake Agassiz on the Northern Pacific Railroad in the vicinity of Wheatland and westward. About 2 miles south of Arthur these two shore-lines, each there marked by a beach ridge, are only an eighth to a quarter of a mile apart.

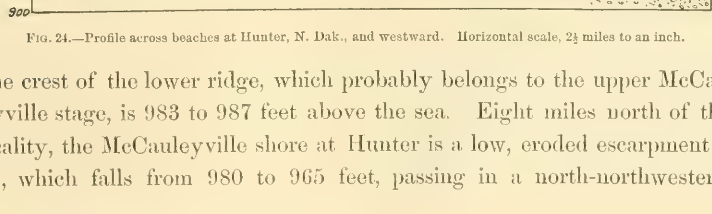


FIG. 24.—Profile across beaches at Hunter, N. Dak., and westward. Horizontal scale, 2½ miles to an inch.

The crest of the lower ridge, which probably belongs to the upper McCauleyville stage, is 983 to 987 feet above the sea. Eight miles north of this locality, the McCauleyville shore at Hunter is a low, eroded escarpment of till, which falls from 980 to 965 feet, passing in a north-northwesterly course a quarter of a mile east of the railway station and about 1 mile east of the similarly eroded Campbell shore. Fig. 24 shows the westward ascent of the border of the lacustrine area in the vicinity of Hunter. Thence these shore-lines extend 15 miles north-northwest and 6 miles north to Mayville and Portland, holding a distance of about 1 mile to 1½ miles apart.

The upper McCauleyville shore, approximately 980 feet above the sea, passes about a mile west and northwest of Mayville, but is not definitely marked on the almost level surface of lacustrine silt. For 12 or 15 miles in this part of its course, from 6 miles south to an equal distance northeast of Mayville, the lower McCauleyville shore, on account of the very slow descent of the land, lies probably 2 or 3 miles farther east, but it too is only dimly traceable.

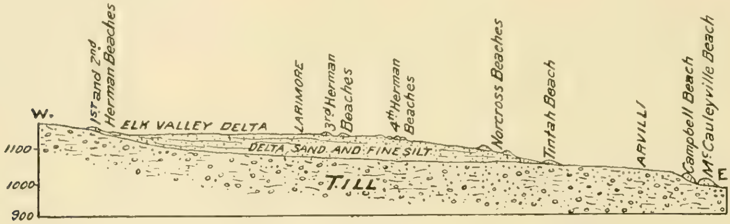


FIG. 25.—Profile across beaches in the vicinity of Arvilla and Larimore, N. Dak. Horizontal scale, 2½ miles to an inch.

Continuing northward to the vicinity of Arvilla, the upper and lower shore-lines converge, and on the Great Northern Railway, as shown on fig. 25, they together form a massive beach ridge, about 50 rods wide, with its crest 991 feet above the sea, from which its slopes descend 18 feet to the east and 8 feet to the west. This ridge lies a mile east of Arvilla, being about a third of a mile east of the still more conspicuous Campbell beach.

Beyond Arvilla the upper and principal McCauleyville shore is almost continuously marked by a fine beach ridge of gravel and sand, 5 to 10 feet above the adjoining surface of till on the west and east, through an extent of more than 30 miles to Park River. In section 14, Hegton, 4 to 5 miles north of Arvilla, the crest of this ridge is 995 feet above the sea, and other determinations of its height in sections 27 and 16 of the next township on the north were 990 to 995 feet. In the southwest part of Strabane, passing about a mile east of Inkster (fig. 26), its elevation is mostly 995 to 998 feet, rising 5 to 8 feet above the depression, a sixth of a mile wide, in the surface of till on its west or landward side, while its lakeward slope falls 10 to 15 feet.

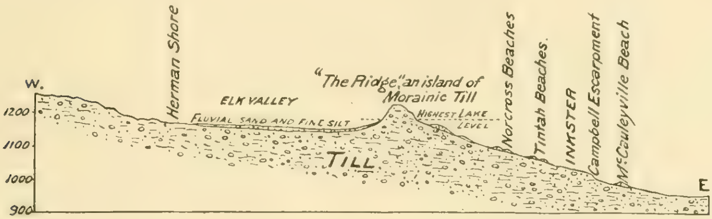


FIG. 26.—Profile across beaches at Inkster, N. Dak., and westward. Horizontal scale, 2½ miles to an inch.

One and a half miles north of Inkster the upper McCauleyville beach is crossed by the Langdon Branch of the Great Northern Railway close south of its bridge over the Forest River. Its crest here is 996 feet above the sea, with descents of 8 feet eastward and 5 feet westward. Thence it runs close along the west side of the railway for a distance of about 8 miles, passing an eighth of a mile west of Conway station. Onward for

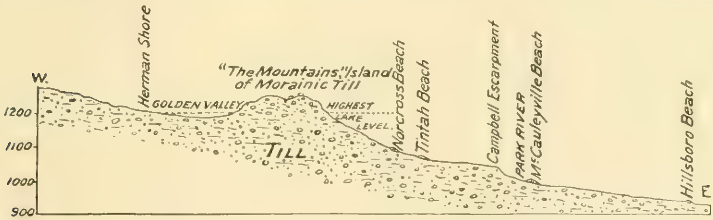


FIG. 27.—Profile across beaches at Park River, N. Dak., and westward. Horizontal scale, 2½ miles to an inch.

the next 8 miles to Park River (fig. 27), the railway is built on the top of the beach ridge, which has an elevation of 996 to 998 feet. Thence along the distance of about 25 miles to the Pembina delta, this shore, probably marked throughout by a deposit of gravel and sand, lies about a half mile east of the Campbell escarpment.

A belt of low dunes in sections 28, 21, and 16, township 161, range 55, running along the eastern base of the great Campbell embankment that was built out to the south from the front of the Pembina delta, probably records the McCauleyville stages, approximately at 1,000 to 980 feet. North of the Tongue River the McCauleyville shores lie a third to a half of a mile east of the Campbell embankment and beach ridge along a distance of 5 miles. Thence through the next 6 miles, extending northwest to the Pembina River and Walhalla, they run along the base of the "first Pembina Mountain," which is the very steep ascent, 100 to 175 feet high, of the eroded east border of the Pembina delta plateau.

The road from Olga to Walhalla, coming down from this plateau about a mile southeast of the Pembina River, crosses at its foot a terrace of sand and gravel, 30 to 50 rods wide, having an elevation of 1,000 to 1,004 feet above the sea, which was formed during the upper McCauleyville stage. The highest part of the terrace is where it rests against the "mountain," and its surface descends a few feet to its northeastern verge. There is next a somewhat rapid slope to 985 feet at the bottom of a depression about 15 rods wide, beyond which the road passes over the beautifully developed lower McCauleyville beach. This ridge is 20 to 30 rods wide, with smoothly rounded top at 990 to 993 feet, very level along a visible distance of a third of a mile or more of its course from southeast to northwest, but hidden farther away by trees and bushes scattered here and there on its otherwise prairie surface. Its lakeward northeastern slope falls about 20 feet within 25 rods, and from its base a slower descent continues eastward.

All the land of this vicinity, including the plateau and front of the delta, the terrace and beach ridge, the intervening hollow, and the flat country on the east, consists of gravel, sand, and fine silt, belonging to the delta as it was originally deposited, or as it has been worked over by the lake waves during later stages. Indeed, proceeding eastward 30 miles to the Red River at Pembina, St. Vincent, and Emerson, one crosses only the fine silt which was of like origin with the delta, but was carried farther into the lake, or the similar alluvial beds that have been laid down from floods of the Pembina, Tongue, and Red rivers since Lake Agassiz was drained away.

Between Walhalla and the international boundary the McCauleyville shore-lines lie on the western margin of the flat expanse that stretches from the Red River to the Pembina Mountain, being a quarter of a mile to 1 mile east of the first conspicuous westward ascent, as shown in fig. 28. In section 2, township 163, range 57, about 2 miles south of the boundary, they form a tract of sand and fine gravel, 40 to 50 rods wide, drier than the adjoining surface on the west and east, passing by Elm Point, the eastern limit of the groves, at that place consisting mostly of large white elms, which extend outward from the wooded Pembina escarpment along springy water courses scarcely depressed below the general surface. The elevation of this gravelly tract is 997 to 1,002 feet. It is not a distinct ridge or even swell, and is recognizable chiefly by the contrast of its comparative dryness,

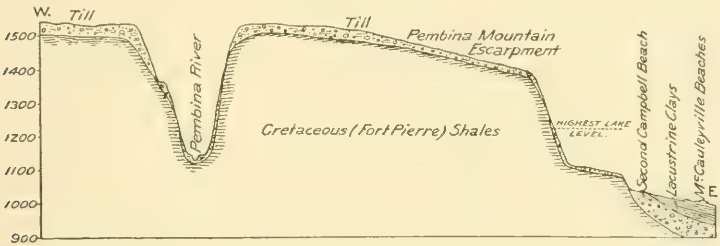


FIG. 28.—Section on the international boundary, south of ranges 6 and 5, Manitoba. Horizontal scale, 2½ miles to an inch.

which has caused it to be selected as the site of farmhouses. The adjoining moist and springy land on the east descends 15 or 20 feet in the first third of a mile; but thence the surface sinks very slowly to the axial lowest part of the lake basin on this latitude, at the Red River, its gradients in this distance being gradually diminished from 15 feet to only 2 or 3 feet per mile.

WESTERN M'CAULEYVILLE SHORES IN MANITOBA.

(PLATES XXX–XXXIII.)

In the southwest quarter of section 12, township 1, range 5, the upper McCauleyville shore is indicated by very scanty deposits of fine gravel, 1,006 to 1,007 feet above the sea, from which there is a descent of 3 or 4 feet in 20 rods east. Through the east half of section 23, the middle of section 26, and the west half of section 35 of this township, two McCauleyville beaches are developed as small parallel ridges of gravel and sand. The upper one has an elevation of 1,000 to 1,002 feet at its crest, from which there is a descent of 1 to 2 feet within 2 or 3 rods to the west and 5 to 8 feet in 10 or 12 rods to the east. Thence a nearly level surface of till with frequent bowlders occupies a width of 10 or 12 rods, and is succeeded on the east by the second ridge, the western slope of which rises 2 or 3 feet to its crest. This is about 5 feet lower than the upper beach, and has a similar descent of 5 feet or more on its east side.

Fig. 29 presents a section crossing the McCauleyville and higher beaches on the latitude of Mountain City, where the Pembina Mountain ascends less steeply than throughout the greater part of its extent.

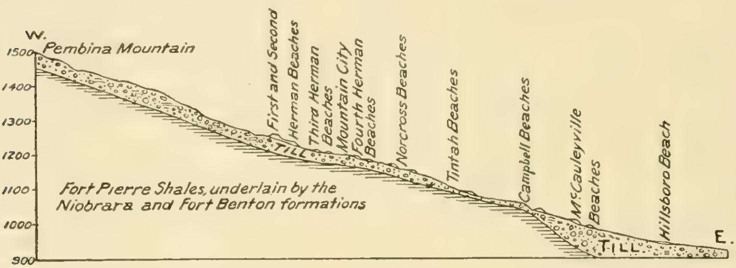


Fig. 29.—Section across ranges 6 and 5, Manitoba, 9 to 10 miles north of the international boundary. Horizontal scale, 2½ miles to an inch.

About a quarter of a mile east of Nelson the upper McCauleyville shore is a line of erosion with a descent of 5 to 10 feet within a short distance from west to east. Four miles thence to the north-northwest it is a well-defined beach ridge running close to the bridge over Boyds Creek, near the northeast corner of section 21, township 4, range 6; and it continues, but is less conspicuous, through the next 3 miles northward to the church in the northeast corner of section 5, township 5, range 6, a quarter of a mile east of Miami post-office. Its crest at Boyds Creek is 8 to 10 feet, and at Miami 5 feet, above the more massive second or middle McCauleyville beach, which lies a quarter to a half of a mile farther east, passing north-northwesterly through the west edge of section 27, and the east half of section 33, township 4, in which latter it is offset nearly a quarter of a mile to the east, and through the middle of section 4 and the west half of section 9, township 5.

Three McCauleyville beach ridges are crossed by the Manitoba and Northwestern Railway on the north side of sections 32 and 33, township 14, range 13, about 4, 4½, and 5 miles southeast of Arden, the elevations of their crests being respectively 1,039, 1,029, and 1,016 feet above the sea. Each of these rises about 5 feet above the surface on the east. They continue as prominent gravel ridges north-northwestward through the west half of township 15 and the southwest part of township 16, range 13, and through the northeast part of township 16, the east half of township 17, and the west half of township 18, range 14, to the vicinity of Phillips's ranch. The relationship of the Campbell, McCauleyville, and lower beaches near Arden and eastward is shown in fig. 30.

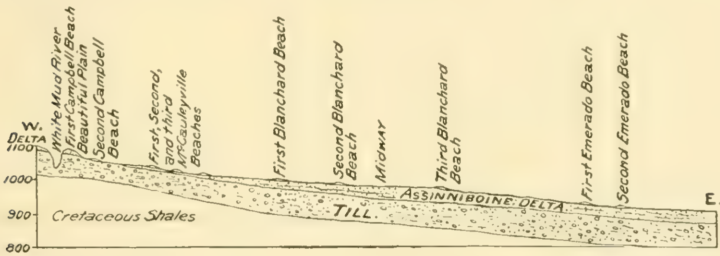


FIG. 30.—Section on the south side of townships 15, ranges 13 and 12, Manitoba, between Arden and Gladstone. Horizontal scale, 2½ miles to an inch.

In township 15, range 13, next east of Arden, the most western and upper one of the McCauleyville beaches is called Lowdons Ridge, from Thomas Lowdon, whose house, the first built on it, is in the middle of the east edge of section 30. The middle beach appears to be twofold in sections 20 and 29, Joshua Ritchie's house being built on one of its ridges and the Rose schoolhouse, a quarter of a mile farther east, on the other. About three-quarters of a mile east of the Rose Ridge is the lower McCauleyville beach, on which the trail to Lake Dauphin runs northward through townships 15 and 16. Lewis McGhie's house is built on the eastern slope of this beach, in the northeast quarter of section 28, township 15. Lowdon's, Ritchie's, and McGhie's wells, and others in this township on these beach ridges, pass through gravel and sand 5 to 15 feet and through till below to total depths of 30 to 40 feet, obtaining water in gravelly seams, from which it usually rises 10 to 20 feet within a few hours, to its permanent level.

East and north of Duck Mountain beaches of the McCauleyville stages are shown as follows by Mr. Tyrrell's map, according to my correlation with these shores southward in Manitoba and North Dakota:

On the Vermilion River, which flows from the northeastern flank of Riding Mountain to Lake Dauphin, the beach ridges of two of these stages are mapped, the elevation of the lower one being noted as 1,068 feet above the sea. Twelve miles to the northwest their elevations are 1,084 and 1,075 feet, at the north side of the Valley River, which flows from the gap between the Riding and Duck mountains. Both these beaches are probably represented by the upper shore-line farther south.

The higher beach was followed by Mr. Tyrrell 20 miles thence north to the Shanty Creek, but without further notation of its height. About 20 miles farther north, near the south side of Pine River, it is found at 1,175 feet. Fifteen miles onward, at latitude 52°, close south of Duck River, the upper McCauleyville beach is 1,201 feet above the sea, having thus an ascent of 117 feet in its course of 55 miles from the Valley River. Three miles beyond the Duck River where it turns sharply westward, adjacent to the base of the northeastern angle of Duck Mountain, its height is 1,198 feet. After a course of a few miles to the west the beach ridge of this shore, or the foot of its eroded escarpment, was followed along the next 15 miles west-southwesterly, at the base of the steep mountain slope, by the original location survey for the Canadian Pacific Railway.

Curving thence again to the north, this upper McCauleyville shore-line, where it crosses the Swan River, about 30 miles west of its crossing of the Duck River, is marked by a prominent gravel ridge or embankment known as the "Square Plain," 1,160 feet above the sea. It is thus shown that the former lake level has now an ascent here of a little more than a foot per mile from west to east, or about half of its rate of ascent from south to north in this district. The direction of the differential uplift, as in the southern part of the lake area, was from south-southwest to north-northeast, toward the region on which the ice-sheet had been thickest and where it lingered latest as the barrier of Lake Agassiz.

CHAPTER VIII.

BEACHES FORMED WHEN LAKE AGASSIZ OUTFLOWED NORTHEASTWARD.

Fourteen shore-lines of Lake Agassiz have been traced, with determination of their heights, through portions of their extent, which lie below the McCauleyville beaches and were formed after the lake ceased to outflow southward. The River Warren, no longer receiving the drainage from the melting ice-sheet and from the rainfall of the vast basin of Lake Agassiz, was suddenly reduced, when the lake obtained a lower northeastern outlet, to the much smaller Minnesota River; and the alluvium of this stream formed a watershed between Lakes Traverse and Big Stone, partially filling the former channel of outflow from the glacial lake. Chapter V has already considered the courses of the successive new avenues of outflow to the northeast, probably at first flowing back southward along the border of the retreating ice-sheet, and thus passing through the great Laurentian lakes to the Mississippi, and later to the Hudson. Though the courses of the northeastward outlets remain unexplored, the beaches marking the stages of Lake Agassiz while tributary to them are found to be separated only by vertical intervals varying from 10 or 15 to 45 feet through all the time of its reduction from the level of Lake Traverse and the McCauleyville beaches to Lake Winnipeg. On the latitude of the south end of Lake Winnipeg the fall of the surface of the glacial lake during this time was about 280 feet, Lake Winnipeg having stood at first above its present height and having been since lowered 20 feet by the erosion of the Nelson River.

The three highest shore-lines on the area from which the lake receded during its northeastward drainage are named the Blanchard beaches, and the next five in descending order the Hillsboro, the two Emerado, and the two Ojata beaches, from towns on or near their course in North Dakota.

The remaining six, enumerated in the same order, are designated, from places of their typical development in Manitoba, as the Gladstone, Burnside, Ossowa, Stonewall, and two Niverville beaches. Like the shores marking the higher stages of the lake while flowing southward, these beaches are found to have a northward ascent, due to the differential uplifting of the earth's crust. The gradual decrease of their ascent from a considerable amount along the earlier and higher shore-lines to very little along the latest and lowest shows that the northward uplifting was in progress while the ice barrier was receding. It had been nearly completed before the glacial recession uncovered the area traversed by the Nelson, changing Lake Agassiz to Lake Winnipeg.

Beyond the limit of my survey, which was extended into Manitoba to Gladstone and Orange Ridge and to the south ends of Lakes Manitoba and Winnipeg, very interesting observations of the beaches east and northeast of Riding and Duck mountains are supplied by Mr. J. B. Tyrrell in his exploration of that district for the Canadian Geological Survey.[1] It is there found that the earlier shore-lines of the series formed during the northeastern outflow were uplifted about a foot per mile from south to north for 150 miles northward from the latitude of Gladstone, and that this rate diminishes in the successively lower beaches. According to my correlation of Mr. Tyrrell's observations with my own in southern Manitoba and southward, the last shore-line known to have been formed by Lake Agassiz is about 60 feet above the south end of Lake Winnipeg and 80 feet above its north end, having thus a northward ascent of only 20 feet in a distance of about 275 miles from south-southeast to north-northwest. Here, too, as in the earlier uplifting of the large region on the south, the upward movement of the earth's crust was interrupted by stages of repose or of only very slow progress, affording time for the accumulation of beach gravel and sand; and these recognized shore marks are most numerous northward, where the extent of the uplift was greatest. The Emerado beach thus seems to be represented in Mr. Tyrrell's observations by two beaches on

[1] Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. III, for 1887-88, Part E, 16 pages, with map. Bulletin, G. S. A., Vol. I, 1890, pp. 395-410. Am. Geologist, Vol. VIII, pp. 19-28, July, 1891.

Kettle Hill, near the south side of Swan Lake, separated by a vertical interval of 20 feet; and the Niverville beach is subdivided into three at the Grand Rapids of the Saskatchewan. Instead of the eleven or twelve shore-lines observed by me in the United States and in southern Manitoba, belonging to the time of northeastward outflow, Mr. Tyrrell therefore has at least fourteen upon the country 150 to 200 miles farther north.

From the following detailed descriptions of the beach deposits of these lower shores it will be seen that their magnitude and the distinctness of their development are very similar to those of the earlier and higher shores formed during the stages of southern outflow. It should be noted, however, that on account of the favorable surface of the lake bed in North Dakota, consisting in large part of gently sloping till, they are more generally traceable there than on the Minnesota side of the Red River Valley, where some extensive tracts, having mostly a surface of silt with smaller areas of till, were traversed and cursorily examined without detecting distinct shore-lines. If they should be more thoroughly searched for on these tracts, with leveling along their known height, as shown by their nearest beaches observed elsewhere, doubtless some evidences of shore erosion or deposition would be found almost continuous, though their character and significance might not be otherwise recognizable with certainty; but it has been impracticable to give the time for field work that would be required to survey and map in this manner the exact course of these shores through their whole extent. It is believed that the portions which have been mapped with leveling, shown mostly on Pls. XXIII to XXXIII, inserted in Chapter VI, are sufficient to show reliably the successive stages in the concurrent uplifting of the land and subsidence of the lake.

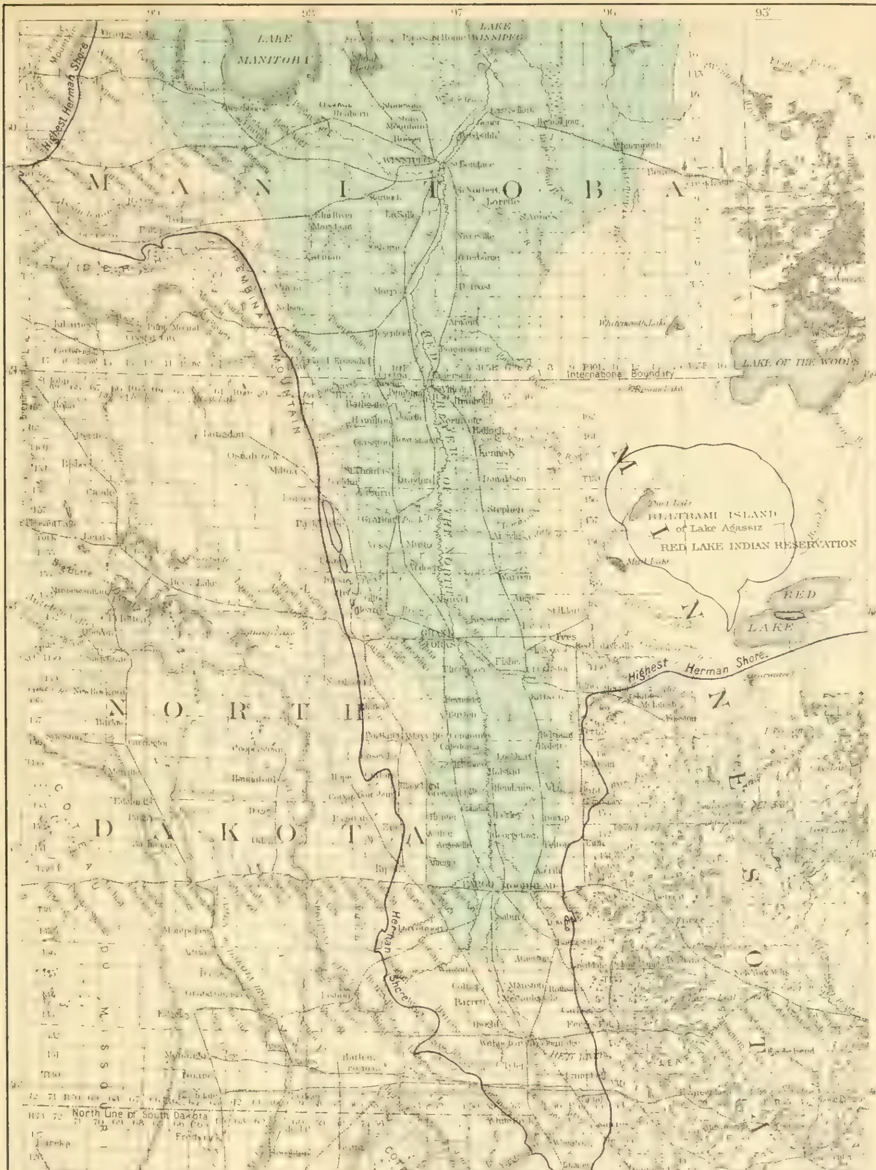
BEACHES OF THE BLANCHARD STAGES.

Three successive levels of Lake Agassiz, or pauses in the crustal uplift while the lake shore passed near Blanchard, N. Dak., seem to be indicated by sand and gravel deposits which are crossed by the Duluth and Manitoba Railroad 5 to 7 miles southeast of Euclid, Minn., and by the Manitoba and Northwestern Railway near Midway station, Manitoba. The lowest of these, however, has most definitely the form of a beach ridge, and the stage of the lake to which it belongs, mapped on Pl. XXXV, is the only one of the three which is generally marked plainly by a shore-line in Minnesota and North Dakota.

With the description of the Blanchard beaches in Minnesota, closely associated portions of the next lower or Hillsboro beach are also described near Glyndon and from 5 to 15 miles north of Crookston.

The principal and lowest Blanchard shore, having a height of about 925 feet, crosses the Red River close to Wolverton station, on the Great Northern Railway, almost exactly halfway between Wahpeton and Moorhead. Passing northward into Clay County, this shore is marked by a belt of gravel and sand thinly spread upon a broad, gently rising swell of till which is known as Pleasant Ridge, traceable in a nearly due-north course about 15 miles through the west parts of Alliance, Elmwood, and Glyndon townships. The South Branch of the Buffalo River flows nearly parallel with it, at a distance of a half mile to 1 mile farther east. Shore currents, carrying southward much of the gravel and sand derived from the shallow wave erosion of the till along the northern part of the ridge, deposited it in a rounded and partly almost flat tract a half mile to three-fourths of a mile wide in the northwest part of Alliance, having a height of 925 to 935 feet above the sea. Through Elmwood and Glyndon the beach deposits are narrow and scanty, lying on the western slope of Pleasant Ridge and along its crest. At Sabin they are bounded on the west by a typical beach slope, with its top at 930 feet, from which there is a descent of about 10 feet westward within 40 or 50 rods. In Glyndon the crest of the ridge is in part a sand and gravel beach, extending north through the centers of sections 32, 29, 20, and 17, declining slowly in height from 927 feet at the south to 922 feet at the north. Where the continuation of this line crosses the Northern Pacific Railroad the surface was a few feet below the Blanchard level of Lake Agassiz, and no beach was accumulated.

A few miles south of this railroad a scanty lower beach deposit was noted in sections 30 and 19, Glyndon, three-fourths of a mile west of the preceding, with its crest at 919 to 921 feet. This represents the Hillsboro stage of the lake, and, indeed, the formation of the main beach in this township, as just described, seems referable to the time of recession of the lake between the lower Blanchard and Hillsboro stages.



MAP OF THE SOUTHERN PORTION OF LAKE AGASSIZ, SHOWING ITS EXTENT IN THE LOWER BLANCHARD STAGE.

Scale, about 42 miles to an inch.

From Glyndon to the vicinity of Crookston the Blanchard shore is mapped approximately in accordance with the known elevations and slope of the land, but its beaches have not been examined.

About 5 miles northeast of Crookston, in the southern edge of section 3 and of the southwest quarter of section 2 in this township, a portion of the Hillsboro shore-line extending a mile from east to west bears a well-defined, rather wide beach ridge, which rises 5 to 15 feet above the adjoining surface of till, with crest mostly 936 to 940 feet above the sea. S. M. McKee's house is built on an exceptionally high part of this beach, at the elevation of 944 feet, the thickness of its sand and gravel there being 20 feet.

One and a half miles northeast from this beach deposit the lowest Blanchard shore in Parnell, the next township northward, bears a scarcely higher beach ridge of gravel and sand, which rises 5 to 10 feet above the adjacent till and extends northwestward across section 35, having an elevation at its crest of 935 to 940 feet. Thence the Blanchard shore runs due north or a few degrees west of north through Parnell and the next two townships. It is marked along the greater part of this distance of 18 miles by a definite beach ridge which varies in height from 938 to 946 feet. A half mile to a quarter of a mile west from this beach a lower and smaller gravel and sand ridge on the northward continuation of the Hillsboro shore, with crest at 930 to 932 feet, was observed along a distance of about 4 miles, passing nearly through the center of section 4, Parnell, and sections 33, 28, and 21, Belgium.

The profile of the Duluth and Manitoba Railroad on the south line of sections 35 and 34, Belgium, shows beach ridges of three Blanchard stages, with their crests at 962 feet, 954 feet, and 946 feet, in their order from east to west. Again, about 8 miles farther north two or three small beach ridges of gravel and sand, lying on the surface of till and separated by successive intervals of about a mile, were noted between the lower Blanchard and McCauleyville beaches. The Blanchard shore-lines on the east side of Lake Agassiz have not been traced farther northward, but they are known to lie close west of the McCauleyville shore in its north-northwestward course across Marshall and Kittson counties, Minn., to the international boundary.

In North Dakota the lowest Blanchard shore runs northwestward from the Red River for its first 35 miles, passing close west of Davenport and close east of Everest and Casselton, but it is not easily traceable across this area of lacustrine silt associated with the Sheyenne delta. Next it extends north about 40 miles, running a few miles east of Amenia, Arthur, and Hunter, and about $1\frac{1}{2}$ miles east of Greenfield and Blanchard. The height of this shore in the distance of 75 miles from the Red River to Blanchard, ascends from 925 to 935 feet, approximately, above the sea-level. It crosses the Goose River about 8 miles north of Blanchard, and thence runs several miles northeastward, beyond which it curves to the north, passing about 3 miles west of Cummings and 1 mile west of Buxton, where it is marked by a prominent beach ridge, with crest at 945 feet, very nearly. This gravel and sand ridge runs thence at least 15 miles northwestward. Near the southwest corner of section 7, Michigan, about 11 miles northwest from Buxton, its crest has an elevation of 942 to 945 feet. It there lies nearly 4 miles east of the principal McCauleyville beach, but within a few miles farther northwest the distance between them is diminished to less than 2 miles. Thence they continue close together and nearly parallel through their whole extent of about 80 miles northward in North Dakota; but this part of the Blanchard shore has not been followed with leveling.

The shores formed during the middle and upper Blanchard stages of Lake Agassiz have not been traced in North Dakota. Their elevations determined in Minnesota and Manitoba, however, indicate that Greenfield and Blanchard are situated on the middle shore or very near it. A single observation of the upper shore, which passes about 2 miles west of Blanchard, was obtained 7 miles farther north. It there is marked by a low escarpment of till, which descends 3 or 4 feet from west to east, between 965 and 960 feet, along a south-to-north line that is crossed by the railway about a mile north of Murray station.

On the international boundary the Blanchard shore-lines enter Manitoba in the west part of township 1, range 4, passing near Kronsfeld, in section 7 of this township, and extending north-northwest within about a mile east of Morden; but they are not marked along this distance by distinct beach deposits or lines of erosion. The lowest of these shore-lines crosses the Canadian Pacific Railway a mile west of McGregor, where it forms a slight swell on the gentle eastward slope of the Assiniboine delta. On the Manitoba and Northwestern Railway three Blanchard beaches appear to be identifiable, being crossed successively 2 miles and three-fourths of a mile west and 1 mile east of Midway. The upper two are nearly flat tracts of fine gravel and sand, an eighth to a quarter of a mile wide, at 994 and 979 feet above the sea, each being bordered on the west by a depression of about 2 feet and on the east by a gentle slope descending 4 or 5 feet. The third and lowest is a beach ridge of the usual form, about 30 rods wide, with a descent of 5 feet both to the east and west from its crest, which is at 969 feet. After crossing the McCauleyville beaches on the way from Arden to Gladstone the surface is wholly silt and sand, with fine gravel, very flat, excepting these slight ridges and others at lower levels. In their continuation northward, portions of the Blanchard beaches are noted on the plats of the Dominion Land Surveys through townships 15 to 20, range 13.

The highest of the Blanchard shores is probably represented on Mr. Tyrrell's map of the Riding and Duck mountains by two observations of beach ridges, namely, on the Ochre River, about 8 miles south of Lake Dauphin, at 1,025 feet above the sea; and on latitude 52°, close south of the Duck River, at 1,151 feet. A few miles north of the Duck River the second Blanchard beach, according to my correlation, is shown at the height of 1,135 feet; and the third and lowest beach formed during these stages appears to be represented on the north side of Swan River, nearly 25 miles farther west, by a beach approximately at 1,070 feet, being 100 feet higher than near Midway, on the latitude of Gladstone, about 160 miles distant to the south-southeast.

THE HILLSBORO BEACH.

My only observations of the shore-line in Minnesota which seems referable to the Hillsboro stage of Lake Agassiz, excepting as already noted with the descriptions of the Blanchard beaches, were in Alma and Wanger townships, Marshall County.

A somewhat broad beach ridge, 915 to 923 feet above the sea, consisting of gravel and sand on an area of till, extends from a cemetery in the northeast corner of section 26, Alma, northward through the east edge of sections 23 and 14 to the Middle River. This deposit, however, is about 15 feet lower than would seem accordant with the Hillsboro beach 5 to 15 miles north of Crookston and on the opposite side of the lake in North Dakota, while yet it is distinct from the next lower Emerado beach, which was observed at its normal elevation a mile distant to the west. The low position of the Hillsboro beach here may be due to its subdivision in advancing from south to north, this beach being referable to a secondary Hillsboro stage; otherwise it would imply a noteworthy and very exceptional irregularity in the crustal uplift.

Probably the same Hillsboro shore continues north through the distance of 6 miles to another beach ridge noted on the Tamarack River, in or near the west edge of sections 13 and 12, Wanger. A search with leveling to the south and north from these localities would quite surely prove this shore to be traceable through long distances on the east side of the lake.

The elevation of the Hillsboro shore where it crosses the Red River, near Holy Cross and Hickson stations, about 15 miles south of Moorhead and Fargo, is approximately 915 feet. Thence its course in North Dakota is first northwestward about 20 miles, passing by Horace, to Durbin, on the Maple River. It here lies on an area of fine silt, and is not distinctly marked either by a beach ridge or by erosion.

Along the northwest and north side of the Maple River, at an average distance from it decreasing from 2 miles to 1 mile, a prolonged beach of sand and fine silt (mapped on Pl. XXVIII) was formed by erosion from the margin of the Sheyenne delta and from the adjoining lake bed, and by transportation toward the northeast and east, being thus built out into the lake as a spit, during the Blanchard and Hillsboro stages. This spit, which is sometimes called the Maple Ridge from its parallelism with the Maple River, is crossed by the Great Northern Railway 2 miles northwest of Durbin. It is there a wave-like, massive swell about 50 rods wide, rising 10 feet above the flat expanse on each side, with its top 930 feet above the sea, showing that this portion was formed during the time of the Blanchard beach. Six miles to the northeast, where it is crossed by the Northern Pacific Railroad at Greene, it has a width of 60 rods, with its crest at 919 feet, from which its eastern slope descends 10 feet and its western slope about 5 feet. This part of the Maple Ridge was accumulated by Lake Agassiz at the stage of the Hillsboro beach, rising then only 2 or 3 feet above the level of the lake. Following the ridge onward 9 miles farther to the northeast and east, it is found to become broader and less definite, and its height sinks slowly about 20 feet to 900 or 895 feet in the south edge of section 13, Raymond, about a quarter of a mile north of the Maple River, where it ceases to be traceable even as a slight swell above the general level of the surrounding expanse of lacustrine and alluvial silt. Shore currents appear to have come together from both the north and south along this curved spit while the Blanchard and Hillsboro beaches were being accumulated and during the fall of the lake surface below each of these stages.

From the vicinity of Greene the Hillsboro shore-line runs northward 50 miles, passing about 3 miles west of Grandin and Kelso, 1½ miles west of Hillsboro, about three-fourths of a mile east of Cummings, and 1 mile west of Buxton. Opposite to Grandin and Kelso it is marked by a typical gravel and sand ridge, with slopes descending 10 feet on the east and 5 or 6 feet on the west to the adjoining surface of till. Mr. R. T. Kingman's house, west of Hillsboro and close south of the Goose River, is built on the crest of the Hillsboro beach ridge of gravel and sand, at an elevation of about 920 feet above the sea. The slopes of this beach fall about 15 feet toward the east and 5 feet westward. Within a quarter of a mile farther west, an escarpment of till rises 10 feet, from 915 to 925 feet, approximately, having been cut by the waves of the lake when it stood a few feet above its later level by which the beach ridge was deposited. One and a half miles south of Mr. Kingman's the Hillsboro shore has no beach deposit, being indicated only by an escarpment of till which rises 6 to 10 feet within a distance of 15 to 20 rods from east to west.

A slightly higher shore-line, marked by an escarpment 6 to 8 feet high, eroded in fine silt, was observed a mile west of each of these localities, being thus traced about 2 miles southward from the Goose River.

Three pauses in the crustal uplift are thus shown near Hillsboro by the former levels of Lake Agassiz, approximately at 925 or 928 feet, 920 feet, and 915 feet, represented successively by the western escarpment of silt, the eastern escarpment of till, and the shore deposit of sand and gravel at Mr. Kingman's house. Elsewhere these stages seem to be united, unless the lower one was also observed, as before noted, in Marshall County, Minn.

Where it is crossed by the Great Northern Railway, 2 miles south of Cummings, the Hillsboro shore is an eroded escarpment of till, ascending somewhat steeply 8 or 10 feet, with no considerable beach deposits. Continuing thence on the east side of the railway for 12 miles northward by Cummings and Buxton, it is marked through nearly the entire distance by a conspicuous beach ridge of gravel and sand, bordered on each side by till. The crest of this beach is 925 to 930 feet above the sea, with an average descent of 10 feet to the east and 5 feet to the west. At its next intersection by the railway, $1\frac{1}{2}$ miles south of Reynolds, the gravel and sand of the beach have been extensively excavated for railway ballast. The ridge there is about 30 rods wide; the elevation of its crest is 928 feet, and its slopes to the northeast and northwest fall respectively about 8 and 6 feet.

Through its further course of about 100 miles in North Dakota this shore-line runs to the northwest and north-northwest, excepting that it deviates to a north-northeastward course for 15 miles, between the North Branch of Park River and Tongue River, turning thus aside to pass by the Pembina delta. In section 27, Michigan, about 3 miles northwest of Reynolds, the crest of its beach ridge is 926 feet above the sea, having a descent of 6 feet eastward and 3 feet westward. In section 16 of this township the beach is a broad, flattened ridge of sand and fine gravel, about 40 rods wide, with top at 923 to 926 feet. It slowly rises 10 feet above the flat surface of till on the east, and descends 3 to 5 feet westward to a depression which is partly a grassy slough mown for hay. Through its next mile northwestward the shore is an escarpment of till, rising a few feet, with its crest at 923 feet.

No exact determination of the height of the Hillsboro shore was obtained along its next 25 miles to the southeast part of section 25, township 153, range 54, about 2 miles west of Beans station, on the Duluth and Manitoba Railroad, where the crest of its gravel and sand ridge is very nearly 930 feet above the sea. Again, about 20 miles farther north the beach ridge of this shore has the same height, or 930 to 935 feet, in sections 25, 24, and 13, Rushford. Thence through an extent of about 50 miles to the international boundary, although the course of the Hillsboro shore is mapped approximately on Pl. XXX, its height is known by leveling in only one place, near the center of section 15, Walhalla, about 2½ miles northeast of Walhalla village, where the top of the beach is 940 feet above the sea, rising 15 feet above its base 20 rods distant to the east and bordered by a depression of 2 to 5 feet on the west.

The Hillsboro beach enters Manitoba near the middle of the south side of range 4 and passes north-northwestward. It is not conspicuous on the international boundary, but near the west line of section 21, township 1, range 4, about a mile east of Blumenfeld, it is a noticeable ridge, with a descent of 3 to 5 feet on the east, its crest being about 940 feet above the sea. Its sand has there been excavated for use in plastering. Northward it passes about a half mile east of Oesterwick, 1½ miles east of Morden, and nearly 4 miles east of Miami, where Henry York's house is built on its crest, at an elevation of about 950 feet. Thence its slopes descend 15 feet in a short distance to the east and 5 feet or more to the west, the beach being much larger than along most of its course. Mr. York's cellar and well are in sand and fine gravel, but the lower land adjoining on each side is till. Twelve miles farther north this beach passes near Mr. Field's house, in the southeast quarter of section 4, township 7, range 6, about three-fourths of a mile west of Almasippi post-office. The road from Carman to Treherne there ascends a few feet, and in its next third of a mile northwestward crosses a tract of sand with hollows 3 to 5 feet below its highest portions, showing that it was formerly wind-blown. This beach deposit is derived from the erosion of the eastern margin of the Assiniboine delta, within a few miles to the north. On the road from Arden to Gladstone this beach was not noticed, but it seems to be traceable on the township plats northward nearly through the middle of townships 15, 16, and 17, and through the west part of townships 18, 19, and 20, in range 12.

On the Swan River and its tributaries, north of Duck Mountain, the Hillsboro beach, according to my correlation of Mr. Tyrrell's observations, has been traced fragmentarily along a distance of 20 miles from east to west, having an elevation of about 1,030 feet above the sea; and it was again noted at the height of 1,070 feet some 30 miles farther northeast, on Kettle Hill, close south of Swan Lake.

BEACHES OF THE EMERADO STAGES.

The Emerado shore-line, approximately 885 feet above the sea, crosses the Red River between Kragnes, Minn., and Harwood, N. Dak., a few miles north of Moorhead and Fargo; but its course has not been traced for the first 50 miles thence northward to the vicinity of Crookston, Minn., and Reynolds, N. Dak. Through both of these States it appears as a single shore-line, and is perhaps the one most clearly traceable of all that belong to the time of northeastward outflow. The crustal uplifting of this part of the lake basin had become very slow at the time of formation of the Emerado beach, but in Manitoba a somewhat rapid uplift was in progress, increasing in amount from south to north, and two beaches there, separated by a vertical interval of 10 to 20 feet, seem to represent the single beach farther south.

In the west part of sections 17, 8, and 5, Crookston, a beach ridge of the Emerado stage was traced 2 miles in a nearly due-north course. Harvey Cook's house, in the south edge of section 8, is built on its top, which ranges in height from 898 to 902 feet above the sea, having a descent of 10 or 12 feet on the west and half as much on the east. About a mile northwest from the north end of this beach irregular and short gravel and sand ridges, accumulated on an area of till, mark this shore on the Great Northern Railway, and extend thence close along its east side 2 miles northward to Shirley, the elevations of their crests being 905 to 910 feet. Portions of these deposits have been excavated for railway ballast.

From 1 to 2 miles north of Shirley the Emerado beach is a typical and continuous gravel ridge, with crest at 910 feet, approximately, rising about 5 feet above the adjoining surface of till. Here and through the next 3 miles northward the shore lies an eighth to a half of a mile east of the railway. It continues in a nearly due-north course through the west edge of Belgium and of township 153, range 46, passing 1½ miles east of

Euclid and 4 miles east of Angus. In the southeast part of Angus Township and the southwest part of township 153, range 46, its beach deposits of gravel are somewhat irregularly accumulated in three belts lying on an area of till and separated by intervals of about 1 mile and a half mile in order from east to west. The crests of these short gravel ridges vary in elevation from 900 to 905 feet, their higher portions being usually 3 to 5 feet above the surface on their east side and 6 to 8 feet above the land next west.

Twelve miles north of Angus a short beach ridge of gravel and sand, having nearly the same height with the foregoing, was noted on the east edge of section 15, McCrea, close south of a creek tributary to the Snake River. Again, 4 to 5 miles farther north, a broad, irregular sand beach, with crest at 905 feet, being 3 to 5 feet above the general level, runs along the east line of section 22, Alma. It reaches a mile or more south from the Middle River, and is a mile west of the Hillsboro beach. Its surface has been somewhat changed into small ridges and hollows by wind action at some former time, but it is now wholly covered by grass. Thence the Emerado shore runs nearly due north through Wanger and Augsburg, townships 157 and 158, range 47, as shown by their contour; but it has not been traced there nor in its farther course, which is slightly west of north through Kittson County to the international boundary.

In North Dakota the Emerado shore-line runs nearly along the Great Northern Railway by Harwood, Argusville, Gardner, and Grandin, and within 1 to 1½ miles east of Kelso, Alton, and Hillsboro; but most of its course is not distinctly traceable on the flat surface of fine silt which is crossed in this distance of 30 miles. Through the next three townships north of Hillsboro, passing Cummings and Buxton, it lies 1½ to 2 miles east of the railway, but approaches within about 1 mile at Reynolds. The Emerado shore here traverses a large area of till, which reaches eastward across the Red River Valley. On this more favorable surface it is doubtless clearly marked, like the next higher Hillsboro shore, by a well-defined beach ridge, or in part by a low, eroded escarpment.

The railway intersects this beach ridge 1½ miles north of Reynolds, its crest being about 900 feet above the sea, with descent of 3 or 4 feet to the southwest and 8 or 10 feet to the northeast. Thence the Emerado shore runs north-northwesterly 70 miles through Grand Forks and Walsh counties. In sections 20 and 17, Allendale, 9 to 10 miles northwest of Reynolds, it bears an excellent gravel ridge, which rises 10 feet from its northeast base and 3 to 5 feet above the surface on the southwest, the land on both sides being till. The elevation of its crest is 898 to 902 feet.

At Emerado, on the Devils Lake line of the Great Northern Railway, this beach is crossed less than a quarter of a mile east of the station. Its crest is 894 feet above the sea, being 10 feet above the adjacent surface of till on the east; but within the next mile, both to the southeast and northwest, its height is mostly 895 to 900 feet. Two to 3 miles northwest, in section 26, Mekinock, the crest of the beach lies at 897 to 900 feet, with a descent of 5 to 8 feet eastward and half as much toward the west.

In sections 33, 32, and 29, Gilby, the Emerado beach ridge is magnificently developed, passing close west of Beans station, on the Duluth and Manitoba Railroad. The top of the beach has an elevation of 898 to 902 feet, with descents of about 10 feet in 15 or 20 rods east and 3 to 5 feet within 10 rods west to very flat expanses of till on each side. Again, in sections 19 and 18, Gilby, it has the same character and elevation; but in the northwest part of section 7 and on the west line of this township, also thence northward 3 miles into section 25, Strabane, there is no beach deposit, its place being taken by an escarpment of till, 6 to 8 feet high, with its top at 900 to 902 feet. Northward from the northwest part of this section 25, Strabane, the Emerado shore is again marked by the usual ridged deposit of gravel and sand, with its crest very level, varying not more than a foot above or below 901 feet in its extent of about 3 miles to the Forest River.

Entering Walsh County, the crest of this beach ridge in sections 35 and 34, Ops, is still 901 feet above the sea, with descent thence of 6 or 7 feet in 6 rods northeastward and 4 feet in the same distance to the southwest. Through sections 27, 22, 16, 9, and 4, Ops, it also holds very constantly the same character and height, 900 to 902 feet, being a typical ridge of sand and gravel, lying on till. In the east half of section 29, Prairie Center, its elevation is 903 feet, and it continues as a well-defined gravel ridge, with crest at 901 to 903 feet, through this township, and at a slightly greater height, 902 to 906 feet, through the west part of Fertile and the east part of Dundee, crossing the South and Middle branches of Park River.

In the southern part of Pembina County the Emerado shore curves to a north-northeast course, passing by Crystal to Willow Creek, and thence runs nearly north, crossing the Tongue River about a mile west of Cavalier. Along a distance of 6 miles north from Willow Creek a low and broad secondary beach ridge, or more likely in part an offshore sand deposit that was formed a few feet beneath the lake surface, has an elevation of 890 to 895 feet, with slopes sinking a few feet below this on each side. The adjoining surface is lacustrine silt, deposited in front of the Pembina delta, and the ridge is fine sand which has been somewhat gullied and hummocked by the wind, but is now all grassed.

Between the Tongue and Pembina rivers and onward to the international boundary this beach takes a northwestward course. Turning to that direction about 2 miles northwest of Cavalier, it thence runs nearly straight 10 miles to St. Joseph, being through the greater part of the distance a typical beach ridge of sand, with scanty layers of very fine gravel. Its crest is mainly 892 to 898 feet above the sea, having a gradual ascent from south to north; but as it approaches St. Joseph and the Pembina River its last 2 miles rise to 900 and even 905 feet. The slopes fall commonly 5 to 10 feet northeastward and 2 to 4 feet southwestward. The depth of the beach deposit is the same as the fall of its eastern slope, with hard and dark stratified clay beneath. In section 2, and again in section 13, township 162, range 55, lying 2 to 5 miles southeast of St. Joseph, this beach widens into sandy tracts, each of which has a width of a quarter of a mile or more and is slightly raised, like the typical narrower ridge, above the adjacent surface of clayey lacustrine and alluvial silt.

About a mile north of the Pembina River the Emerado level of Lake Agassiz formed a low escarpment of erosion, which passes north-northwesterly by the northeast corner of section 17, township 163, range 55. Within

40 rods or less from west to east it descends about 10 feet, from 905 to 895 feet above the sea, approximately.

The Emerado beach crosses the international boundary about $1\frac{1}{2}$ miles east of the west line of range 3, Manitoba, passing thence northwestward. In townships 1 and 2, range 4, the Mennonite villages of Rheinland, Neuenburg, and Rosenthal are partly built on it. At the windmill in Rheinland, and thence along its course as seen for a half mile or more to the south-southeast and north-northwest, this shore is marked by an ascent of 3 to 6 feet in as many rods from east to west; and from its crest, about 905 feet above the sea, the surface extends nearly level westward. The beach consists of loamy sand, while the adjoining land is fine lacustrine silt or clay. On the Canadian Pacific Railway this beach is raised a few feet above the general slope of the Assiniboine delta, passing in a west-northwest course 2 miles east and 1 mile north of Bagot. The Manitoba and Northwestern Railway crosses it 5 miles west of Gladstone, where it is a ridge about 30 rods wide, wind-blown in hollows 1 to 2 feet below the crest, which is 927 to 929 feet above the sea, with descent of 5 feet from it to the west and 12 to 15 feet to the east. A lower and less conspicuous beach ridge, also belonging to this stage, lies three-fourths of a mile farther east, with its crest at 916 feet. The Emerado beach continues north through the east part of townships 15 to 19, range 12, and through the center of township 20, to the east side of Lake Mary.

Two Emerado stages are again noted by Mr. Tyrrell, according to my correlation, at the heights of 1,015 and 995 feet above the sea, as shown by beaches on Kettle Hill, about 150 miles north of Gladstone. The upper beach has an ascent of 95 feet in this distance, and the lower, 85 feet, approximately.

The lower of these shores, which is the more strongly marked on Kettle Hill, is probably also shown by a beach ridge mentioned by Tyrrell near the Pine River, some 40 miles farther south, at a height of 960 feet above the sea, as determined by the original location of the Canadian Pacific Railway.

BEACHES OF THE OJATA STAGES.

The upper Ojata shore-line has an elevation between 870 and 875 feet above the sea where it crosses the Red River near Perley, Minn., and Noble, N. Dak., about 20 miles north of Moorhead and Fargo. Its course in Minnesota has been mapped approximately for 25 miles through Norman County, lying from 2 to 6 miles east of the river, according to the contour shown by the Drainage Survey; but it is not known how much of the shore is there marked by any beach ridge or line of erosion. Probably a considerable part is thus definitely traceable, especially northward, where the surface is till.

After curving eastward, near the boundary between Norman and Polk counties, to a distance of 10 miles from the Red River, this shore turns to the north and north-northwest, crossing the east part of the great marsh which is formed by the waters of the Sand Hill River and of many springs. In the northeastern edge of this marsh it bears a conspicuous beach ridge, which runs from near the center of section 10, township 147, range 47, 6 miles to the north side of section 18, Hammond. The crest of the dry ridge of sand and gravel is 873 to 878 feet above the sea, and the surface of the marsh adjoining it is about 3 feet lower on the east and 5 feet lower on the west.

About 2 miles northwest from Crookston a large beach deposit of gravel and sand on this shore-line is crossed by the Great Northern Railway in sections 24 and 23, Lowell, and has been much excavated for railway ballast. The elevation of its crest is 880 to 882 feet, and its thickness is 3 to 5 feet, lying on till. The pebbles of the gravel seldom exceed 3 inches in diameter, and are mostly magnesian limestone, similar to the strata which outcrop near Winnipeg.

The Drainage Survey shows that the farther course of this shore is nearly due north for the next 40 miles, passing about 2 miles west of Shirley, a mile west of Euclid, 1½ miles east of Angus, about 3 miles east of Warren, and 5 miles east of Argyle. Through the greater part of this extent it lies on or near the western edge of the till, which is succeeded toward the Red River by lacustrine and alluvial silt. In a few places the shore is known to be indicated by erosion or by gravel and sand deposits, but more commonly it is not clearly traceable. It thence runs slightly west of north to the international boundary, but has not been examined along that distance of nearly 50 miles.

Lying about 10 feet below the preceding, the lower Ojata shore crosses the Red River near Caledonia and the mouths of the Goose and Marsh rivers, being there about 865 feet above the sea. From 5 to 12 miles northward in Minnesota it runs along the west margin of the great marsh of the Sand Hill River. Onward through this State it must lie mostly 1 to 2 miles west of the upper Ojata beach, though generally it is indistinct and its course has been nowhere exactly noted.

Portions of the Ojata beaches in North Dakota have come under my observation from the vicinity of Reynolds and Thompson north-northwestward across Grand Forks and Walsh counties. The upper shore is not clearly exhibited where it is crossed by the Great Northern Railway, about 2 miles south of Thompson, but the lower shore is marked by a beach ridge of gravel and sand, which is crossed 1 mile north of this station. The crest is about 868 feet above the sea, with descent of 6 to 8 feet from it toward the northeast and 2 or 3 feet southwestward.

On the south line of section 36, Oakville, and of section 31, Brenna, 7 to 8 miles northwest from Thompson and 5 miles south of Ojata,[1] the heights of the crests of the well-developed upper and lower Ojata beaches are respectively about 880 feet and 872 to 875 feet. One to 2 miles southeastward, however, these shore-lines have neither beach deposits nor any notable erosion on the smooth, gently sloping surface of till.

The Great Northern Railway between Emerado and Ojata intersects the crest of the upper Ojata shore-line a quarter of a mile west of the northeast corner of section 8, Oakville, about 3 miles west of Ojata. It consists of a somewhat prominent escarpment of till, which falls from west to east at first 7 or 8 feet within 15 or 20 rods, and as much more within the next third of a mile, its base being 862 to 865 feet above the sea, whence

[1] Meaning *forks* in the Dakota or Sioux language, and referring, like Grand Forks, to the junction of the Red and Red Lake rivers (A. W. Williamson, in Thirteenth Annual Report, Geol. and Nat. Hist. Survey of Minnesota, for 1884, p. 110).

a very flat and almost level surface of till, with alkaline soil, extends eastward. The top of the escarpment is capped to the depth of a few feet with beach gravel and sand, at 877 and 880 feet, deposited during the upper Ojata stage of the lake, and the erosion of the steep slope below may have been accomplished mostly during a lower and later portion of this stage. A better interpretation, however, seems to be found in attributing the upper gravel to the highest fluctuation of the lake when raised several feet by the rapid glacial melting in the summer, the till below having been cut away by the reduced water level in the winters, when it was lashed into powerful waves by storms.

But a large share of the erosion of the less steep lower slope was done by the lake during the lower Ojata stage. In the latest and lowest portion of that stage there was also formed a discontinuous beach ridge of gravel and sand, which lies in isolated, irregular accumulations a half mile east of the escarpment, and rises 6 to 8 feet above the flat expanse on each side, with crests at 870 feet, approximately. This fragmentary beach divides a tract of till on the west which has suffered much erosion of its surface, being therefore strewn with frequent or abundant bowlders, from another tract on the east, where the upper part of the till to the depth of 5 to 10 feet or more, still lying as it was deposited in Lake Agassiz, bears marks of imperfect stratification, and has fewer bowlders and less gravel on the surface than at a slight depth. Within 10 to 15 feet beneath the surface, as shown by wells and the ravines of streams in the neighborhood of Ojata, the lacustrinely modified till, which was englacial, is succeeded below by the wholly unstratified ground moraine. It is also to be noted that a thin layer of lacustrine clayey sand and fine silt, doubtless derived chiefly from the erosion of the escarpment on the west, is spread with a thickness varying from a few inches to a few feet on much of the surface eastward from the lower Ojata beach.

Ten to 15 miles northwest of Ojata the upper one of these two shorelines is well-marked in Gilby by a typical beach ridge of gravel and sand, lying on or near the eastern limit of the till, beyond which lacustrine and alluvial silt stretch east to the Red River. Mr. John Gilby's house, in the southwest quarter of section 22, is built on the gravel beach, which thence runs north-northwestward through the middle of section 9, a half mile east of Gilby station, on the Duluth and Manitoba Railroad. The lower Ojata shore lies about a mile farther east, but was not examined. The upper shore extends from section 4, Gilby, into the southwest quarter of section 33, Milan, being there an escarpment 5 feet high, eroded on an area of fine silt. Its base and crest are approximately 870 and 875 feet above the sea. This shore passes about a mile west of Johnstown, and the lower shore lies close east of that railroad station.

A conspicuous beach ridge of gravel and sand, running nearly along the boundary between till on the west and silt on all the country eastward, extends from the west half of section 36, in an almost straight course, a few degrees west of north, 5 miles to the northwest corner of section 2, Ops, having an elevation at its crest of 875 to 880 feet, with descent of 5 to 10 feet east and 2 to 5 feet west. A mile farther east a smaller ridge, about 10 feet lower, marks the second Ojata shore. Through the remaining 50 miles of its course northward to the international boundary the upper shore-line is mapped approximately on Pl. XXX, conforming with the eastward descent of the land surface. It will probably be found easily traceable if followed by leveling.

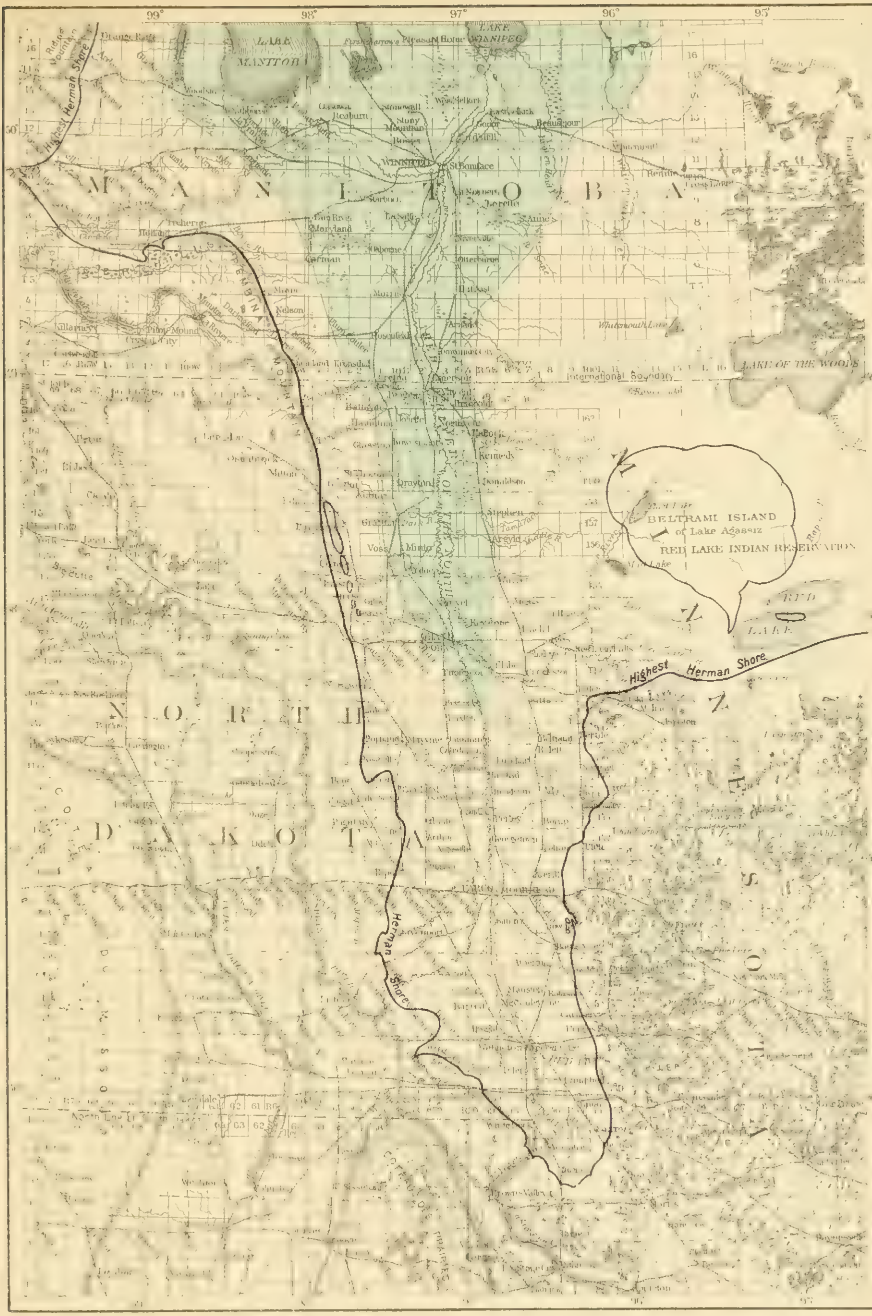
Along the course of the Ojata shores, lying between the Emerado and Gladstone beaches, no ridge of gravel and sand nor line of erosion was observed where they were crossed on the international boundary and elsewhere during my exploration in Manitoba, excepting a slight beach ridge, 3 to 5 feet high, which runs from Pomeroy, in section 19, township 5, range 4, north-northwest through the east part of township 6, range 5, passing about 2 miles west of Carman.

Mr. Tyrrell notes the lower Ojata beach on Kettle Hill, if my correlation is true, at the elevation of 955 feet above the sea.

THE GLADSTONE BEACH.

The extent of the southern part of Lake Agassiz at the time of formation of the Gladstone beach is shown approximately on Pl. XXXVI.

Crossing the Red River near Belmont, N. Dak., about 20 miles south of Grand Forks, at a height approximately 845 feet above the sea, the



JULIUS BIEN & CO. N.Y.

MAP OF THE SOUTHERN PORTION OF LAKE AGASSIZ, SHOWING ITS EXTENT IN THE GLADSTONE STAGE.

Scale, about 42 miles to an inch.

Gladstone shore-line runs northward through Minnesota, mostly at a distance of about 15 miles east of the Red River. It crosses the Red Lake River near the head of the Grand Marais, about a mile northwest of Fisher.

Thence northward for a distance of more than 25 miles to Warren there is frequently found along the contour line of 840 feet a somewhat more rapid descent from east to west than on the adjoining surface of fine clayey silt at each side. This may be due mainly to erosion by the waves of great storms, especially when the lake surface was lowered a few feet on account of the diminished rate of melting of the ice-sheet during winters. In part, however, there appears to have been formed along this course an offshore deposit several feet thick, rising nearly to the lake level. Such a broad ridge, with crest at 838 to 841 feet, runs northward through the center of section 15 and the west half of section 10, Tabor, having a descent of 1 to 3 feet eastward and of 3 to 5 feet westward within a third of a mile from its top. Wells on this swell obtain good water at the depth of 10 to 12 feet, in layers of sand from a quarter of an inch to 1 foot thick, inclosed in the fine stratified silt which, excepting these sandy beds, is almost impervious to water.

In the northern part of Kittson County the old St. Paul trail, lying 12 to 14 miles east of the Red River, ran for 6 miles south-southeastward from the international boundary on and near to the Gladstone beach, whose crest there has a height of 858 to 863 feet above the sea. It is a ridge of gravel and sand 10 to 30 rods wide, resting on till, to which its eastern slope falls 2 to 3 feet and its western slope 5 to 8 feet.

Through North Dakota the Gladstone shore has been mapped approximately, passing from Belmont north-northwesterly by Merrifield, Kelleys, and Voss, lying about 4 miles west of Grafton, 2 to 3 miles west of Auburn, St. Thomas, and Glasston, about 4 miles west of Hamilton and Bathgate, and 5 miles west of Neche. In this distance of 100 miles the shore rises from 845 to 857 feet, approximately, above the sea. Only small portions of its course have been examined, these near Merrifield and 2 miles east of Ojata being marked by slight erosion in the lacustrine and alluvial silt over which it asses.

On the international boundary and for several miles thence to the north-northwest the Gladstone beach is a prominent ridge, having an ascent of 10 to 15 feet in a distance of 30 to 50 rods west from its base to its crest, which is approximately 860 feet above the sea. The slightly undulating surface of this shore deposit occupies a width of a quarter of a mile or more, and thence westward there is no noteworthy descent, but a nearly level expanse. In many shallow pits dug to obtain sand for masons' use the material of the beach is shown to be fine sand, unmixed with gravel, excepting that very rarely a pebble is found inclosed in it, the largest being a half to two-thirds of an inch in diameter. This ridge enters Manitoba about 1½ miles west of Blumenort, and crosses sections 5, 7, and 18, township 1, range 2, to Kronsthal, which is situated upon it. Northward it passes about a mile west of Lowestoft post-office and a mile east of Carman. George Anderson's house is built on its crest in the northeast quarter of section 31, township 6, range 4, 2 miles north-northeast of Carman, at an elevation of 865 feet. It crosses the Canadian Pacific Railway near the Rat Creek bridge, and is well developed along a distance of several miles thence to the northwest, passing through the southeast corner of section 12, township 12, range 9, where the elevation of its crest is about 875 feet, with a descent of 4 to 6 feet to the northeast and 1 to 3 feet to the southwest. Thence its course is along the southwest side of the Squirrel Creek marsh and east of the chain of Dead Lakes (a former channel of the White Mud River), which lie in sections 17, 18, and 19, township 14, range 11. A half mile east of Gladstone this shore is marked by a line of erosion in the expanse of lacustrine silt, with slope from 882 to 875 feet in a short distance, and by a small beach ridge of sand with its crest at 878 feet. Continuing almost due north, this Gladstone shore-line, occasionally marked by beach gravel and sand, lies a half mile to 1 mile west of the Big Grass Marsh, through townships 15, 16, and 17, range 11, the elevation of the marsh being, approximately, 865 feet, and of Lake Agassiz here during this stage about 875 feet above the present sea-level.

The Gladstone beach is noted by Mr. Tyrrell on Kettle Hill at 920 feet. Combined differential uplifting of the land and depression of the geoid surface of level, both due to removal of the ice-sheet, have amounted to about 45 feet in the distance of 150 miles northward from Gladstone to this locality.

THE BURNSIDE BEACH.

From its crossing of the Red River at Grand Forks the Burnside shore in Minnesota runs northeastward to the southwest corner of Tabor Township, and thence northward at a distance of 10 to 13 miles from the river for about 70 miles to the south line of Manitoba. Although its course is known approximately by the Drainage Survey and by railway leveling, no portions of it distinctly showing marks of erosion or beach accumulation have been observed in this State excepting close upon the international boundary. There it is found at "the Ridge," about 11 miles east of the Red River and Emerson, which is a low, eroded escarpment extending from south to north across the boundary. It consists of till with frequent bowlders, nearly all Archean granites, gneiss, and schists. A deposit of beach gravel and sand a few feet deep rests on the base of this slope, 835 to 840 feet above the sea.

Two miles northward, in the southwest quarter of section 15, township 1, range 4 east, Manitoba, the Burnside beach is a typical gravel and sand ridge 20 to 25 rods wide; its crest is 845 feet above the sea, and the descent from it to the east is about 3 feet and to the west 6 or 7 feet. About a mile farther north, near the southeast corner of section 21, the elevation of this beach ridge is 844 feet, with a descent of 1 or 2 feet on the east and 10 feet within 20 rods on the west. Another mile to the north its elevation is 846 feet, with 2 feet descent east and 6 feet west in 6 rods; next a surface of till, with many bowlders, falls about 5 feet in 40 rods to the west; beyond this a tract of gravel and sand continues with the same slope, falling from 835 to 830 feet, and is succeeded farther west by a slowly descending surface of till. The beach ridge continues with similar features through the east half of section 28, excepting a short distance in the southeast quarter of this section, where it is replaced by a line of erosion in the very rocky till. Through the next 3 miles the uneven contour causes the beach ridge to be somewhat irregular in its course and size; but it again attains its typical development in section 9, township 2, range

4 east, where it was excavated several years ago along a distance of a third of a mile for railway ballast, a branch track nearly 8 miles long being laid for its transportation to Dominion City. The crest of the beach at Charles Aime's house, near the north end of this excavation, is 846 to 847 feet above the sea, with a descent of 2 to 5 feet on the east and 6 to 8 feet in 8 to 12 rods west. Its width, including both slopes, is 15 to 30 rods, and the maximum depth of the gravel and sand deposit is about 8 feet, lying on till. The coarser portions of the gravel contain pebbles up to 3 inches or rarely 6 inches or more in diameter. Nine-tenths or a larger proportion of them are magnesian limestone, the remainder being almost wholly Archean granite and gneiss. This shore-line continues north and north-northeast by Green Ridge post-office and through the east part of townships 3 and 4, range 4 east, beyond which it has not been traced.

In North Dakota the course of the Burnside shore is known somewhat nearly and has been drawn provisionally on Pls. XXIX and XXX, in accordance with the elevations ascertained by railway surveys; but, as in Minnesota, no part of it has been observed to be clearly traceable by either a continuous beach ridge or an eroded escarpment. It lies on the wide, flat tract of silt which adjoins the Red River, a surface most unfavorable for the preservation of definite shore-lines; yet undoubtedly it can be found and followed by careful search with leveling.

A few feet below the average Burnside level of Lake Agassiz marks of wave action, perhaps belonging to the lowest fluctuations of the lake in this stage, are somewhat indistinctly exhibited by an irregularly ridged contour which was seen near Schurmeier and along the east side of the railway thence northwestward to Manvel, also in the west edge of Manvel village. These swells, extending parallel with the railway, rise 2 to 3 feet above the depressions on either side, their crests being 820 to 825 feet above the sea. Proceeding northwest along the railway, which holds a nearly level grade, no further noteworthy observations of this kind were obtained for the next 12 miles to Ardoch, where again a beach-like swell or very low ridge, 2 to 3 feet high and having a width of 30 rods or more, with crest at 826 to 827 feet, runs from south to north across the railway about an eighth of a mile north of the station.

This western Burnside shore enters Manitoba near Blumenort, 19 miles west of the Red River, but it is not distinctly marked on the international boundary. Passing northward about a mile east of Lowestoft and 3 miles east of Carman, it crosses the Carman Branch of the Manitoba and Southwestern Railway at Maryland, where the elevation of the crest of its beach ridge is 844 feet. About a mile north-northwest of Maryland this ridge has been extensively excavated, its gravel and sand being used for railway ballast. One and a half miles farther north it crosses the main line of this railway about a mile west of Elm Creek station (the junction of the branch), its crest there being at 845 feet, from which its slopes fall 10 feet in 25 rods east and 7 feet in an equal distance west.

The Canadian Pacific Railway crosses this shore about halfway between Portage la Prairie and Burnside, and in the next 10 miles of its course, passing northwest nearly through the center of township 12, range 8, it is marked by a large gravel ridge, the crest of which, in the south part of section 11, $1\frac{1}{2}$ to 2 miles north of Burnside, has an elevation of 858 to 860 feet, with descent from it of 6 to 10 feet northeastward and half as much to the southwest. This beach is similarly prominent on the Manitoba and Northwestern Railway, by which it is crossed and excavated for ballast halfway between Westbourne and Woodside, its crest there being 860 to 862 feet above the sea. Along the next 40 miles the Burnside shore-line is generally marked by a well-developed beach ridge which is traceable on the plats of the Dominion Land Surveys parallel with the west shore of Lake Manitoba and 4 to 5 miles distant from it, passing about halfway between the lake and the Big Grass Marsh. It thus lies near the line between ranges 9 and 10 as far north as to the east side of the lake in sections 13 and 24, township 18, range 10, beyond which it runs north-northwest.

Between the south ends of Lakes Manitoba and Winnipeg the country about Shoal Lake was uncovered by the fall of Lake Agassiz from the Gladstone to the Burnside beach, which latter is crossed by the Winnipeg and Hudson Bay Railway near the southwest corner of section 36, township 14, range 2, about 3 miles south of Shoal Lake. The crest of the beach is 860 feet above the sea, being 10 feet above Shoal Lake. Here its course is from west to east along the verge of a nearly level expanse of till reaching to the lake, to which its drainage is tributary. Two or 3 miles farther east, where the road to Stonewall and Winnipeg crosses this beach, it has a descent of 20 feet in 30 or 40 rods south from its crest, the whole slope being gravel and sand, the combined shore deposits of the Burnside and Ossowa stages of Lake Agassiz. Westward the beaches of these stages are separated by a width of 1 to 2 miles, the Burnside beach running southwest and west through the south half of township 14, range 3. Near the west side of this township it curves northward, and thence passes north and north-northwest between Shoal and Manitoba lakes. East of the road before mentioned the course of this beach is northeastward across township 15, range 1 east, and township 16, range 2 east, to Pleasant Home post-office. Numerous short beach ridges noted on the township plats northwest of this beach, between it and Shoal Lake, were probably formed during the Gladstone stage of Lake Agassiz where the highest parts of that area rose above its level.

Passing over the eastern Mossy portage from Lake Winnipegosis to Cedar Lake, on the Saskatchewan, Mr. Tyrrell found that the highest land crossed is a gravel ridge with crest 921 feet above the sea, being 93 feet above the first of these lakes. It probably is a beach belonging to a level of Lake Agassiz near 910 feet, the same stage that formed the Burnside shore-line farther south. This locality is about 70 miles northeast of Kettle Hill, and the continuation of the Gladstone beach with the gradient which it has from Gladstone to Kettle Hill would carry it at Mossy portage 35 or 40 feet above the Burnside level there.

THE OSSOWA BEACH.

Lake Agassiz at the time of the Ossowa beach extended into the United States nearly 60 miles, but the only part of this shore which has been recognized and examined south of the international boundary is an extent of a few miles in Pembina County, N. Dak. In sections 21, 16, and 17, township 162, range 52, close south of the Tongue River, at a distance of 4 miles northeast from Hamilton, two or three parallel low, beach-like ridges were observed, elevated 2 to 4 feet above the intervening hollows and general surface, their height being between 815 and 820 feet above the sea. They run from southeast to northwest, and their continuation north of this river was noted at the same height 4 to 6 miles northwestward in sections 36 and 25, Neche, about $2\frac{1}{2}$ miles east-northeast from Bathgate. Both the ridges and the adjoining surface are fine silt.

Ossowa post-office, from which the shore-line takes its name, is situated near the middle of the north half of section 27, township 13, range 4, Manitoba, on a well-defined beach ridge which runs from west-southwest to east-northeast through this township. Its crest varies in elevation from 843 to 848 feet, with descent of 3 to 8 feet on its north side and 12 to 15 feet on the south. The Canadian Pacific Railway was originally constructed from Stonewall due west to this beach, which it cut through in the east edge of section 28. In the railway cut its material is wholly gravel, in part very coarse, containing pebbles and subangular rock fragments up to 4 inches and rarely 6 or 8 inches in diameter, of which fully nineteen-twentieths are magnesian limestone. On each side the surface is till, with plentiful bowlders, mostly Archean granite and gneiss, but including many of this limestone, which is the underlying rock of the region. In the north part of township 13, range 3, this beach curves to the south, east, and northeast, and thence passes through the southeast part of township 14, range 3, and the north half of township 14, range 2, gradually approaching and in some places joining the Burnside beach, with which the Ossowa beach is approximately parallel, lying a half mile to 1 or 2 miles southeast of it onward to Pleasant Home.

The only other locality where a beach referable to this stage was observed is on the top of Stony Mountain, on which a broad, smoothly rounded ridge of gravel and sand extends nearly a quarter of a mile, and is the site of some of the penitentiary buildings. Its crest is about 835 feet above the sea, and the top of the underlying limestone about 825 feet.

The western Ossowa shore-line crosses the international boundary 3 or 4 miles east of Gretna, and the eastern enters Minnesota about three-quarters of a mile west of "the Ridge," but they are not there marked by noteworthy beach deposits nor erosion.

North of Lake Winnipegosis, the Ossowa shore on the ascent of the eastern Mossy portage, as described by Mr. Tyrrell, takes the form of an escarpment, with its crest 63 feet above this lake, or 891 feet above the sea. It was probably eroded by the waves of Lake Agassiz when its surface there was approximately at 875 feet, midway between its Burnside and Stonewall levels at this locality.

THE STONEWALL BEACH.

In the town of Stonewall, Manitoba, the main street crosses a conspicuous beach ridge which runs from south-southwest to north-northeast a third of a mile or more. Its crest is 820 to 825 feet above the sea, and its depth is about 10 feet. Only 2 or 3 feet of till intervene between this gravel and sand and the underlying limestone, which, thinly covered by drift, rises in a swell here about 25 feet above the adjoining country a half mile distant to the east and west. Beach deposits belonging to this stage were not elsewhere observed in southern Manitoba, but they are doubtless traceable from Stonewall northward through the west half of townships 14 and 15, range 2 east. Lake Agassiz, at the time of the Stonewall beach, probably extended on the flat Red River Valley to a distance of about 25 miles south of the international boundary, being some 15 feet deep at Emerson, St. Vincent, and Pembina, while over the site of Winnipeg its depth was about 60 feet.

A somewhat ridged contour upon the otherwise very flat surface of fine alluvial silt was noted 6 to 7 miles east of Hamilton and Bathgate, N. Dak. The wave-like and almost beach-like undulations, rising 2 to 4 feet above the depressions which separate them and above the general level, run north-northwesterly through the east part of section 11 and the central part of section 2, township 162, range 52, close southeast of the Tongue River. Similar contour was also noticed in the continuation of this course within a few miles northward between the Tongue and Pembina rivers. The height of this belt is about 805 feet above the sea.

On the eastern Mossy portage the crest of the Stonewall beach, as observed by Mr. Tyrrell, is 27 feet above Lake Winnipegosis, or 855 feet above the sea, being probably 10 feet higher than the level of Lake Agassiz there when the beach was accumulated. Again, on the line of the tramway at the Grand Rapids of the Saskatchewan, the same beach is found by Mr. Tyrrell at the elevation of 850 feet; and he states that it is also well seen at Point Brabant and other places along the east side of Lake Winnipegosis, and that it probably is represented by the ridge in the grove behind Manitoba House, which is situated on the west shore of Lake Manitoba, close south of the Narrows.

BEACHES OF THE NIVERVILLE STAGES.

The road on the east side of the Red River between Winnipeg and Emerson crosses a beach ridge about a half mile southeast of Niverville. It has a width of 15 rods, and its crest, 777 to 778 feet above the sea, is raised about 4 feet above the adjoining surface of lacustrine silt on each side. Beginning near Niverville station, it extends southeasterly at least a mile. Another beach ridge of similar size, with its crest at 780 feet, is crossed by this road a third of a mile farther south. This also runs southeast, holding its ridged form a mile or more, beyond which it is less distinct. Again, a few miles to the south from these, a beach ridge extends along this road in a nearly due-south course across the southeast quarter of section 17 and the east half of sections 8 and 5, township 7, range 4 east. It rises 2 to 4 feet above the land adjoining on each side, which is partly sloughs, with water throughout the year, the elevation of the beach crest being 782 to 784 feet. Other beach deposits at nearly the same elevation occur a mile southwest of Otterburne; a few miles farther to the south in the northeast part of township 5, range 3 east; and about a mile east of the Red River, opposite to Morris. At the last-named locality they are excavated for masons' sand. From the southern end of Lake Agassiz in this stage, near Morris, Manitoba, its western shore extended north and northwest to the vicinity of Starbuck, thence north and northeast to Little Stony Mountain, 5 miles northwest of Winnipeg, and thence nearly due north, passing between Stonewall and Stony Mountain and onward along the west side of Lake Winnipeg, at a distance of a few miles from it. Gravelly and sandy deposits at the base of Stony Mountain on its north and south sides are attributable to erosion by the lake, there only a few feet deep, at the time of formation of the Niverville beach. Its level was 15 to 20 feet above the surface where the city of Winnipeg is built.

Numerous observations of the Niverville beach have been made by Mr. Tyrrell on the shores and islands of Lake Winnipeg. Its occurrence on Black Island, about 150 miles north of the international boundary, is described by him as follows, excepting that his later determination of the height of the beach as 60 feet above Lake Winnipeg is substituted instead of his previous estimate, which was 20 feet lower:

> At Ox Head, near the northeastern extremity of Black Island, an ancient beach is very conspicuous at about 60 feet above the water. On the south side of the island the beach is marked by a line of sand dunes, and on the north side a sandy terrace rises gently to a height of 60 feet and ends abruptly at the foot of a steep slope thickly strewn with bowlders. On ascending this slope the land is found to rise to a height of 100 feet above the lake and its summit to consist of an irregular aggregation of knolls, thickly strewn with large bowlders of gneiss, very few or none being derived from the immediately adjoining or underlying Keewatin schists. This ridge is the summit of the Black Island moraine, which would seem to have been dropped here when the higher parts of the island were above the surface of Lake Agassiz, as there is no sign of water action on the moraine above the line of the 60-foot beach. It is possible that the moraine may have been deposited about the water level, and that the water afterwards rapidly receded to a height 60 feet above the present lake.[1]

Instead of the view taken by Mr. Tyrrell, however, concerning the depth of Lake Agassiz here when the Black Island moraine was formed, I believe that it was deposited in water 600 to 700 feet deep, bordering the ice front, contemporaneously with the formation of the Herman or Norcross shore-lines. The morainic accumulations, lying thenceforward at the bottom of Lake Agassiz, could not have been exposed to erosion by its waves until the very late change of its northward outlets, by which the lake fell about 50 feet between the Stonewall and Niverville beaches; and this reduction appears to have taken place so quickly that no beach ridge nor eroded escarpment was made on the upper part of Black Island.

At the Grand Rapids of the Saskatchewan, according to Mr. Tyrrell, the tramway of the portage, which is some 4 miles from the mouth of the

[1] Am. Geologist, Vol. VIII, p. 25, July, 1891.

river and extends about 1 mile, crosses three beach ridges of gravel and sand that together represent the single Niverville beach farther south. Their heights, in order from west to east, are 95, 90, and 80 feet above Lake Winnipeg, or 805, 800, and 790 feet above the sea. Two Niverville stages of Lake Agassiz, or we may say three, are thus shown to have been caused here by the northward uplifting of the land, with intervals of 5 and 10 feet between its stages of temporary repose.

All the shore-lines described in this chapter and in the two preceding chapters must be referred to the glacial Lake Agassiz, held on its northern side by the barrier of the waning ice-sheet; for the country north of Lake Winnipeg presents no barrier of land through which the Nelson River has cut its passage so high as the Niverville beach. Lake Winnipeg and its outflowing stream have been lowered by erosion only about 20 feet from the level of the beach noted by Hind thirty-five years ago.[1]

[1] See Cha ter V, p. 221.

CHAPTER IX.

CHANGES IN THE LEVELS OF THE BEACHES.

THE NORTHWARD ASCENT OF THE WESTERN SHORE-LINES.

The successive shore-lines of Lake Agassiz are not parallel with each other and with the present levels of the sea and of Lakes Winnipeg and Manitoba, but have a gradual ascent from south to north, which is greatest in the earlier and higher beaches and slowly diminishes through the lower stages of the lake, being at last only slightly different from the level of the present time. On the west side of Lake Agassiz the elevations of its beaches have been determined by my continuous leveling, referred to sea-level by railway surveys, through a distance of more than 300 miles from its mouth at Lake Traverse northward to near Riding Mountain in Manitoba; and the accompanying table, on page 476, shows approximately the stages of the lake during the formation of these shore-lines in their relations to each other and to the present level. These stages of the water surface have been assumed to coincide generally with the foot of the lakeward slope of the beach ridges, and with the base of the eroded shore escarpments, the crests of the beaches having had a variable height from 5 to 15 feet above the lake, corresponding with their less or more massive development, while the escarpments rose from the water's edge 10, 20, or rarely 30 feet.

In this table the estimated stages of the lake are noted for comparison at its mouth, where it outflowed by the River Warren at the north end of Lake Traverse, and on four lines of latitude which are nearly equidistant from each other, passing through Fargo, Grand Forks, Emerson, and Gladstone, respectively 75, 150, 224, and 308 miles north of Lake Traverse. Though the fourth of these intervals is somewhat greater than the others, it may still be considered equivalent to them in the observed elevations and northward ascent of the lake shores, because, as will appear further on, the northward rise of the land and subsidence of the lake had their maximum increase from south-southwest to north-northeast or nearly in that direction. Therefore the more western course of these beaches in the northern part of the area examined compensates approximately for the additional distance between the third and fourth of these groups of observations.

The letters *a b c d* represent successive beaches along the northern part of Lake Agassiz, which are merged in a single beach toward its south end. Several of the beaches thus noted in a preliminary report[1] are found to become double in some parts of their northward extent, and a correspondence in notation is here preserved by designating subordinate stages by double letters, as *aa*, *bb*. There are also added the two stages of the Tintah beaches which were discovered after the publication of that report.

The lake shore belonging to the highest or Herman stage *a* has now a northward ascent of about 35 feet in the first 75 miles north from Lake Traverse, about 60 feet in the second 75 miles, and about 80 feet in the third distance of 74 miles to the international boundary. Its whole ascent thus in 224 miles is 175 feet by a slope which increases from slightly less than a half of a foot per mile in its southern third to slightly more than 1 foot per mile in its northern third. Through six lower stages represented by separate beaches northward, which seem to be united in the single Herman beach along the southern third of the lake, the northward ascent is gradually diminished to approximately 30, 40, 60, and 70 feet in the four portions of the observed course of these shore-lines, amounting thus to 200 feet in about 300 miles. On the international boundary the lowest Herman stage, *dd*, is about 55 feet below the Herman stage *a*, while the probable erosion of the outlet and consequent lowering of the south end of the lake between these stages appears not to have exceeded 10 feet.

Between the series of Herman beaches and the series of Norcross beaches the River Warren eroded its channel about 15 feet; and the upper Norcross shore ascends northward in these successive distances about 25, 35, 55, and 70 feet, amounting to 185 feet in the entire distance of 308 miles. In the most southern quarter its ascent is a third of a foot per mile, and this gradually increases to nearly 1 foot per mile in the most

[1] U. S. Geol. Survey, Bulletin No. 39, p. 20.

Stages of the glacial Lake Agassiz, western shore.

	Beaches.		Numerical order.	Mouth of Lake Agassiz outflowing by the River Warren, at the north end of Lake Traverse.	On the latitude of Fargo and Wheatland, N. Dak., 75 miles north of Lake Traverse.		On the latitude of Grand Forks and Larimore, N. Dak., 150 miles north of Lake Traverse.		On the international boundary, 224 miles north of Lake Traverse.		On the latitude of Gladstone, Arden, and Neepawa, Manitoba, 308 miles north of Lake Traverse.	
				Feet above the sea.	Feet above the sea.	North ascent from Lake Traverse.	Feet above the sea.	North ascent from Lake Traverse.	Feet above the sea.	North ascent from Lake Traverse.	Feet above the sea.	North ascent from Lake Traverse.
Stages during outflow southward.	Herman beaches	a	1	1,055	1,090	35	1,150	95	1,230	175	....	....
		aa	2	1,055	1,090	35	1,145	90	1,222	167	....	....
		b	3	1,050	1,085	35	1,135	85	1,212	162	1,315	265
		bb	4	1,050	1,085	35	1,132	82	1,205	155	1,295	245
		c	5	1,045	1,080	35	1,125	80	1,190	145	1,275	230
		d	6	1,045	1,075	30	1,117	72	1,180	135	1,255	210
		dd	7	1,045	1,075	30	1,115	70	1,175	130	1,245	200
	Norcross beaches	a	8	1,030	1,055	25	1,090	60	1,145	115	1,215	185
		b	9	1,025	1,050	25	1,080	55	1,130	105	1,185	160
	Tintah beaches	a	10	1,015	1,035	20	1,065	50	1,105	90	1,150	135
		b	11	1,000	1,017	17	1,045	45	1,080	80	1,120	120
	Campbell beaches	a	12	990	1,000	10	1,015	25	1,045	55	1,080	90
		aa	13	985	995	10	1,010	25	1,035	50	1,070	85
		b	14	980	988	8	1,000	20	1,022	42	1,055	75
	McCauleysville beaches	a	15	970	977	7	987	17	1,007	37	1,035	65
		aa	16	965	971	6	981	16	998	33	1,023	58
		b	17	960	965	5	975	15	990	30	1,012	52
Stages during outflow northeastward.	Blanchard beaches	a	18	[1](945)	950	(5)	960	(15)	975	(30)	995	(50)
		b	19	(935)	940	(5)	948	(13)	960	(25)	980	(45)
		c	20	(925)	928	(3)	935	(10)	947	(22)	965	(40)
	Hillsboro beach		21	(915)	918	(3)	923	(8)	935	(20)	953	(38)
	Emerado beaches	a	22	(882)	....	....	890	(8)	902	(20)	920	(38)
		b	23	(880)	....	....	885	(5)	897	(17)	915	(35)
	Ojata beaches	a	24	(870)	....	....	875	(5)	887	(17)	905	(35)
		b	25	(860)	....	....	865	(5)	877	(17)	895	(35)
	Gladstone beach		26	(840)	....	....	845	(5)	857	(17)	875	(35)
	Burnside beach		27	(822)	....	....	827	(5)	837	(15)	855	(33)
	Ossowa beach		28	(805)	....	....	....	....	817	(12)	835	(30)
	Stonewall beach		29	(795)	....	....	....	....	805	(10)	820	(25)
	Niverville beaches	a	30	(755)	....	....	....	....	....	....	775	(20)
		b	31	(750)	....	....	....	....	....	....	770	(20)

[1] Figures in parentheses in the first column of elevations give approximately the heights which the stages of the lake during its outflow northeastward would have had at Lake Traverse if the land there had been low enough to permit the lake to extend south to its former outlet. From these estimated elevations the northward ascents of these stages, also in parentheses, are obtained, so as to be directly compared with the northward ascents of the beaches that were formed while the lake outflowed southward, showing the changes which were gradually taking place in the levels of the beaches of Lake Agassiz during the whole time of its existence.

Stages of the glacial Lake Agassiz, western shore.

[Continued by observations of Mr. J. B. Tyrrell in the region of Riding and Duck mountains and northward.]

Numerical order.	On Valley River, Manitoba, 375 miles north of Lake Traverse.			On Shanty Creek, Manitoba, 395 miles north of Lake Traverse.			On Pine, Duck, and Swan rivers, Manitoba, 420 to 440 miles north of Lake Traverse.			On Kettle Hill, Manitoba, about 460 miles north of Lake Traverse.			On Mossy portage, and at the Grand Rapids of the Saskatchewan River, both in the Province of Saskatchewan, about 510 miles north of Lake Traverse.		
	Feet above the sea.	North ascent from Lake Traverse.	North ascent from latitude of Gladstone.	Feet above the sea.	North ascent from Lake Traverse.	North ascent from latitude of Gladstone.	Feet above the sea.	North ascent from Lake Traverse.	North ascent from latitude of Gladstone.	Feet above the sea.	North ascent from Lake Traverse.	North ascent from latitude of Gladstone.	Feet above the sea.	North ascent from Lake Traverse.	North ascent from latitude of Gladstone.
1	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
2	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
3	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
4	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
5	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
6	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
7	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
8	1,280	250	65	1,365	335	150	1,440	410	225	......	......	......	......	......	......
9	1,260	235	75	1,319	294	134	......	......	......	......	......	......	......	......	......
10	1,220	205	70	1,287	272	137*	1,365	350	215	......	......	......	......	......	......
11	......	......	......	1,235	235	115	......	......	......	......	......	......	......	......	......
12	......	......	......	1,190	200	110	1,290	300	210	......	......	......	......	......	......
13	1,135	150	65	1,180	195	110	......	......	......	......	......	......	......	......	......
14	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
15	1,084	114	49	[2]1,120	150	85	[3]1,201	231	166	......	......	......	......	......	......
16	1,075	110	52	......	......	......	......	......	......	......	......	......	......	......	......
17	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
18	[1]1,040	95	45	......	......	......	1,151	206	156	......	......	......	......	......	......
19	......	......	......	......	......	......	1,130	195	150	......	......	......	......	......	......
20	......	......	......	......	......	......	[4]1,100	175	135	......	......	......	......	......	......
21	......	......	......	......	......	......	1,030	115	77	1,070	155	117	......	......	......
22	......	......	......	......	......	......	......	......	......	1,015	133	95	......	......	......
23	......	......	......	......	......	......	960	80	60	995	115	100	......	......	......
24	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
25	......	......	......	......	......	......	......	......	......	955	95	60	......	......	......
26	......	......	......	......	......	......	......	......	......	920	80	45	......	......	......
27	......	......	......	......	......	......	......	......	......	......	......	......	910	88	55
28	......	......	......	......	......	......	......	......	......	......	......	......	875	70	40
29	......	......	......	......	......	......	......	......	......	......	......	......	845	50	25
30	......	......	......	......	......	......	......	......	......	......	......	......	800	45	25
31	......	......	......	......	......	......	......	......	......	......	......	......	790	40	20

[1] Estimated from its elevation of 1,025 feet on Ochre River.

[2] Estimated from its elevations on Valley and Pine rivers.

[3] 1,175 on Pine River; 1,201 on Duck River; 1,160 at Square Plain, Swan River.

[4] Estimated approximately for the vicinity of the two preceding; about 1,075 feet at Oak Creek, on the north side of Swan River.

northern quarter. These rates of ascent are slightly reduced in the second Norcross stage, where the total ascent is 160 feet. While the outlet was being eroded probably 5 feet between the Norcross stages, the combined rise of the land and decline of the lake level were about 10 feet on the international boundary and 25 feet on the latitude of Gladstone. The lake shore belonging to the Tintah stage *a* ascends about 20, 30, 40, and 45 feet in the successive distances from south to north, amounting in total to 135 feet; in the same distances the Campbell *a* shore ascends about 10, 15, 30, and 35 feet, in total 90 feet; the McCauleyville *a* shore ascends about 7, 10, 20, and 28 feet, in total 65 feet; and the McCauleyville *b* shore ascends about 5, 10, 15, and 22 feet, in total 52 feet. The erosion of the River Warren from the Norcross *a* stage to the McCauleyville *b* stage, at the end of which the southward outflow ceased, was about 70 feet; but the vertical distance between the shore-lines of these stages on the latitude of Gladstone is about 200 feet, the difference of 130 feet being attributable to the northward rise of the land and the fall of the lake level on account of the diminished attraction of the ice-sheet. The rate of northward ascent is reduced to less than an inch per mile along the southern part of the lowest McCauleyville shore, and to 3 or 4 inches per mile along its northern part, the average being 2 inches.

From the time of this lowest beach, formed during the southward outflow of Lake Agassiz, to the time of the first beach, formed during its northeastward outflow, the lake fell only about 15 feet. Thence there is now a descent, on the latitude of Gladstone, of about 220 feet to the Niverville beach, below which Lake Agassiz, while its northern barrier of ice remained, fell about 45 feet more before it was reduced to Lake Winnipeg. The northward ascent of these shore-lines of northeastward outlet decreases only slightly in the distance of 75 or 80 miles examined north of the international boundary, the change being approximately from 20 feet to 15 feet or less—that is, to the rate of about 2 inches per mile. If these stages of the lake had reached south to Lake Traverse, they would probably show a decrease from about 50 to 25 feet, or to 20 feet, in their total northward ascent above the level of the present time along the distance of more than 300 miles from Lake Traverse to the south ends of Lakes Manitoba and Winnipeg. The whole descent, on the latitude of Gladstone, between the lowest McCauleyville beach, where Lake Agassiz ceased to outflow southward, and the original level of Lake Winnipeg, about 20 feet above the present surface of that lake, is about 280 feet, of which probably 25 or 30 feet may be due to the northward rise of the land and diminution of gravitation toward the ice-sheet, while about 250 feet are due to the gradual lowering of Lake Agassiz by its successive northeastern outlets.

The depth of Lake Agassiz above the present surface of the south end of Lake Winnipeg was about 600 feet during its higher Herman stages, 500 feet at the upper Norcross stage, 440 feet at the upper Tintah stage, 370 feet at the upper Campbell stage, and 325 and 300 feet in the upper and lower McCauleyville stages, being thus reduced to half of its earlier depth before it ceased to flow to the south. During the lower stages of outflow to the northeast the depth of Lake Agassiz above Lake Winnipeg decreased to 285 feet at the upper Blanchard stage, about 240 feet at the time of the Hillsboro beach, 210 feet in the Emerado stage, and successively about 185, 165, 145, 130, 110, and 65 feet in the Ojata, Gladstone, Burnside, Ossowa, Stonewall, and Niverville stages.

The greatest expansion of Lake Agassiz was perhaps reached before the Herman series of beaches was completed, and it apparently was maintained during the greater part of the time of outflow by the River Warren; but through the successive stages of outflow northeastward the lake was diminished in area by nearly proportionate gradations as its depth decreased. When it began to flow in this direction it probably still occupied about half of its area that was attained during the formation of the Herman and Norcross beaches; but, in compensation for loss on its western and southern borders, it may have received meanwhile as great addition by growth toward the north and northeast, thus retaining, until it ceased to outflow at Lake Traverse, nearly its maximum extent.

Beyond the limits of my leveling, portions of nearly all the shore-lines of Lake Agassiz below those of the Herman series have been observed by Mr. J. B. Tyrrell, of the Canadian Geological Survey, at localities in northwestern Manitoba and eastern Saskatchewan. From a careful comparison of the elevation of the beaches noted by Mr. Tyrrell with those determined by my survey, I am enabled to correlate very satisfactorily the two sets of shore-lines. The northern continuations of the successive lake levels from the upper Norcross stage to the Niverville stages, inclusive, are thus identified upon a region lying 50 to 200 miles beyond the area examined by me. This correlation has been tabularly presented on page 477, in juxtaposition with the table showing how the shore-lines ascend along their extent from Lake Traverse to Gladstone.

In the southern area of my exploration nearly equal distances divide the several sections across the shore-lines which are compared together; but upon the country described by Mr. Tyrrell the spaces dividing successive sections are of various lengths. Between the latitude of Gladstone and the Valley River is a distance of 67 miles. Thence to Shanty Creek, the next locality of numerous observations, there is an interval of only 20 miles. Notations of the heights of nine beaches near the Pine, Duck, and Swan rivers are upon an area 25 to 45 miles farther north. In this group the observations in the valley of the Swan River are 20 to 30 miles west of the others, and therefore have, on account of the north-northeastward direction of the ascent of the former lake levels, a nearer equivalence with the elevations of beaches on the Pine River than on the Duck River. The fourth series of beaches recorded is on Kettle Hill, close south of Swan Lake, at a distance of some 20 or 25 miles north from the Duck River and the northern end of Duck Mountain, and about 150 miles north from the latitude of Gladstone. Finally, the fifth series was noted on Mossy portage and at the Grand Rapids of the Saskatchewan, about 50 miles north of the last.

As already stated in Chapters V and VIII, the beaches east and north of Riding and Duck mountains are found to have a more rapid northward ascent than along their southern portion traced by my leveling. It is also very noteworthy that this large amount of differential uplifting was chiefly done after the time of formation of the Campbell beaches, whereas nearly all the uplifting of the area from the southern mouth of Lake Agassiz to Gladstone had taken place earlier. During the first third or half of the period of the entire duration of Lake Agassiz the southern and central part of the lake basin, reaching north to Gladstone, had been raised nearly to its present height. Then followed a time, during the second third of the lake's existence, in which the district that includes Riding and Duck mountains and extends north to the mouth of the Saskatchewan was being rapidly uplifted. But this later northward and northeastward advance of the wave of upheaval had passed beyond the Saskatchewan before Lake Agassiz was reduced to Lake Winnipeg, as is shown by the nearly level Niverville beaches, the latest formed while the ice barrier remained. The rise of the land approximately to its present height is thus known to have followed close upon the glacial recession by which the land was relieved of the ice weight.

The remnants of the ice-sheet adjoining Hudson Bay were not melted away until the Recent or post-Glacial epoch had begun in the northern United States, their departure being possibly even nearer to the present day than to the time of withdrawal of the ice barrier of Lake Agassiz. Moving onward pari passu with the departure of the ice, the uplifting wave of the earth's crust has raised the basin of Hudson Bay 300 to 500 feet since the sea was admitted to it, and the upheaval there is not yet completed. Though doubtless slower than at first, it is still in progress, according to Dr. Bell's observations, at a probable rate of 5 to 7 feet per century.

Three stages of the elevation of this region from its Champlain subsidence are thus indicated by the beaches of Lake Agassiz and the fossiliferous marine beds overlying the till about Hudson Bay, the first extending from Lake Traverse to Gladstone and the south end of Riding Mountain, the second reaching thence probably to the northern and northeastern limits of the area that was occupied by Lake Agassiz, and the third affecting the basin of James and Hudson bays. On the common borders of these contiguous areas the uplifts were of course interblended; but it seems to be clearly shown by the Campbell and Niverville beaches that there was essential rest from the uplifting movement, with a permanence of height nearly as now, upon the southern part of the basin of Lake Agassiz while its northern part was rising, and afterward upon the whole of this basin while the country surrounding Hudson Bay has been elevated. A wave of permanent uplift has advanced from near the southern border of the glaciated area to its central portion, where the ice-sheet was thickest and where it lingered in remnants probably long after its principal mass was melted.[1]

According to my correlation, the highest beach observed by Mr. Tyrrell east of Riding and Duck mountains belongs to the upper Norcross stage of Lake Agassiz, which now has an ascent of 410 feet from its mouth, near Lake Traverse, to Pine River, in a distance of about 420 miles. The rate of ascent of this beach from the latitude of Gladstone to Valley River is about 1 foot per mile, but thence for nearly 50 miles northward to Pine River it somewhat exceeds 3 feet. The same rates of ascent continue, with only slight changes in the Tintah and Campbell beaches, for the distances from the latitude of Gladstone to the Valley and Pine rivers. This portion of the western shore of Lake Agassiz had risen almost uniformly throughout its extent while these beaches were being formed. It had been lifted as a whole to the same amount as its southern part near Gladstone, but it experienced scarcely any differential elevation or tilting until after the formation of the Campbell beaches.

The rate of northward ascent of the upper McCauleyville beach is 9 inches per mile between Gladstone and the Valley River, and thence northward for 55 miles to the Duck River it ascends a little more than 2 feet per mile. In the case of the upper Blanchard beach, the lowest noted near the Valley River, these rates of ascent are respectively 8 inches and 2 feet.

After Lake Agassiz began to outflow northeastward, the differential northward uplifting of this district of the Riding and Duck mountains went on rapidly, amounting probably to 70 feet within the distance of 50 miles next northward from the Valley River during the time between the upper Blanchard beach and the lower Emerado beach. The latter has an ascent of only 60 feet in about 110 miles northward from Gladstone to the Pine River, while in the next 40 miles north to Kettle Hill it rises, like the preceding Hillsboro beach, 1 foot per mile.

Below these shore-lines the later lake levels have been changed comparatively little from their original horizontality. In the distance of 150

[1] Journal of Geology, Vol. II, pp. 383–395, May–June, 1894.

miles northward from the latitude of Gladstone to Kettle Hill the lower Ojata beach and the Gladstone beach ascend, respectively, 60 and 45 feet; and in 200 miles from Gladstone to the Mossy portage and the mouth of the Saskatchewan the successive ascents of the Burnside, Ossowa, and Stonewall beaches are 55, 40, and 25 feet, or only about 3 inches to $1\frac{1}{2}$ inches per mile.

The very regular northward rise of the beaches of this lake throughout all their explored extent, nowhere having any abrupt changes of level, indicates clearly that this region has not experienced violent orogenic disturbance nor faulting since the departure of the ice-sheet. Its changes of level, which have been of large amount, as shown by the tilted planes of the former lake surfaces, took place gradually and continued through the entire duration of the lake. They went forward most rapidly upon the areas which had been latest bared from the retreating ice-sheet, and they were essentially finished, bringing the basin to the same height and attitude as now before the ice barrier was removed from the course of the Nelson River. The continuity of the beaches and the slow and gradual changes in their gradients prove that no faults or dislocations attended the uplifting, tilting, and bending of the subjacent rock formations.

EASTWARD ASCENT OF THE FORMER LAKE LEVELS.

Exploration of the beaches formed on the east side of Lake Agassiz has been mostly limited to Minnesota, because the eastern part of this lake area in Manitoba is covered by forest and is almost wholly without settlements or roads, so that for the present a survey of the shore-lines there is impracticable. For the same reasons the upper shores in Minnesota have not been exactly traced east of Maple Lake, which lies 20 miles east-southeast of Crookston. Within the prairie area across which the highest eastern shore has been surveyed and its elevation determined by leveling its northward ascent is about 115 feet in 140 miles, from 1,055 feet above the sea at Lake Traverse to 1,170 feet at the north side of Maple Lake. As on the western shore of Lake Agassiz, the rate of ascent gradually increases from south to north, ranging from 6 inches to 1 foot per mile in its southern portion for about 75 miles, and from 1 foot to 16 inches per mile farther north. Before the lake in Minnesota had fallen below its highest eastern beach in the south half of its explored extent the rise of the land and diminution of attraction of the waning ice-sheet had caused a slightly lower parallel beach, three-fourths of a mile to $1\frac{1}{2}$ miles distant, to be formed through the northern third of Clay County; and this secondary beach, sometimes double or triple, is observable at several places along the next 30 miles northward. At the northwest side of Maple Lake definite beach ridges belonging to the Herman stages of Lake Agassiz lie successively about 8, 15, 30, and 45 feet below its highest beach. Yet all these shore-lines were formed while the relative heights of the land and the lake continued stationary or with only slight change, not sufficient for the formation of any secondary beach ridge, along a distance of some 75 miles northward from Lake Traverse and Herman.

The Norcross beaches in Minnesota have been explored and their height measured through the same extent of 140 miles, in which the upper Norcross beach ascends northward about 65 feet by a slope that increases slightly from south to north, averaging nearly 6 inches per mile. In like manner the northward ascents of the Tintah, Campbell, and McCauleyville beaches in Minnesota, and of the lower beaches formed on this east side of the lake during its outflow to the northeast, show a gradual decrease nearly as on the west in North Dakota and Manitoba.

But comparison of the western and eastern shores reveals another very interesting feature of the levels of this glacial lake, namely, an ascent from west to east similar to that from south to north, but of less amount and diminishing in a similar ratio between the successive stages of the lake. On the latitude of Larimore and Grand Forks the ascent of the highest Herman stage of Lake Agassiz above a line now level is approximately 33 feet in about 70 miles from west to east, the rate per mile being very nearly half as much as from south to north; and in the later Herman stages it is diminished to about 30, 25, and 20 feet. On the Norcross shore-lines this ascent toward the east is approximately 10 feet in about 60 miles, and it is reduced in the McCauleyville stages to only 3 or 4 feet in about 50 miles; yet it continues through all these stages approximately half as much per mile as the ascent toward the north. The rate of ascent eastward also increases, like that northward, in proceeding from south to north. At the latitude of Wahpeton and Breckenridge, 35 miles north from the mouth of Lake Agassiz, the ascent of its highest stage is 10 feet from west to east in 45 miles; at the latitude of Fargo and Moorhead, 75 miles north from the outlet, it is 15 feet in 50 miles; and at the latitude of Grand Forks, 150 miles north from the outlet, it is 33 feet in 70 miles.

RATE OF ASCENT GREATEST TOWARD THE NORTH-NORTHEAST.

These observations that the corresponding beaches are higher on the east than on the west side of the lake, taken in connection with the doubly more rapid northward ascent of the west and east shores, indicate that the changes in the relations of the land and surfaces of level during the existence of Lake Agassiz and through subsequent time have given to the former levels of this glacial lake a maximum ascent from south-southwest to north-northeast, its rate in this direction being somewhat greater than that noted in following the shores in their nearly due-north course. The maximum rates of northward ascent of about 1 foot per mile observed in North Dakota and southern Manitoba, and of 1 foot to 16 inches per mile in Minnesota, therefore belong to a lake level which in its northern portion, within the limits of my exploration, differs from the present level by an ascent of approximately $1\frac{1}{2}$ feet per mile toward the north-northeast. Similar north-northeastward ascent continues through the successive lower stages of the lake, in which its amount in southern Manitoba, between the international boundary and Gladstone, is reduced to about 4 inches per mile at the lowest stage of southward outflow; and it is scarcely 1 inch per mile in the Niverville beaches along their whole observed extent of about 260 miles from Morris, Manitoba, north to the mouth of the Saskatchewan. No more than 20 feet of differential northward uplift has taken place within this distance since the course of the Nelson River was uncovered by the receding ice-sheet.

Preliminary descriptions and discussions of the uplifting of this basin which have been given in the chapter on the history of Lake Agassiz showed that the movement of elevation of the country at Lake Traverse after the ice above was melted probably did not exceed 90 feet; that thence northward the rise of the land and sinking of the geoid level, as affected by ice attraction, increased to a combined value of about 350 feet at Gladstone and nearly 500 feet in the district of the northern part of Duck Mountain, where, as in North Dakota and Minnesota, the maximum rate of ascent of the beach planes is toward the north-northeast; and that probably thence north to the Saskatchewan and the Churchill, northeast to Hudson Bay, and east to James Bay, the Ottawa basin, and Montreal, the amount of uplift, since the departure of the ice, of a very large central part of the area which it had covered was somewhat uniformly 500 to 600 feet. It has been also shown from Mr. Tyrrell's observations in the district of Riding and Duck mountains that after the southern half of the lake area had been raised almost to its present height, and while that country north to Gladstone lay nearly undisturbed, a great uplift of later date took place in the next 100 miles to the north; and that, after both these movements, the region of Hudson and James bays was still later raised, probably from its maximum depression to its present height. Throughout the area of my survey of the Lake Agassiz shore-lines, and northward along the Riding and Duck mountains, the epeirogenic movement was a tilting with ascent to the north-northeast, toward the region where the ice-sheet had its greatest thickness; but the more northern and northeastern part of this lake bed, with a great adjoining central portion of the vast expanse which had been ice-enveloped, were elevated to an approximately uniform amount. The elevation progressed from south to north and northeast like a wave, permanently uplifting successive areas, excepting so far as the borders of each necessarily shared in the movements of the contiguous tracts earlier or later uplifted.

CHANGES OF LEVELS NEARLY COMPLETED DURING THE EXISTENCE OF LAKE AGASSIZ.

Nearly the entire amount of the changes in the levels of the beaches of Lake Agassiz was evidently contemporaneous with the existence of this lake, taking place gradually, but apparently progressing comparatively fast between the stages marked by the formation of definite beaches, which doubtless belong to times when these changes advanced very slowly or were interrupted by intervals of repose. Great as were the combined epeirogenic uplift and modification of the geoid surface of level, producing a differential rise of the highest western shore of the lake in Manitoba to the extent of 175 feet at the international boundary, 265 feet at the latitude of Gladstone, and about 400 feet at the latitude of 51° 52′ north on the east side of Duck Mountain, 200 miles north of the international boundary, in the relation of the land to the water level, as compared with the vicinity of Lake Traverse, they were yet almost or perhaps quite completed before the ice-sheet was so far withdrawn that it was no longer a barrier to prevent free drainage from the basin of the Red River and Lake Winnipeg.

During the subsequent postglacial period, to the present time, only very slight changes have taken place in the relative elevations of the part of this area where the heights of the beaches of Lake Agassiz have been determined in Minnesota, North Dakota, and Manitoba; and these small changes of level, shown by the Niverville beaches, have been merely a continuation of the movements which accompanied the recession of the ice-sheet and are recorded by the successive shore-lines of this lake.

CAUSES OF THE CHANGES OF LEVELS.

In attempting to discern the causes of the changes of levels shown by the shore-lines of Lake Agassiz, three diverse agencies, which certainly must have been factors working together to produce the observed results, are to be studied with respect to the proportion contributed by each. They are considered in the following order: (1) Gravitation of the water of Lake Agassiz toward the ice-sheet; (2) changes in the temperature of the earth's crust due to the ice-sheet, or, in other words, to the cold of the Glacial period and the return of the warmer climate now enjoyed; (3) epeirogenic movements, or downward and upward bending, often more or less accompanied with the formation of faults, affecting large areas of the earth's surface, which may be due (*a*) to the imposed weight of the ice-sheet and to its removal, or (*b*) to conditions and stresses of the earth's crust and interior originating otherwise, as by secular cooling and contraction.

The order in which we shall thus examine these several parts of the complex causation of the changes of levels is not, however, the order of their importance or several shares in the work. The third agency, manifested in obedience to the pressure of the ice and in resilience when relieved from it, is found to have been the principal factor, producing far the greater part of the changes of levels. Its manifestation within the area of Lake Agassiz during the Glacial and Recent periods on account of the other conditions and stresses mentioned appears to be only a small element in the problem; though, when thus originating, it is seen to have had great importance in causing such changes in other parts of the world, and even in parts of North America, contemporaneously with the uplifting of the basin of this lake. The first agency noted is found to be a considerable factor, working in the same directions as the epeirogenic effects of the transient ice weight, and contributing perhaps a fifth or a fourth as much toward the changed relations of the water level and the land area. But the second agency, upon investigation, proves to have been slight in its effect, and within the basin of Lake Agassiz, so far as it availed, it was opposed to the other two.

GRAVITATION TOWARD THE ICE-SHEET.

Consideration of the character of the changes in the levels of the beaches, resulting in a greater ascent upon the northern part of the area examined than farther south, and gradually approximating, through the successive stages of the lake, to parallelism with the present geoid surface of level, led me in my earlier studies to attribute these changes almost wholly to gravitation of the water of the lake toward the ice-sheet. The cause of the present relations of the old shore-lines seemed to be discovered in the explanation that at first this attraction had a large effect upon the lake level because of the nearness of a great depth of ice on the east in northern Minnesota and on the north in British America, but that afterward it was gradually diminished to a comparatively small influence when the southern portion of the ice-sheet had been melted and the attracting force proceeded from the region far north between Lake Winnipeg and Hudson Bay.[1] Under this view the earth's crust was believed to be so

[1] Geol. and Nat. Hist. Survey of Minnesota, Eleventh Annual Report, p. 152; U. S. Geol. Survey, Bulletin No. 39, p. 18.

rigid that it was not depressed by the vast weight of the ice nor raised when relieved of that weight, and the changes were believed to consist chiefly in the differential subsidence of the lake level, not in the differential elevation of the land basin.[1] The general uniformity of these changes in their direction and extent, and their probable completion during the departure of the ice-sheet, seemed to accord with this hypothesis. The exact comparison of the shore-lines surveyed by me, with leveling, on both the east and west sides of the lake, extending for its upper stages 140 miles from south to north in Minnesota and more than 300 miles from south to north in North Dakota and southern Manitoba, shows no considerable irregularity in the rates of northward and eastward ascent—that is, of north-northeastward ascent—of the former lake levels, which thus seem to be attributable to gravitation toward the waning ice-sheet, rather than to a progressive elevation of the land, for that would be expected to present noteworthy irregularities upon so large an area. It is probable, however, that close scrutiny of the shore-lines will disclose small divergences, within limits of a few feet, from the uniformity of slopes which they should have for agreement with this explanation; and it is to be noticed that the highest shores in the vicinity of Treherne, Brandon, and Neepawa, Manitoba, have more nearly a northward than north-northeastward ascent; also that a slightly disproportionate increase in the ascent of the highest Minnesota shore-line in the next 10 or 15 miles north of the Buffalo River was ascribed to the proximity of a portion of the ice-sheet on the east, where it was forming the Fergus Falls and Leaf Hills moraines. Though it now appears true that the greater part of these changes of level are due to the differential rise of the land, the gravitation of the lake toward the ice-sheet certainly operated in conjunction with that cause, contributing to the full extent of its competency in producing the results observed.

Mr. R. S. Woodward, of the United States Geological Survey, has worked out the mathematical problem of determining the effect of any

[1] Similar oscillations in the relative heights of sea and land, associated with glaciation, have been thus ascribed to ice attraction by Adhemar, in Révolutions de la Mer, 1840; by Croll, in Climate and Time, 1875; and by Penck, in Schwankungen des Meeresspiegels, Jahrbuch der Geographischen Gesellschaft zu München, bd. VII, 1882.

added mass, as an ice-sheet, upon the earth's surface, to disturb the levels of the sea and of lakes.[1] Assuming an ice-sheet with a radial extent of 38°, or about 2,600 miles, and a central depth of 10,000 feet, from which the depth decreases at first slowly and then more rapidly to its border, he finds that the average slope within 1 degree of the border of the ice would be about 5 inches per mile, or less than one-third of the north-northeastward ascent of the highest shore-lines of Lake Agassiz in the north part of the area where they have been traced with leveling. If we compare the premises in this problem with the probable conditions affecting this glacial lake, it seems sure that the North American ice-sheet in its maximum extent covered not more than about one-fourth so great an area, its extent being equivalent to a spherical circle with a radius of 1,200 or 1,300 miles; but, on the other hand, it is probable that the maximum depth of this ice-sheet somewhat exceeded 10,000 feet, and that the area of this great depth was a belt extending eastward from a few hundred miles north or northeast of the south part of Lake Agassiz to a distance of about 1,000 miles east-northeast, lying thus much nearer than in the assumed case of Mr. Woodward's investigation. The smaller area and less total mass of the ice-sheet attracting Lake Agassiz may have been offset by the nearer position of a large part of its mass than in the assumption of the problem, so that possibly its influence might be as great in producing an ascent of the lake level above the level of the present time; but, if this mathematical investigation is reliable, gravitation of the lake toward its ice barrier could not give to its highest shore a northward ascent of more than a few inches per mile, at the most not so much as half a foot, whereas its observed ascent within the area of my leveling attains a maximum rate of 1 foot to 16 inches per mile, and this belongs to a north-northeastward ascent of fully $1\frac{1}{2}$ feet per mile. A quarter part, or probably less, of the changes in the levels of these beaches is therefore referable to ice attraction, while the

[1] U. S. Geol. Survey, Sixth Annual Report, for 1884–85, pp. 291–300; and Bulletin No. 48, "On the form and position of the sea level," 1888, p. 88. Compare also Prof. Edward Hull's computations, "On the effect of continental lands in altering the level of the adjoining oceans," Geol. Magazine (3), Vol. V, pp. 113–115, March, 1888; "Polar ice-caps and their influence in changing sea levels," by Sir William Thomson, Trans., Geol. Society of Glasgow, Vol. VIII, 1888, pp. 322–340; and "The study of the earth's figure by means of the pendulum," by E. D. Preston, Am. Jour. Sci. (3), Vol. XLI, pp. 445–460, June, 1891.

remaining three-quarters, or a larger part, amounting at least to about 130 to 300 feet, from south to north, in southwestern Manitoba, belongs to a differential elevation of the land.

CHANGES IN THE TEMPERATURE OF THE EARTH'S CRUST.

Among the conditions producing changes in the height and slopes of the land on which Lake Agassiz lay are the cooling and contraction of the earth's crust by the ice-sheet and glacial waters, and the subsequent warming and expansion owing to the amelioration of the climate. The superficial portion of the earth's crust in the Red River Valley has a temperature of 47° to 42° F., as shown by the water of artesian wells situated respectively at Ada and Donaldson, Minn.[1] But during the time when this district was covered by the ice-sheet the temperature of the underlying land surface was reduced to the freezing point, 32° F., and a similar lowering of temperature may have affected the crust to a considerable depth, largely through the influence of percolating water, causing a slight depression of the isogeotherms, with consequent contraction of the rocks and lowering of the land surface. By comparison with the present mean annual temperature of the Red River Valley, ranging approximately from 41° at Lake Traverse to 33° at Winnipeg,[2] it is evident that the artesian waters before noted receive part of their heat from the earth's interior. In like manner probably the interior heat kept the superficial portion of the earth's crust beneath the ice-sheet as warm as 32°, at which temperature the earth's heat would be continually melting the ice, though certainly at a very slow rate.

The differences in the temperatures of the earth's crust, due to the ice-sheet and to water permeating downward from it, would not, therefore, probably exceed 15° from that of the present time in the southern part of the basin of Lake Agassiz, and would decrease to 10° at Donaldson, in Kittson County, the most northwestern in Minnesota, and to even a less amount at Winnipeg. The extent to which these slight changes in the

[1] Geol. and Nat. Hist. Survey of Minnesota, Eleventh Annual Report, pp. 147, 148. Detailed descriptions of these wells are given in the next chapter.

[2] C. A. Schott in Smithsonian Contributions to Knowledge, Vol. XXI, 1876; Atlas of the Tenth Census of the United States; Report of the Department of Agriculture and Statistics of Manitoba for 1882, p. 318. Also see Chapter XI for statements of the monthly and mean annual temperature of this district.

crustal temperatures would depress the land while it was ice-covered and raise it when the ice was withdrawn depends on the ratios of contraction and expansion of the underlying rocks. These ratios have been experimentally determined in the case of various building stones, and computations therefrom indicate that only a very small amount of subsidence and elevation of the land could be caused in this way.[1] The total elevation so produced was probably not more than 50 feet in the southern part of the Red River Valley, and not more than 30 feet at Winnipeg; and its slight differential effect would be in the opposite direction to that which has given to the beaches of Lake Agassiz their northward ascent. This element in the causation of the changes of elevation appears to be comparatively insignificant in itself, and its small component in the oscillation of the shorelines would be opposed to that for which we are seeking an explanation.

EPEIROGENIC MOVEMENTS APPARENTLY DEPENDENT ON GLACIATION.

It seems to be very clearly indicated by the gradual diminution in the northward ascent of the beaches, until the lowest and latest have nearly the level of the present time, that these progressive changes of elevation were directly dependent upon the departure of the ice-sheet, with which great geologic event they were contemporaneous. As already noted in Chapter V and on a foregoing page of this chapter, these changes were so directly proportionate with the glacial recession that the northward ascents of the successive beaches were at first referred to the diminishing gravitation of the lake toward the ice-sheet; but, apart from the inadequacy of this cause, determined by Mr. Woodward's investigations, the great extent of the highest beach and its relation to terminal moraines marking stages in the glacial recession sufficiently demonstrate that other causes contributed even more than ice attraction to produce the changes observed in the levels of the beaches.

There remain to be considered, as probable causes, first, the relationship between the earth's crust and its interior which may have permitted a

[1] T. C. Chamberlin in Sixth Annual Report, U. S. Geol. Survey, p. 302, and in paper read before the Philosophical Society, Washington, March 13, 1886; G. K. Gilbert in Am. Jour. Sci. (3), Vol. XXXI, p. 297, April, 1886, and in U. S. Geol. Survey, Monograph I, "Lake Bonneville," pp. 377, 378.

sinking of the crust beneath the vast weight of the ice-sheet and a reelevation when that weight was removed, and, second, oscillations which may have occurred without dependence on the glaciation. For the discrimination of these movements it will be very instructive to notice the changes of elevation that have been going forward at the same time in other parts of the North American and European glaciated regions, and also in various areas which were never thus ice-laden. If Lake Agassiz is found to be an instance where nearly all these changes are apparently referable to glaciation, there will be no lack of opportunity for comparing it with other regions where the effects due to glaciation are combined with independent crustal movements.

Discussion of the relationship of the earth's crust to the interior.—My former reference of the northward ascent of the beaches of Lake Agassiz to ice attraction, with the assumption that the earth was so rigid that its form would not be changed by the load of the ice-sheet nor by its removal, seemed more probable because of the well-known physical and mathematical researches of Hopkins, Thomson, Pratt, and Prof. G. H. Darwin, who conclude that the earth is probably solid, with not less rigidity than that of glass or of steel. In deference to their investigations, this conclusion is accepted and taught in recent text-books of geology by A. Geikie and Le Conte;[1] but in similarly recent text-books Prestwich and Dana teach that the earth probably consists of a comparatively thin crust, underlain by a molten interior, which may change within a moderate depth to a great nucleal solid mass. Among other geologists and physicists who have discussed the conditions of the earth's interior, King,[2] Shaler,[3] and

[1] Since the publication of Le Conte's Elements of Geology, revised second edition, 1882, this eminent geologist has abandoned the opinion here noted, and now believes "that the general structure of the earth is that of a solid nucleus constituting nearly its whole mass, a solid crust of inconsiderable comparative thickness, and a subcrust liquid layer, either universal or over large areas, separating the one from the other. * * * Also that the crust rests upon the subcrust liquid as a floating body." American Geologist, Vol. IV, pp. 38–44, July, 1889; Am. Jour. Sci. (3), Vol. XXXVIII, pp. 257–263, Oct., 1887; Elements of Geology, third edition, 1891, pp. 84–87, 264.

[2] U. S. Geological Exploration of the Fortieth Parallel, Vol. I, Systematic Geology, 1878, pp. 117, 696–725.

[3] Proc., Boston Soc. Nat. Hist., 1866, Vol. XI, pp. 8–15; 1868, Vol. XII, pp. 128–136; 1874, Vol. XVII, pp. 288–292. Memoirs, Boston Soc. Nat. Hist., 1874, Vol. II, pp. 320–340. Scribner's Magazine, Vol. III, pp. 201–226, Feb., 1888.

Reade[1] believe it to be solid, while Whitney,[2] Dutton,[3] Powell,[4] Wadsworth,[5] Crosby,[6] Claypole,[7] Phillips,[8] Airy,[9] Fisher,[10] and Jamieson[11] believe that it is molten, or at least is surrounded by a molten layer, and that the earth's crust floats in a condition of isostasy[12] or gravitational equilibrium upon the heavier liquid or viscous mobile interior or layer enveloping the interior, subject, however, to stresses and resulting deformation because of the earth's contraction. The thickness of the crust, according to this hypothesis, is variously estimated to be from 20 to 50 miles, or possibly 100 miles or more.

Another statement of the probable relationship of the earth's crust to the interior, which seems to come between these diverse opinions and in some measure to express the important features of each, is given as follows by Gilbert, in his discussion of faults and displacements of the Wasatch range and the area of Lake Bonneville:

> We are forced to conclude that the mountain ranges of the Bonneville basin and the valleys between them do not, with reference to each other, obey the law of flotation.
>
> It follows with equal cogency that the faults do not penetrate to a layer characterized by fluidity or semi-fluidity, implying by these terms the power to flow under small shearing strain, but terminate in a region of rigidity, implying by that term the ability to withstand relatively large shearing strain. I conceive them to terminate at the upper limit of the region of plasticity by pressure, implying by that phrase that at and below a certain depth the rocks of the crust, however rigid, are

[1] The Origin of Mountain Ranges, 1886, pp. 6, 7, 256, 267, 270, etc. Philosophical Magazine, June, 1891 (also in Am. Geologist, Nov., 1891).

[2] Earthquakes, Volcanoes, and Mountain Building, 1871, pp. 77–87.

[3] Penn Monthly, Vol. VII, pp. 364–378, and 417–431, May and June, 1876. U. S. Geol. Survey, Fourth Annual Report, pp. 183–198; Sixth Annual Report, pp. 195–198.

[4] Science, Vol. III, pp. 480–482, April 18, 1884. The Forum, Vol. II, pp. 370–391, Dec., 1886.

[5] Am. Naturalist, Vol. XVIII, June, July, and August, 1884.

[6] Proc., Boston Soc. Nat. Hist., 1883, Vol. XXII, pp. 443–485. Geol. Magazine (2), Vol. X, 1883, pp. 241–252.

[7] Am. Naturalist, Vol. XIX, pp. 257–268, March, 1885. Am. Geologist, Vol. I, pp. 382–386, and Vol. II, pp. 28–35, June and July, 1888.

[8] Vesuvius, 1869, pp. 324, 329.

[9] Nature, Vol. XVIII, pp. 41–44, May 9, 1878.

[10] Physics of the Earth's Crust, 1881, pp. 223, 270, etc.

[11] Geol. Magazine (3), Vol. IV, 1887, pp. 344–348.

[12] A term proposed by Capt. C. E. Dutton in a paper "On some of the greater problems of physical geology," Bulletin of the Philosophical Society of Washington, Vol. XI, pp. 51–64, April 27, 1889. See also an important discussion of this condition of the earth's crust, "The Gulf of Mexico as a measure of isostasy," by W J McGee, in Am. Jour. Sci. (3), Vol. XLIV, pp. 177–192, Sept., 1892.

subject to such pressure that their yielding under shearing strains exceeding the elastic limit is not by fracture, but by flow. I conceive the orogenic blocks as confluent with the subjacent layer, excepting such as may wedge out by the convergence of fault planes.[1]

This view is closely allied with that which regards the interior as solid, and, indeed, if I understand the authors holding the doctrine of solidity, forms a necessary postulate of their explanation of orogenic and epeirogenic movements. It is again well stated by Becker, who regards the earth "as a solid mass of extremely high viscosity which would yield slowly to relatively moderate forces of constant terrestrial direction and long duration, but which would probably yield almost imperceptibly to any force of brief duration or rapidly changing direction."[2] For such a condition, however, which seems to me probably or possibly true for all the earth excepting its volcanic areas, I should prefer, as more intelligible to ordinary readers, to speak of the interior as plastic rather than as either solid or liquid, though in its rigidity or resistance to change of form it may equal or surpass the hardest rocks of the earth's surface.

In the present state of our knowledge, the elevation of the area of Lake Agassiz, increasing in amount from south to north, during the departure of the ice-sheet, seems most clearly intelligible by supposing it to have been an uplifting of the crust by the inflow of plastic if not perfectly molten rock from districts outside the glaciated area, occurring probably between the depths of 20 and 100 miles, in obedience to gravitation, which, to preserve the condition of isostasy, would cause the crust, when loaded by the ice-sheet, to sink and displace part of the plastic interior, and when the ice-sheet was removed would cause the plastic rock to flow back and raise the crust approximately to its former height.

It must be confessed that we have only a very inadequate knowledge of the conditions which would result from the enormous pressure and high temperature of the earth's interior; and wide diversity in speculations on this subject will probably long continue. Professor Shaler, while holding that the earth is mainly solid throughout, perhaps having in its most mobile layer beneath the crust "a rigidity such as belongs to the metals of average

[1] U. S. Geol. Survey, Monograph I, Lake Bonneville, 1890, pp. 358, 359.
[2] Bulletin, G. S. A., Vol. II, 1891, p. 70.

resistance to compression," yet is one of the earliest and most decided advocates of the opinion that the weight of an ice-sheet may depress the area on which it lies, and that the departure of the ice would be attended by reelevation. In comparison, however, with the physical conditions and laws familiar to us upon the earth's surface, the subsidence and elevation of extensive areas, as of nearly all glaciated regions, seem to demonstrate a mobility of the earth's interior as if it were fused rock. The same conclusion is indicated by volcanoes, which are probably the openings of molten passages that communicate downward through the crust to a heavier melted portion of the interior, thence deriving their supply of heat, while their outpoured lavas consist largely or wholly of fused portions of the crust, the phenomena of eruption being caused by the access of water to the upper part of the molten rock, near the volcanic vent. But the great plications of the strata in the formation of mountain chains evidently involve only the upper part of the earth's crust, crumpled into smaller area in adapting itself to the diminishing volume of the lower portion of the same crust, which, with the nucleus, is undergoing contraction on account of the gradual loss of its heat, and perhaps also on account of progressing solidification and compression. There is in this process no dependence on the plastic or perhaps molten condition of the interior, except as that seems to be necessary for distortion of the earth, both of the crust and nucleus or mobile layer enveloping the nucleus, whereby considerable shrinkage of volume can take place before the accumulated stress becomes sufficient for the formation of a mountain chain. At the present time depressions and elevations, probably caused by accumulating stresses, are slowly changing the relations of land and sea upon many parts of the earth's surface. In the same way the downward and upward movements which would be caused by the burden of the ice-sheet and its removal are doubtless in many places complicated by concomitant or subsequent movements thus due to deformation under stresses, by which the elevation attributable to the departure of the ice-sheet may be augmented or partly or wholly counteracted, giving much irregularity to the glacial and postglacial oscillations of the land.

The area of Lake Bonneville has experienced changes of level since the formation of its highest shore-line, which Mr. Gilbert finds to be in harmony with the explanation that they were due to the evaporation of the lake and the consequent partial restoration of equilibrium by the underflow of plastic rock; but he regards his observations as too incomplete to furnish absolute proof of this hypothesis.[1] A supplementary and more satisfactory test is supplied by this survey of Lake Agassiz. Debarred from referring the northward ascent of the beaches of this glacial lake chiefly to ice attraction, I regard my observations of their increasing rate of ascent in proceeding from south to north, the gradual approximation in the lower beaches toward horizontality, and the probable completion of these changes in relative elevation during the existence of Lake Agassiz and the departure of the ice-sheet, as all strikingly accordant with this explanation, and, indeed, as demonstrative of its truth. These changes in the levels of the beaches of Lake Agassiz, partly pertaining to the lake itself and in larger part to the crust of the earth, are thus believed still to be wholly referable to the influence of the ice-sheet in its recession, with which they show such remarkable correspondence in the direction, character, and gradual decrease of the northward ascent. No irregularities of the differential changes in elevation are found which seem to require other explanation, the rise caused by the removal of the ice-sheet not being combined upon this area, so far as can be determined, with independent earth movements either of elevation or depression.

History of the doctrine of crust deformation by the ice-sheet.—Jamieson appears to have been the first, in 1865, to suggest this view, which I receive from him, that the submergence of glaciated lands when they were loaded with ice has been caused directly by this load pressing down the earth's crust upon its fused interior, and that the subsequent reelevation was a hydrostatic (or we may better say isostatic) uplifting of the crust by underflow of the inner mass when the ice was melted away.[2] Two

[1] Am. Jour. Sci. (3), Vol. XXXI, pp. 284–299, April, 1886. U. S. Geol. Survey, Monograph I, Lake Bonneville, 1890, pp. 379–392.

[2] Quart. Jour. Geol. Soc., Vol. XXI, p. 178. Later discussions of this subject by Mr. Jamieson are in the Geological Magazine (2), Vol. IX, pp. 400–407 and 457–466, Sept. and Oct., 1882; and (3), Vol. IV, pp. 344–348, Aug., 1887. In the article last cited he applies this explanation to the changes of the beaches of Lake Agassiz, which up to that time I had attributed mainly to ice attraction. The same principle, however, was brought forward by Sir John Herschel in 1836, and had been advocated by Prof. James Hall, of New York, in 1859, in attributing to the weight of sediments the long-continued subsidence of the areas on which they have been deposited in great thickness.

years later Whittlesey published a similar opinion.[1] In 1868 Shaler referred the subsidence of ice-covered areas to a supposed rise of isogeothermal lines in the subjacent crust, operating, in conjunction with the ice-sheet, to produce downward flexure;[2] but in 1874 and later he regards the depression as due directly to the weight of the ice, and the reelevation as due to its removal.[3] The same view is advanced also by Chamberlin to account for the basins of the Laurentian lakes, where he believes a considerable part of the glacial depression to have been permanent.[4]

Tardiness in the beginning of the changes of levels of the Lake Agassiz basin.—That the greater part of the changes of levels upon the area of Lake Agassiz has been due to differential elevation of the earth's crust, instead of ice attraction, seems to be proved by the tardiness of their beginning, as shown by the relationship of the highest beach of Lake Agassiz to the contiguous terminal moraines formed on the adjacent land areas during the recession of the ice-sheet, of which a detailed description has been given in Chapter IV. The highest beach is continuous on the east from Lake Traverse about 140 miles north to Maple Lake, which is as far as exact exploration of it has been carried. On the west this shore-line is unbroken along an extent of about 250 miles from south to north, reaching into Manitoba. Now the adjacent Dovre, Fergus Falls, Leaf Hills, and Itasca moraines appear to have been successively accumulated during the time of formation of this single highest beach, which marks, through so great distances and so large a portion of the glacial recession, a nearly or quite unvarying stage of the lake and undisturbed repose of the earth's crust. If diminishing gravitation of the water of the lake toward the ice-sheet had been the chief cause, or even an element of large importance among component causes, of the changes of levels of the beaches, the surface of the lake must have fallen considerably in its northern portion

[1]Proc., A. A. A. S., Vol. XVI, pp. 92–97.

[2]Proc., Boston Soc. Nat. Hist., Vol. XII, pp. 128–136.

[3]Proc., Boston Soc. Nat. Hist., Vol. XVII, pp. 288–292; Memoirs, Boston Soc. Nat. Hist., Vol. II, pp. 335–340. Am. Jour. Sci. (3), Vol. XXXIII, pp. 220, 221, March, 1887. Scribner's Magazine, Vol. I, p. 259, March, 1887.

[4]Geology of Wisconsin, Vol. I, 1883, p. 290; Proc., A. A. A. S., Vol. XXXII, 1883, p. 212. The problems of ice attraction and of deformation of the earth's crust have been further discussed by Professor Chamberlin before the Philosophical Society of Washington, March 13, 1886; and, jointly with Professor Salisbury, in the Sixth Annual Report, U. S. Geol. Survey, pp. 291–304.

because of the decreasing attraction of the ice during the stages of its retreat between these moraines. But the extent of the highest beach shows that no appreciable changes of level took place while the ice-sheet was being melted back 250 miles or more and was probably much reduced in thickness upon a large area farther north, meanwhile, at times of halt in its recession, or perhaps of some readvance, accumulating the most massive morainic deposits of this region. The stability of the crust had been maintained during this great reduction of the ice pressure; and when at length an uplift ensued, the process was slow and marked by no paroxysmal action, but progressed in a gradual manner, though yet with pauses, as was also doubtless the method of the continued retreat of the ice.

Pauses in the crustal uplift recorded by the series of beaches.—The successive beaches of Lake Agassiz, numbering seventeen in its northern part while the lake outflowed southward by the river Warren, and fourteen while it outflowed northeastward, appear to have been formed during pauses in the differential elevation of this area. Between the times of formation of the beaches the uplift of the land was too rapid to be recorded by wave erosion and beach deposits, and the definitely marked shore-lines belong to stages of interruption or slower progress of this crustal uplift.

At the southern end of the lake each of the beaches, into which several in their course from north to south become merged, may belong to a slowly sinking lake surface, with change of 5 feet, or in some cases 10 feet, during the accumulation of the single beach ridge; and the intervals of 10 or 15 feet between the levels held by the mouth of the lake while the beaches of its southern part were being formed appear to represent times of exceptionally rapid erosion because of comparatively fast elevation of that area and of the country crossed by the River Warren. Along the course of this stream, the present valley of the Minnesota River, no outcropping rocks are found at so high levels that they would be touched by the continuation of the planes of the upper beaches of Lake Agassiz, having in their southern part a descent to the south of about a half of a foot per mile. The River Warren cut its channel wholly in glacial drift, until during the McCauleyville stages of the lake it reached the ledges of granitoid gneiss which outcrop in the bottom of the valley along a distance of several miles next below Big Stone Lake.

Changes in levels of the beaches only a partial measure of the ice weight.—If the thickness of the ice-sheet upon the area of Lake Agassiz was a half mile to 1½ miles, as seems probable, increasing from south to north and northeast, the crustal uplift measuring the inflow to this area of an equal weight of plastic or molten rock would range from 880 feet, or a sixth of a mile, at Lake Traverse, on the south, to 2,640 feet, or a half mile, at the north end of Lake Winnipeg, on the assumption that the density of the inflowing rock or magma were that of the upper portion of the earth's crust. The density of ice is taken as 0.9, water being 1.0; and that of the rocks forming the earth's surface is assumed to average 2.7, the earth's mean density, determined by three independent methods with closely accordant results, being about 5.5. But the mobile stratum next beneath the solid crust is surely somewhat heavier than the crust. Comparison of the earth's superficial and mean densities indicates for this magma a probable density of 3.5 or more, which would reduce the computed uplift to 680 feet at the south, with increase of about 2 feet per mile northward to 2,040 feet, in round numbers 2,000 feet, at the mouth of Lake Winnipeg and along the Nelson River, or less than these amounts if the density of the uplifting magma was greater than 3.5. It is very probable that the subsidence caused by the ice-sheet, depressing the crust below its preglacial height, was more than would be thus strictly proportionate to the weight added by the ice accumulation; but on the other hand it seems probable, as shown by the northward ascent of the beaches of Lake Agassiz, that only a minor fraction, perhaps nowhere within this basin exceeding one-fourth, of the weight of ice removed was compensated by the differential uplift of the land.

But could we well explain the facts of glacial striation and drift transportation by assuming for the ice-sheet a less thickness, as one-third of a mile to 1 mile from south to north upon the lacustrine area, which may, indeed, be nearer the truth, the rate of ascent of the shore-lines within the area of my survey, resulting apparently from the departure of the ice, would be closely in accordance with the hypothesis that the earth's crust is floating in isostatic equilibrium upon a plastic or molten interior, though the vertical extent of elevation of the whole basin is probably several hundred feet less than would be expected as a full measure of the weight removed. Even with the presumption that the uplift in its rate of increase toward the north is only approximately half, and in its aggregate amount only a quarter part, or less, of what computation would require, this hypothesis still seems to afford the best explanation that we are able to offer for the northward ascent of these beaches, beyond such small portion as can be referred to ice attraction. And it is to be observed that glaciated areas generally show by their fjords that part of their depression by the ice-sheet continues to the present time, not having been equaled by the crustal elevation when the ice-sheet was dissolved.

REVIEW OF PLEISTOCENE OSCILLATIONS OF LAND AND SEA.

Having thus examined the probable causes of the changes in relative elevations within the area of Lake Agassiz, we shall gain much further knowledge of the evidence supporting the hypothesis concerning the earth's crust and interior, to which it has led us, by reviewing the oscillations that have affected various other parts of the world contemporaneously with the accumulation and disappearance of the Pleistocene ice-sheets. Fjords, fossiliferous marine deposits, and migrations of animals and plants bear important testimony of these vicissitudes of land and sea. It will be well first to consider our own continent, and afterward to inquire whether South America and Europe fared similarly.

PREGLACIAL ELEVATION OF NORTH AMERICA SHOWN BY FJORDS AND SUBMARINE RIVER VALLEYS.

One of the most interesting fjords of North America is that of the Saguenay, tributary to the St. Lawrence. Along a distance of about 50 miles the Saguenay is from 300 to 840 feet deep below the sea-level; its adjoining cliffs rise abruptly in some places 1,500 feet above the water; and the width of its wonderfully sublime and picturesque gorge varies from about a mile to $1\frac{1}{2}$ miles.[1] This fjord, like the many which indent our

[1] J. W. Dawson, Notes on the Postpliocene Geology of Canada, 1872, p. 41.

eastern coast from Maine to Labrador and Greenland, and our western coast from Puget Sound to the Arctic Ocean, was eroded by a stream that flowed along the bottom of the gorge when it was above the sea; and this erosion was probably going forward in the epoch immediately preceding the Ice age, for earlier subsidence during any period of much length, geologically speaking, would have caused the submerged valley to be filled with sediments. The preglacial elevation of the Saguenay region therefore appears to have been at least about 1,000 feet greater than now.

Similarly it is proved by the fjords of Maine, the eastern Canadian provinces, and Newfoundland, of Labrador and Greenland, of the Arctic coasts of North America, and the archipelago west of Baffin Bay, and of the Pacific coast from Alaska to Oregon, that the entire extent of the North American glaciated area was considerably higher before than after glaciation.

But the preglacial altitude of this area was much greater than the depth of the fjords which indent its shores. It is more nearly, but probably still only partially, measured by river valleys and fjords which are now entirely submerged beneath the ocean. The submarine border of the continental plateau to depths of more than 3,000 feet is cut by valleys or channels which if raised above the sea-level would be fjords or canyons. These can be no other than river courses eroded while the land stood much higher than now; and its subsidence evidently took place in a late geologic period, else the deposition of silt must have obliterated the channels. For this continent a most impressive review of the evidences of its lately far greater height, as shown by these submerged river courses, has been given by Prof. J. W. Spencer.[1]

According to the United States Coast Survey charts, as noted by Spencer, the bottom of a submerged valley just outside the delta of the Mississippi is found by soundings at the depth of 3,000 feet. This valley is a few miles wide and is bounded by a plain of the sea bed from 900 to 1,200 feet above its floor. It thus appears that the country north of the Gulf of Mexico has been raised for a short time to a height of not less than

[1] "The high continental elevation preceding the Pleistocene period," Bulletin, G. S. A., Vol. I, 1890, pp. 65–70; also in the Geol. Magazine (3), Vol. VII, pp. 208–213, May, 1890.

3,000 feet; and it is important to note in passing that an equal uplift would wholly close the Strait of Florida, 2,064 to 3,000 feet deep, through which the Gulf Stream now pours into the North Atlantic.

The continuation of the Hudson River Valley has been traced by detailed hydrographic surveys to the edge of the steep continental slope at a distance of about 105 miles from Sandy Hook. Its outermost 25 miles are a submarine fjord 3 miles wide and from 900 to 2,250 feet in vertical depth, measured from the crests of its banks, which, with the adjoining flat area, decline from 300 to 600 feet below the present sea-level. The deepest sounding in this fjord is 2,844 feet.[1]

In a similar position, just inside the bathymetric line of 100 fathoms on the submerged margin of the continental plateau off the mouth of Delaware Bay, the Coast Survey soundings reveal a short fjord which has a depth of 396 fathoms, or 2,376 feet.[2]

Again, the United States Coast Survey and British Admiralty charts, as Spencer states, record submerged fjord outlets from the Gulf of Maine, the Gulf of St. Lawrence, and Hudson Bay, respectively, 2,664 feet, 3,666 feet, and 2,040 feet below sea-level. The bed of the old Laurentian River from the outer boundary of the Fishing Banks to the mouth of the Saguenay, a distance of more than 800 miles, shown by Professor Spencer's map, is reached by soundings 1,878 to 1,104 feet in depth.

Greenland is divided from the contiguous North American continent and archipelago by a great valley of erosion which is estimated from soundings and tidal records to have a mean depth of 2,510 feet below sea-level for 680 miles through Davis Strait, 2,095 feet for 770 miles next northward through Baffin Bay, and 1,663 feet for the next 55 miles north through Smith Strait.[3]

On the Pacific coast of the United States Prof. Joseph Le Conte has shown that the islands south of Santa Barbara and Los Angeles, now separated from the mainland and from each other by channels 20 to 30 miles

[1] A. Lindenkohl, Report of U. S. Coast and Geodetic Survey, for 1884, pp. 435–438; Am. Jour. Sci. (3), Vol. XXIX, pp. 475–480, June, 1885, and Vol. XLI, pp. 489–499, with map, June, 1891. J. D. Dana, Am. Jour. Sci. (3), Vol. XL, pp. 425–437, Dec., 1890, with map reduced from U. S. Coast Survey chart.

[2] A. Lindenkohl, Am. Jour. Sci. (3), Vol, XLI, p. 498.

[3] Smithsonian Contributions to Knowledge, Vol. XV, pp. 163, 164.

wide and 600 to 1,000 feet deep, were still a part of the mainland during the late Pliocene and early Pleistocene periods.[1]

In northern California Prof. George Davidson, of the United States Coast Survey, as cited by Spencer, reports three submarine valleys about 25, 12, and 6 miles south of Cape Mendocino, sinking respectively 2,400, 3,120 and 2,700 feet below the sea-level where they cross the 100-fathom line of the marginal plateau.[2] If the land here were to rise 1,000 feet, these valleys would be fjords with sides towering high above the water, but still descending beneath it to profound depths. The time of great elevation permitting erosion of these and a large number of other submerged valleys of the Californian coast is shown by Le Conte to have been the Pliocene period, with culmination of the uplift in the early part of the Pleistocene.[3]

Farther to the north, Puget Sound and the series of sheltered channels and sounds through which the steamboat passage is made to Glacier Bay, Alaska, are submerged valleys of erosion, now filled by the sea, but separated from the open ocean by thousands of islands, the continuation of the Coast Range of mountains. From the depths of the channels and fjords Dr. G. M. Dawson concludes that this area had a preglacial elevation at least about 900 feet above the present sea-level during part or the whole of the Pliocene period.[4]

The general absence of Pliocene formations along both the Atlantic and Pacific coasts of North America indicates, as pointed out by Prof. C. H. Hitchcock, that during this long period all of the continent north of the Gulf of Mexico held a greater altitude, which from the evidence of these submarine valleys is known to have culminated in an elevation at least 3,000 feet higher than that of the present time. Such plateau-like uplift of the continent appears to have exerted so great influence on its meteorologic conditions, bringing a cooler climate throughout the year, that it finally became enveloped by ice-sheets to the southern limit of the glacial striæ, till, and moraines, stretching from Nantucket and Cape Cod to New York City, Cincinnati, St. Louis, Bismarck, and thence westward to the

[1] Bulletin of the California Academy of Sciences, Vol. II, 1887, pp. 515–520.
[2] Ibid., Vol. II, pp. 265–268.
[3] Bulletin, G. S. A., Vol. II, 1891, pp. 323–330.
[4] Canadian Naturalist, new series, Vol. VIII, pp. 241–248, April, 1877.

Pacific somewhat south of Vancouver Island and Puget Sound. The thickness of the ice in the region of the White Mountains and Adirondacks was about 1 mile; and Dana has shown, from the directions of striation and transportation of the drift, that its central portion over the Laurentide highlands between Montreal and Hudson Bay had probably a thickness of fully 2 miles. In British Columbia, according to Dr. G. M. Dawson's observations, it covered mountain summits 5,000 to 7,640 feet above the sea.[1]

LATE GLACIAL OR CHAMPLAIN SUBMERGENCE SHOWN BY FOSSILIFEROUS MARINE BEDS OVERLYING THE TILL.

While thus heavily ice-laden, nearly the whole glaciated area of North America sank below its present level, but for the most part only to a slight amount in comparison with its previous elevation. Beginning at or near a line drawn northeastward through New York City, Boston, and Nova Scotia, the extent of the submergence of the land by the sea at the time of the recession of the ice-sheet, as shown by fossiliferous marine deposits overlying the till, increased from 150 feet in southeastern New Hampshire, and 200 to 300 feet on the coast of Maine and New Brunswick, to 375 feet on the St. Lawrence opposite to the mouth of the Saguenay, and 560 feet at Montreal. It was 300 to 400 feet, increasing from south to north, in the basin of Lake Champlain; about 275 feet at Ogdensburg, and 450 feet near the city of Ottawa; and 300 to 500 feet, likewise increasing northward, on the country southwest of James Bay.[2] In Labrador the submergence was of small amount at the south, adjacent to the Gulf of St. Lawrence and Newfoundland; but was about 1,500 feet at Nachvak, near latitude 59° N., according to Dr. Robert Bell;[3] and in northern Greenland and in

[1] Geol. Magazine (3), Vol. VI, 1889, pp. 350–352. Transactions, Royal Society of Canada, Vol. VIII, Sec. IV, 1890, pp. 31, 32.

[2] A. S. Packard, jr., Memoirs, Boston Soc. Nat. Hist., Vol. I, pp. 231–262. J. W. Dawson, Notes on the Postpliocene Geology of Canada; and Am. Jour. Sci. (3), Vol. XXV, 1883, pp. 200–202. C. H. Hitchcock, Proc., A. A. A. S., Vol. XXII, 1873, pp. 169–175; Geology of New Hampshire, Vol. III, pp. 279–282; and Geol. Magazine (2), Vol. VI, 1879, pp. 248–250. G. H. Stone, Am. Jour. Sci. (3), Vol. XL, pp. 122–144, Aug., 1890. R. Chalmers, Transactions of the Royal Society of Canada, Sec. IV, 1886, pp. 139–145. Baron Gerard de Geer, Am. Geologist, Vol. IX, pp. 247–249, April, 1892; and Proc., Boston Soc. Nat. Hist., Vol. XXV, 1892, pp. 454–477. Warren Upham, Proc., Boston Soc. Nat. Hist., Vol. XXIV, pp. 127-141, Dec., 1888; Am. Jour. Sci., May, 1889.

[3] Bulletin, G. S. A., Vol. I, 1890, p. 308.

Grinnell Land it was from 1,000 to 2,000 feet, as shown by raised beach deposits containing marine shells.[1]

That the land northward from Boston was so much lower while the ice-sheet was being melted away is proved by the occurrence of fossil shells of far northern range, including *Yoldia* (*Leda*) *arctica* Gray, now found living only in arctic seas where they receive muddy streams from existing glaciers and from the Greenland ice-sheet. This species is plentiful in the stratified clays resting on the till in the basin of James Bay, in the St. Lawrence Valley, and in New Brunswick and Maine, extending south to Portsmouth, N. H.

Scantier but yet conclusive proofs of the depression of British Columbia under the ice load are found in the valley of the Fraser River and on the Pacific coast, in Vancouver Island and the Queen Charlotte Islands. Lamplugh has observed recent marine shells in a railway cutting on the west bank of the Harrison River, near its junction with the Fraser, at an elevation not less than 100 feet above the sea.[2] At New Westminster, on the Frazer, near its mouth, raised beaches inclosing fragments of marine shells are reported by Bauerman about 30 feet above the river.[3] Fossiliferous marine deposits found in the vicinity of Victoria and Nanaimo, in the southeast part of Vancouver Island, at small elevations above the sea, are believed by Dr. G. M. Dawson to have been formed at or near the wasting edge of the ice-sheet;[4] and near the middle of the northeast side of this island two distinct deposits of till occur, with intervening beds of loess-like silts, from which this author infers two times of glaciation, separated by an interval during which the land was submerged from 100 to 200 feet.[5] Again, in the northeast part of the Queen Charlotte Islands Dr. Dawson

[1] Quart. Jour. Geol. Soc., Vol. XXXIV, 1878, pp. 66, 566. Geol. Magazine (3), Vol. I, 1884, p. 522. A. W. Greely, Report on the U. S. Expedition to Lady Franklin Bay, Grinnell Land, Vol. II, 1888, p. 57.

[2] Quart. Jour. Geol. Soc., Vol. XLII, 1886, pp. 284, 285.

[3] Geol. and Nat. Hist. Survey of Canada, Report of Progress for 1882–83–84, p. 33 B.

[4] Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. II, for 1886, p. 99 B; Quart. Jour. Geol. Soc., Vol. XXXIV, 1878, pp. 97, 98, and Vol. XXXVII, 1881, p. 279. Compare also Mr. G. W. Lamplugh's observations of glacial shell beds at Esquimault, near Victoria, Quart. Jour. Geol. Soc., Vol. XLII, 1886, pp. 276–284.

[5] Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. II, p. 105 B.

finds evidence of submergence to the amount of 200 or 300 feet, while the glacial conditions still endured.[1]

REELEVATION CLOSELY FOLLOWING THE DEPARTURE OF THE ICE-SHEET.

From the Champlain submergence this continent, since the ice weight depressing it was removed, has been uplifted to its present height. The changes in the levels of the beaches of Lake Agassiz prove that in the interior of the continent this movement closely followed the recession of the ice; but on the shores of Hudson Bay the reelevation is still in progress, indicating that no long time has passed since large remnants of the ice in that region melted away. On the Atlantic coast we have different evidence of the rise of the land soon after the ice-sheet disappeared, and the movement there, as also on the coast of British Columbia, resulted in an elevation somewhat higher than now, so that the latest oscillation of these regions has been a subsidence, which is still very slowly continuing.

The recent depression of the eastern seaboard is shown by submarine stumps of trees, rooted where they grew, and by submerged peat bogs, which prove that the whole coast from New Jersey to southern Greenland has lately sunk to a moderate extent. The maximum known by these observations is about 80 feet, at which depth a peat bed occurs under the Tantramar salt marsh at the head of the Bay of Fundy.[2] After the land had recovered from the Champlain depression to its present level, or perhaps to the higher stage noted, the temperature of the North Atlantic was for a time somewhat warmer than now. Southern species of marine mollusks were then able to extend northward to the Gulf of St. Lawrence; but they have since become exterminated by a considerable refrigeration of

[1] Geol. and Nat. Hist. Survey of Canada, Report of Progress for 1878-79, p. 95 B. Trans., Royal Society of Canada, Vol. VIII. Sec. IV, 1890, pp. 3-74. Important notes of recent changes in level of the coast of British Columbia, of the State of Washington, and of southern Alaska, are given by Dr. Dawson in the Canadian Naturalist, new series, Vol. VIII, pp. 241-248, April, 1877. He concludes that this area had a preglacial elevation at least about 900 feet above the present sea-level during part or the whole of the Pliocene period, this being indicated by the fjords; that it was much depressed during the Glacial period; and that in Postglacial time it has been reelevated to a height probably 200 or 300 feet greater than now, followed by subsidence to the present level, the latest part of this oscillation being a somewhat rapid depression of perhaps 10 or 15 feet during the latter part of the last century—a movement which may still be slowly going on.

[2] Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. IV, for 1888-89, pp. 42 A and 10 N.

the sea along the coast north of Cape Cod, excepting isolated colonies.[1] The coast had been reelevated soon after the retreat of the ice-sheet and before the southern mollusks migrated northward, for in the extensive lists of the fossil fauna of the Champlain beds, also denominated in their two principal phases the Leda clays and Saxicava sands, none of the southern species is included, excepting perhaps the oyster in southwestern Maine.[2]

Postglacial elevation of the country along the East Main coast of Hudson Bay and on Hudson Strait is shown by conspicuous raised beaches, according to Dr. Robert Bell, up to heights of at least 300 feet, while probably others much higher exist farther inland.[3] In the region draining from the southwest to James Bay Dr. Bell reports marine shells in stratified beds overlying the glacial drift along the Moose, Mattagami, and Missinaibi rivers up to about 300 feet above the sea;[4] along the Albany and Kenogami rivers up to a height of about 450 feet;[5] and on the Attawapishkat to about 500 feet above the sea.[6] It is also evident that the shores of Hudson and James bays are still undergoing elevation, this being proved by the fresh appearance of the raised beaches, by driftwood far above the limit of the highest waves in storms, and by the gradual shoaling of harbors. The rate of emergence of the eastern coast is estimated by Bell to be between 5 and 10 feet in a century; Outer Digges Island, at the entrance of Hudson Strait, has risen 70 or 80 feet since it was inhabited by Eskimos; and the rise of the mouths of the Churchill, Nelson, and Hayes rivers seems to be similarly rapid, being estimated at about 7 feet in a hundred years.[7]

In British Columbia the reelevation following the Champlain depression was probably completed within a short time, geologically speaking,

[1] Proc., Boston Soc. Nat. Hist., Vol. XXV, 1891–92, pp. 305–316; also Am. Jour. Sci. (3), Vol. XLIII, pp. 201–209, March, 1892.

[2] C. H. Hitchcock, "The geology of Portland," Proc., A. A. A. S., Vol. XXII, for 1873, pp. 163–175. A. S. Packard, Jr., "Observations on the glacial phenomena of Labrador and Maine," Memoirs of the Boston Society of Natural History, Vol. I, 1865, pp. 210–262. J. W. Dawson, "Notes on the Postpliocene geology of Canada," 1872, pp. 112 (from the Canadian Naturalist, new series, Vol. VI).

[3] Geol. and Nat. Hist. Survey of Canada, Report of Progress for 1877–78, p. 32 C; for 1882–83–84, p. 31 D.

[4] Ibid., Report of Progress for 1875–76, p. 340; for 1877–78, p. 7 C.

[5] Ibid., Report of Progress for 1871–72, p. 112; for 1875–76, p. 340; Annual Report, new series, Vol. II, for 1886, pp. 34 and 38 G.

[6] Ibid., Annual Report, Vol. II, p. 27 G.

[7] Geol. and Nat. Hist. Survey of Canada, Report of Progress for 1877–78, pp. 32 C and 25 CC; for 1878–79, p. 21 C; for 1882–83–84, pp. 26, 30, 32 DD; Annual Report, new series, Vol. I, for 1885, p. 11 DD.

after the continental ice-sheet was removed, for Dawson, as before cited, finds that this region since then has stood higher than now, allowing forests to grow on shores which have very recently become again submerged, as on the eastern side of the continent. During the past hundred years, too, a considerable subsidence has taken place, according to Dall, at a locality known as Sinking Point, in Chalmers Bay, Prince William Sound, on the south coast of Alaska; but all of that country west of the one hundred and fiftieth meridian, to Bering Strait and the adjacent Siberian coast, is stated by this author to be now rising at a somewhat rapid rate. Barnacles are found on St. Michael's Island, Norton Sound, at least 15 feet above high tide, and driftwood at many localities on Norton Bay and Sound is "piled in winrows * * * far above the level which the most severe storms and the highest tides now attain, * * * much decayed, but still preserving its shape."[1]

OSCILLATIONS ASSOCIATED WITH GLACIATION IN OTHER COUNTRIES.

Two other areas of great extent, namely, Patagonia and northwestern Europe, have been covered by ice-sheets which have disappeared; and a brief consideration of their oscillations attending the ice accumulation and following its departure will be useful in this discussion of the causes of the Pleistocene earth movements of the basin of Lake Agassiz and of the North American glaciated area.

The many intricate and deep fjords, channels, and sounds on the coast of Patagonia, southern Chile, Tierra del Fuego, and the Falkland Islands, prove that this part of the earth's crust has lately stood for a considerable time at a much higher level than now. This stage of elevation was followed by the envelopment of the southern extremity of the continent by an ice-sheet, which, according to the observations of Darwin and Agassiz, spread its drift northward to latitude 42°, while local glaciers extended farther north. When the ice melted away, the land was depressed lower than now, and since then a reelevation has been in progress. Darwin states that "the land from the Rio Plata to Tierra del Fuego, a distance of 1,200 miles, has been raised in mass (and in Patagonia to a height of between 300

[1] Alaska and its Resources, 1870, pp. 465, 466.

and 400 feet) within the period of the now existing shells. The old and weathered shells left on the surface of the upraised plain still partially retain their colors."[1] Another evidence of the recency of the uplift is supplied by the discovery by Agassiz of a saline lakelet about 150 feet above the sea, in which several species of marine mollusks were found living, identical with those of the neighboring seashores.[2]

Northwestern Europe also had a much greater altitude during the later part of the Tertiary era, in which the land suffered vast denudation, with erosion of fjords and channels that are now submerged hundreds and even thousands of feet beneath the sea. About the northern parts of the British Isles the depths of the submarine channels of the old land surface are approximately from 500 to 800 or 1,000 feet.[3] The Skager Rack, between Denmark and Norway, has a depth of 2,580 feet, with a still deeper submerged valley running from it west and north to the abyssal Arctic Ocean.[4] On the coast of Norway the depth of Christiania fjord below the sea-level is 1,380 feet; of Hardanger fjord, 2,624 feet; and of Sogne fjord, the longest in Norway, 4,080 feet.[5] The preglacial altitude of these portions of the European glaciated area was therefore from 1,000 to 4,000 feet higher than now. Probably many of these submarine channels are more or less filled with the glacial drift, so that valleys originally descending continuously toward the margin of the continental plateau have become in some portions changed to inclosed basins. Another and more probable explanation of the much greater depth of some of the fjords in their inland portion than at their mouths is the depression of the country while it was ice-covered, the coast having subsided much less than the interior.

At the close of the Ice age in Europe, as in America, the glaciated areas were mostly depressed somewhat below their present height. The supposed great submergence, however, up to 1,200 or 1,500 feet or more, which has been claimed by British geologists for northern Wales, northwestern England, and a part of Ireland, on the evidence of marine shells

[1] Voyage of the Beagle, Chapter VIII.

[2] Louis Agassiz: His Life and Correspondence, Vol. II, p. 716.

[3] James Geikie, Quart. Jour. Geol. Soc., Vol. XXXIV, 1878, Pl. XXXIII; The Great Ice Age, 2d ed., pp. 279–284, Pls. IX–XII.

[4] Nature, Vol. XXIII, p. 393, with map of submarine contour.

[5] T. F. Jamieson in Geol. Magazine (3), Vol. VIII, pp. 387–392, Sept., 1891.

and fragments of shells in glacially transported deposits, is shown by Belt, Goodchild, Lewis, Kendall, and others, to be untenable. Indeed, these fossils, not lying in the place where they were living, give no proof of any depression of the land, since they have been brought by currents of the ice-sheet moving across the bed of the Irish Sea. But it is clearly known by other evidence, as raised beaches and fossiliferous marine sediments, that large portions of Great Britain and Ireland were slightly depressed under their burden of ice, and have been since uplifted to a vertical extent ranging probably up to a maximum of about 300 feet.

In Scandinavia the valuable observations and studies of Baron Gerard de Geer, of the Geological Survey of Sweden, have supplied lines of equal depression of the land at the time of the melting away of the ice.[1] This region of greatest thickness of the European ice-sheet is found to have been depressed to an increasing extent from the outer portions toward the interior. The lowest limit of the submergence, at the southern extremity of Sweden, is no more than 70 feet above the present sea-level, and in northeastern Denmark it diminishes to zero; but northward it increases to an observed amount of about 800 feet on the west shore of the Gulf of Bothnia, near latitude 63°. Along the coast of Norway it ranges from 200 feet to nearly 600 feet, excepting far northward, near the North Cape, where it decreases to about 100 feet. In proportion with this observed range of the subsidence on the coasts of Scandinavia, its amount in the center of the country was probably 1,000 feet.

A very interesting history of the postglacial oscillations of southern Sweden has been also ascertained by Baron de Geer, which seems to be closely like the postglacial earth movements of the northeastern border of North America. As on our Atlantic coast, the uplift from the Champlain submergence in that part of Sweden raised the country higher than now. The extent of this uplift appears to have been about 100 feet on the area between Denmark and Sweden, closing the entrance to the Baltic Sea, which became for some time a great fresh-water lake. After this another depression of that region ensued, opening a deeper passage into the Baltic

[1] "Quaternary changes of level in Scandinavia," Bulletin, G. S. A., Vol. III, 1892, pp. 65–68, with map of the late glacial marine area in southern Sweden.

than now, giving to this brackish body of water a considerably higher degree of saltness than at present, with the admission of several marine mollusks, notably *Litorina litorea* Menke, which are found fossil in the beds formed during this second and smaller submergence, but are not living in the Baltic to-day. Thus far the movements of southern Sweden are paralleled by the postglacial oscillations of New England and eastern Canada; but a second uplifting of this part of Sweden is now taking place, whereas no corresponding movement has begun on our Atlantic border. It seems to be suggested, however, that it may yet ensue. The subsidence has ceased or become exceedingly slow in eastern New England, while it still continues at a measurable rate in New Jersey, in Cape Breton Island, and in southern Greenland.

So extensive agreement on opposite sides of the Atlantic, and also in Patagonia, in the oscillations of the land while it was ice-covered and since the departure of the ice-sheets, has probably resulted from similar causes, namely, the pressure of the ice weight and resilience of the earth's crust when it was unburdened. The restoration of isostatic equilibrium in both North America and Europe is attended by minor oscillations, the conditions requisite for repose being overpassed by the early reelevation of outer portions of each of these great glaciated areas.

In view of this harmony in the epeirogenic movements of the two continents during the Glacial and Recent periods, it seems evident that the close of the Ice age was not geologically long ago, for equilibrium of the disturbed areas has not yet been restored. Furthermore, the parallelism in the stages of progress toward repose indicates nearly the same time for the end of the Glacial period on both continents, and approximate synchronism in the pendulum-like series of postglacial oscillations.

PLEISTOCENE OSCILLATIONS INDEPENDENT OF GLACIATION.

In this class of changes are to be included, wholly or in part, the postglacial elevation of Grinnell Land and the northwestern coast of Greenland, 1,000 to 2,000 feet;[1] post-Pliocene upward movements of 2,000 feet or

[1] Quart. Jour. Geol. Soc., Vol. XXXIV, 1878, pp. 66 and 566. Geol. Mag. (3), Vol. I, 1884, p. 522. A. W. Greely, Report of the U. S. Expedition to Lady Franklin Bay, Grinnell Land, Vol. II, 1888, p. 57.

more in Jamaica and Cuba,[1] and of about 1,100 feet in Barbados;[2] the recent uplift of the coast of Peru at least 2,900 feet,[3] which in diminished amount seems to extend along the whole range of the Andes;[4] its probable connection with the upheaval of the Cordilleras of North America, where Le Conte[5] and Diller[6] believe that the elevatory movements reached their greatest intensity in early Quaternary time, causing a rise of several thousands of feet in the Sierra Nevada; and the apparently correlative subsidence of a great area dotted with coral islands in the Pacific. The Pleistocene uplifts of the Andes and Rocky Mountains and of the West Indies make it nearly certain that the Isthmus of Panama has been similarly elevated during this period. On the line of the Panama Railway the highest land rises only 299 feet above the sea, and the highest on the proposed route of the Nicaragua Canal is about 133 feet; while the Isthmus nowhere attains the height of 1,000 feet.[7] It may be true, therefore, that submergence of this isthmus was one of the causes of the Glacial period, the continuance of the equatorial oceanic current westward into the Pacific having greatly diminished the Gulf Stream, which carries warmth from the tropics to the northern Atlantic and northwestern Europe.

Pleistocene mountain-building is known to have occurred on a most massive scale in Asia, where the Himalayas, stretching 1,500 miles from east to west, and towering 20,000 to 29,000 feet above the sea, are known to have been formed in great part during this latest geologic period,[8] con-

[1] J. G. Sawkins, Reports on the Geology of Jamaica, 1869, pp. 22, 23, 307, 311, 324–329; W. O. Crosby, "On the mountains of eastern Cuba," Appalachia, Vol. III, pp. 129–142. Compare William M. Gabb's memoir, "On the topography and geology of Santo Domingo," Trans., Am. Phil. Soc., Vol. XV, pp. 103–111.

[2] "The geology of Barbados," by A. J. Jukes-Browne and J. B. Harrison, Quart. Jour. Geol. Soc., Vol. XLVII, pp. 197–250, Feb., 1891.

[3] A. Agassiz, Proc., Am. Acad. of Arts and Sciences, Vol. XI, 1876, p. 287; and Bulletin of the Museum of Comparative Zoology at Harvard College, Vol. III, pp. 287–290. Above this height, at which corals are found attached to rocks, recent elevation of much greater amount seems to be indicated by terraces, by saline deposits, and by the presence of eight species of Allorchestes, a marine genus of crustacea, in Lake Titicaca, 12,500 feet above the sea.

[4] Darwin's Voyage of the Beagle, Chapter XVI.

[5] Am. Jour. Sci. (3), Vol. XXXII, pp. 167–181, Sept., 1886; Vol. XXXVIII, pp. 257–263, Oct., 1889.

[6] U. S. Geol. Survey, Eighth Annual Report, for 1886–87, pp, 428–432.

[7] Charles Ricketts, "The cause of the Glacial period, with reference to the British Isles," Geol. Magazine (2), Vol. II, 1875, pp. 573–580. A. R. Wallace, The Geographical Distribution of Animals, Vol. I, p. 40.

[8] Manual of the Geology of India, by H. B. Medlicott and W. T. Blanford; Calcutta, 1879; Part I, pp. lvi, 372; Part II, pp. 569–571, 667–669, 672–681.

temporaneously with the glaciation of North America, Europe, and portions of the southern hemisphere. Within the same time the great table-land of Thibet[1] and much of central and northwestern Asia have been uplifted; the tract extending from the Black and Caspian seas northeast to the Arctic Ocean has risen to form a land surface; and the deep basin of Lake Baikal probably has been formed in connection with these crustal movements. Accompanying the formation of the Himalayas, there has been doubtless much disturbance by faults, local uplifts, and here and there plication of strata along the whole complex east to northwest and west mountain system of Oceanica, Asia, Europe, and northern Africa, from New Guinea, the Sunda Islands, Anam, and Siam, to the Caucasus, Carpathians, Balkans, Apennines, Alps, Pyrenees, and Atlas mountains, stretching quite across the Eastern Hemisphere; but the greater part of the relief from the previously existing deformation of the earth was doubtless along the central part of the belt, in the colossal Himalayan range. In like manner the North American Cordilleras and the Andes, reaching in one continuous mountain system from the Arctic Circle to Cape Horn, have experienced within the same period great disturbances, as already noted, similar to those of the mountains of southern Europe and the adjacent part of Africa. With this American orographic belt is also probably to be associated the mountain system, consisting largely of volcanoes now active, which forms the Aleutian Islands, Kamchatka, the Kurile Islands, Japan, Formosa, the Philippines, Borneo, and Celebes, lying nearly in the same great circle with the Andes and Rocky mountains, and with them continuous in an arc of about 240°. Along two lines transverse to each other, one having an extent of half and the other of two-thirds of the earth's circumference, the great lateral pressures of the earth's crust which probably caused the elevation and glaciation of extensive areas during the Pleistocene period have been relieved by plication, faults, and uplifts in the processes of the formation of mountain ranges.

Asia had no extensive ice-sheet like those of Europe and North America, probably because a sufficient elevation was not attained there until the Himalayas and Thibet were uplifted in the Glacial period. The southern

[1]Ibid., Part II, pp. 585, 586, 669-672.

latitude of the Himalayan range and the position of Thibet and Mongolia in an arid and partly rainless belt, which stretches thence west to the Sahara, forbade their glaciation; but from these recently uplifted Asiatic table-lands and mountains the most extensive Pleistocene stratified deposits in the world have been brought down by rivers and spread in the vast low plains of Siberia, eastern China, and northern India, sloping gently toward the sea, into which the finer part of this alluvium is carried. All the puzzling features of the Chinese loess formation,[1] reaching to great elevations with such thickness and slopes of its surface that it could not be so accumulated as alluvium of flooded streams under the present conditions, seem to be readily explained by referring its deposition to annual floods from immense snow melting during the European and North American Glacial period upon the gradually rising central part of the Asiatic continent, which consists largely of easily erosible strata, and had in pre-Glacial time become extensively disintegrated by weathering under a dry climate.

EFFECTS OF ICE ACCUMULATION ON THE SEA-LEVEL.

During the Glacial period significant changes of the sea-level were caused, first, by abstraction of water from the ocean and its deposition on the land as snow, which under pressure made the vast ice-sheets; and, second, by ice attraction of the ocean, lowering it still further, except in the vicinity of glaciated lands. An area of about 4,000,000 square miles in North America and another of about 2,000,000 square miles in Europe were covered by ice-sheets, which in their maximum extent had probably an average thickness of a half or two-thirds of a mile, or perhaps even of 1 mile. Disregarding the accumulation of ice-sheets of smaller extent, which probably or possibly existed at the same time in parts of Asia and of the southern hemisphere, as also the glaciers of mountain districts, the lowering of the ocean surface, which covers approximately 145,000,000 square miles, would slightly exceed 100 feet, if the mean depth of the ice accumulation was a half mile. More probably the sea over the whole globe was thus

[1] Baron Richthofen, Geol. Magazine (2), Vol. IX, 1882, pp. 293–305. J. D. Whitney, Am. Naturalist, Vol. XI, pp. 705–713, Dec., 1877. R. Pumpelly, Am. Jour. Sci. (3), Vol. XVII, pp. 133–144, Feb., 1879. E. W. Hilgard, Am. Jour. Sci. (3), Vol. XVIII, pp. 106–112, Aug., 1879.

depressed fully 150 feet, which would correspond to an average of about 3,600 feet of ice on the glaciated areas of North America and Europe.

For the second factor in causing such changes, Mr. Woodward's computations before cited indicate that gravitation toward the ice would further depress the ocean probably 25 to 75 feet within the tropics and in the southern hemisphere, while it would raise the level enough near the borders of the ice-sheets to counterbalance approximately the depression due to the diminution of the ocean's volume, and would lift portions of the North Atlantic and of the Arctic Sea perhaps 200 or 300 feet higher than now. Stream erosion while the sea was lowered to supply the ice of the Glacial period may explain the indentations of the southeastern coast of the United States, as Pamlico and Albemarle sounds, besides similar inlets in many other parts of the world; but the excavation of Chesapeake and Delaware bays seems more probably referable, at least in part, to the time of preglacial elevation, with the channeling of the now submerged Hudson fjord.

PROBABLE RELATIONSHIP OF EPEIROGENIC MOVEMENTS THROUGHOUT THE WORLD TO GLACIATION.

In view of the extensive Pleistocene oscillations of land and sea both in glaciated and unglaciated regions, it seems a reasonable conclusion that, while some of these movements, as those affecting the beaches of Lake Agassiz, have resulted directly from the accumulation and dissolution of ice-sheets, more generally, when the whole area of the earth is considered, they have been independent of glaciation. May not such movements of the earth's crust, then, have elevated large portions of continents, as the northern half of North America and the northwestern part of Europe, either together or in alternation, to heights like those of the present snow-lines on mountain ranges, until these plateaus became deeply channeled by fjords and afterward covered by ice-sheets? For the recentness of the Ice age, believed to have ended in the region of Lake Agassiz and the Laurentian lakes not more than 10,000 to 6,000 years ago,[1] forbids our referring the glacial climate to conditions brought about by a period of increased eccentricity of the earth's orbit from 240,000 to 80,000 years ago, which has been

[1] See Chapter V, pp. 238-240.

so ably maintained by Croll and Geikie; and some other adequate cause or causes must be sought for the glaciation of these great continental areas and other districts of smaller extent, both in the northern and southern hemispheres, during the Pleistocene period.

The principal cause of the Ice age seems to the writer to be probably found by the clew supplied in the relations already stated of the earth's crust and interior whereby they become somewhat distorted from the spheroidal form while the process of contraction goes forward, the lateral pressure bearing down some portions of the earth's surface and uplifting other extensive areas. The protuberant plateaus, swept over by moisture-laden winds, would be the gathering grounds of vast ice-sheets. A similar explanation of the Glacial period was long ago proposed by Lyell and Dana, but without referring the elevatory movements to the earth's deformation by contraction and accumulating lateral pressure while approaching an epoch of mountain-building, which fundamental principle was first suggested to me in an article from the pen of Prof. W. O. Crosby on the origin and relations of continents and ocean basins.[1]

During the periods immediately preceding great plications and shortening of segments of the earth's crust involved in the formation of lofty mountain ranges, the broad crustal movements causing glaciation would be most widespread and attain their maximum vertical extent. The accumulation of ice-sheets may have brought about the depression of their areas, with corresponding elevation of other plateaus, which in turn would become ice-covered, so that the epochs of glaciation of the Northern and Southern hemispheres, or of North America and Europe, may have alternated with each other.[2] More probably, however, as shown by the observations and studies of Salisbury, Geikie, Chamberlin, the present writer, and others, the glaciations of North America and Europe were approximately synchronous; and even the successive stages of the Ice age on these two continents

[1] Proc., Boston Soc. Nat. Hist., 1883, Vol. XXII, pp. 455–460.

[2] Compare the opinions of Capt. F. W. Hutton, cited in A. Geikie's Text-book of Geology, 2d ed., p. 912, that the former greater extension of glaciers in New Zealand was caused by an increase in the elevation of the land, and that it belonged to a much earlier time than the Ice age in the northern hemisphere, probably to the Pliocene period.

have a remarkable parallelism, which probably indicates a similar sequence of events on the opposite sides of the North Atlantic.[1]

When the building up of a great range of mountains ensued, which may have been initiated and accelerated by the repeated depressions under ice weight and consequent transfers of the earth's deformation from one region to another, the accumulated stress in the earth's crust with development of immense lateral pressure would be diminished below the limit of its competency to cause glaciation.

It seems probable that the rate of the earth's contraction has been somewhat uniform throughout the vast ages known to us by the researches of geology; but the corrugation of the earth's surface in mountain-building has been much more rapid in some epochs than in others, and between the times of formation of great mountain ranges there have been long intervals of quietude.[2] The slowly progressing contraction of the globe has been uninterrupted, and in some way the cooled outer part of the crust which has not shared in this diminution of volume has been able to accommodate itself to the shrinking inner mass. As stated in previous pages, this has probably resulted in distortion of the earth's form, both of the whole thickness of the crust and of the plastic or molten interior, within moderate limits, during the periods of quiet, until so much lateral pressure has been accumulated as to compress, fold, and uplift the strata of a mountain range.

In attributing the severe climate of the Glacial period to great uplifts of the areas glaciated through such deformation preparatory to the process of mountain-building, it is distinctly implied that Pleistocene time has been at first exceptionally marked by such broad crustal movements and has since gained comparative rest from the lateral stress to which they were due by equally exceptional plication, uplifts, and faults, in the birth and growth of mountains. Further, it is implied also that stress in the earth's crust had been gradually increasing through long previous time, while the processes of mountain-building failed to keep pace with contraction, but

[1] R. D. Salisbury, Am. Jour. Sci. (3), Vol. XXXV, pp. 401–407, May, 1888. James Geikie and T. C. Chamberlin, The Great Ice Age, third ed., 1894; Journal of Geology, Vol. III, pp. 241–277, April–May, 1895. Warren Upham, Am. Naturalist, Vol. XXIX, pp. 235–241, March, 1895; Am. Geologist, Vol. XV, pp. 273–295, May, 1895.

[2] Dana's Manual of Geology, 3d ed., p. 795. Prestwich's Geology, Vol. I, Chapter XVII.

were still sufficient to keep the earth's deformation less than is required to produce glaciation; for no evidences of intense and widely extended glacial conditions are found in the great series of Tertiary and Mesozoic formations, representing the earth's history through probably ten to fifteen million years. And, indeed, these conclusions, drawn from the Pleistocene period and the absence of glaciation through vast eras preceding, accord well with the known age and stages of growth of mountain ranges that have been formed during these eras. No period since the close of Paleozoic time has been more characterized by mountain-building than the comparatively short Pleistocene, whose duration may probably be included within 100,000 or 150,000 years.

Elevation of broad areas, as half of North America and half of Europe, either synchronously or, less probably for these companion continental regions adjoining the North Atlantic, in alternation, to such heights that their precipitation of moisture throughout the year was nearly all snow, gradually forming ice-sheets of great thickness, seems consistent with the conditions of the earth's crust and interior which are indicated by the changes in the levels of the beaches of Lake Agassiz. A plastic interior or molten magma beneath the solid crust accounts for the uplift of the area of this glacial lake, with its gradual increase from south to north, and also appears, in connection with contraction of the earth and the formation of mountain ranges, to afford an adequate explanation of glaciation. It is probable that the great uplifts which are thus supposed to have caused ice accumulation were very slow in their progress, and that their effect upon extensive continental areas was so distributed that the maximum changes in slope on their borders would nowhere exceed 20 or 30 feet or at the most 50 or 75 feet per mile, while perhaps some portions of the uplifted region would receive no change of slope. And the subsidence beneath the weight of accumulated ice was probably slow, though apparently much faster than the processes of preglacial and interglacial elevation, and was similarly distributed, no limited district being greatly changed. Excepting the areas where disturbances of mountain-building or extraordinary rising or sinking of mountain ranges were associated with these movements, the contour of the country, with its valleys, hills, and mountains, remained in general the same from preglacial time, through the Ice age, to the present, with only changes of slope, commonly small in any limited tract, which, in long distances, allowed great upheavals and depressions. The elevation of the central part of glaciated areas, with downward slopes on all sides, favored the outward flow of the ice-sheets and their erosion and transportation of the drift. But mountains and hills jutted upward in ridges and peaks within the moving ice-sheets, as they now stand forth in bold relief above the lowlands; and the ice, with its inclosed drift, was pushed around and over them, some portions being deflected on either side, and usually a larger part being carried upward across their tops.

EPEIROGENIC MOVEMENTS INDEPENDENT OF GLACIATION OFTEN COMBINED WITH OTHERS DUE TO THE ICE WEIGHT AND TO ITS REMOVAL.

The foregoing review of the Pleistocene epeirogenic movements of various parts of the world shows that many of them have affected countries which never were glaciated. In these areas they have been mostly or wholly without any demonstrable relationship to glaciation. Again, in countries which have become ice-covered, we learn from fjords and submerged river valleys that great epeirogenic elevation of the land preceded the accumulation of the ice-sheets. These movements also were evidently independent of glaciation, not being caused by it, though, on the other hand, the writer believes that they were the cause of the ice accumulation and of its resulting drift deposits. The more extended epeirogenic movements of the earth within the Pleistocene period have probably arisen from the relationship of the earth's crust and interior, and in areas of sufficiently high latitudes, and in mountain districts, they have here and there produced epochs of glaciation.

While so widespread earth movements not due to glaciation have been taking place throughout this period, it is evident that some of them would probably be in progress in glaciated countries at the same time with the ice accumulation and after the departure of the ice-sheets, being combined in their effects with other crustal movements due to the weighting of the crust by the ice-load, and to its relief by the ice-melting. Thus, for example, while we may refer the rise of the greater part of North America from the

Late Glacial or Champlain subsidence to the resilience of the earth's crust on account of the departure of the ice, the uplifting of northern Labrador and of northern Greenland and Grinnell Land has been too great in vertical extent to be proportionate with the probable thickness of the ice-sheet on those areas. Their uplifting has been in its greater part probably due to a movement independent of glaciation.

Epeirogenic movements of regions which have not been ice-covered seem in some instances referable to a transfer of disturbances from glaciated districts. Accompanying the subsidence of ice-loaded tracts, there were doubtless uplifts of contiguous regions, perhaps sometimes including outer portions of the country glaciated. For example, the upheaval of the St. Elias range and of its foothills, found by Russell to have taken place subsequent to a long and severe glaciation of that region,[1] may very probably have been correlative with the Champlain subsidence ending the Glacial period in the northern United States.

UPLIFT OF THE BASIN OF LAKE AGASSIZ APPARENTLY ATTRIBUTABLE WHOLLY TO THE DEPARTURE OF THE ICE-SHEET.

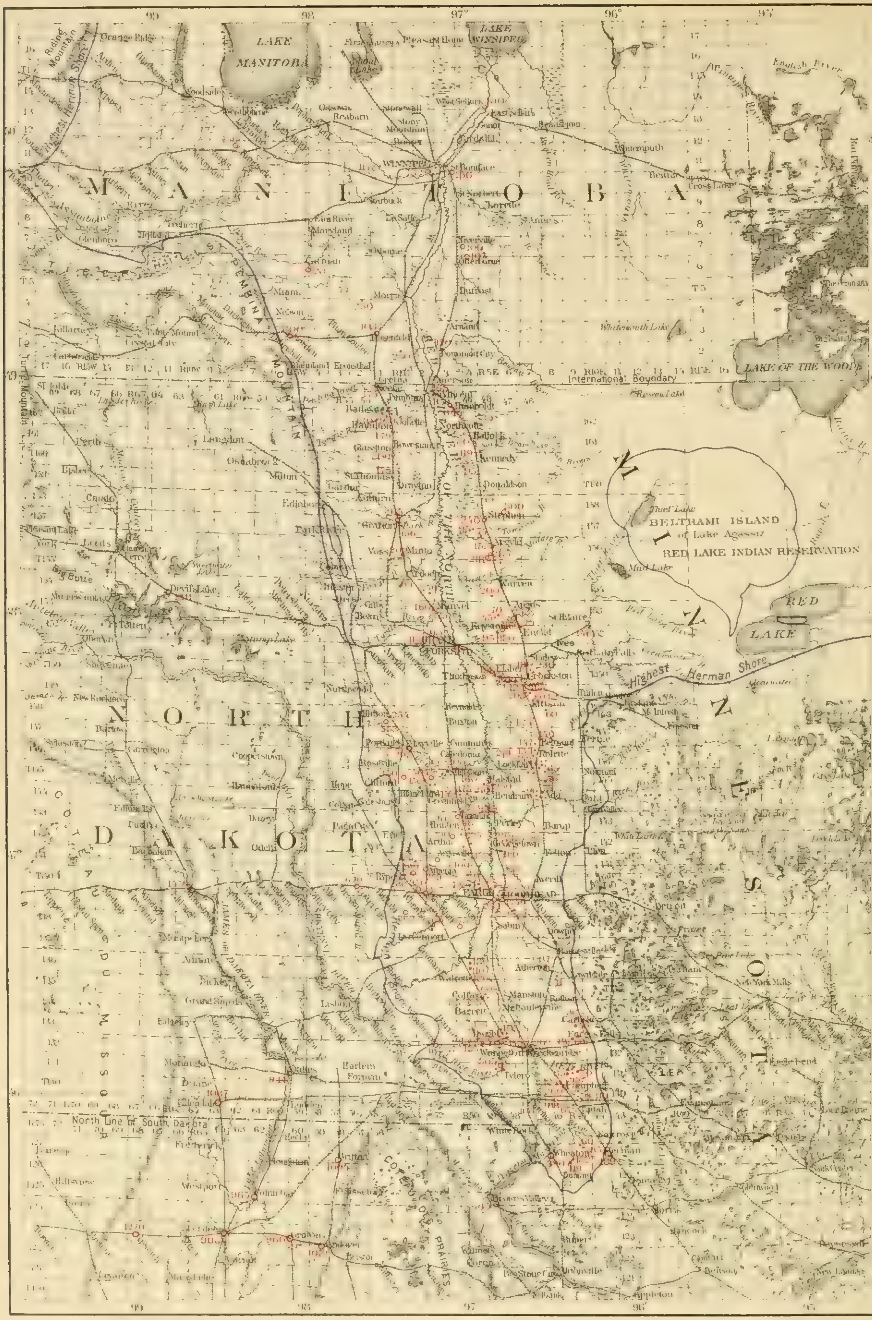
Within the basin of the glacial Lake Agassiz I believe that high preglacial altitude, affecting likewise all the North American glaciated area, was terminated by the depression of the land while it was ice-burdened. All the movements which this basin has since experienced, as recorded by the changes of levels of the beaches, seem to have resulted from the tendency of the earth's crust to regain equilibrium, after the ice melted away, by a moderate uplift, with inflow of the plastic or molten magma beneath. The very regular gradation in the differential uplifting of the old shorelines, and its progress almost to completion while this lake was still held by an ice barrier, accord well with this explanation. No element of epeirogenic disturbance is known here which is not readily accounted for by this hypothesis. The explanation is found to be adequate and applicable to all the features of the progressive changes in the levels of the beaches. The very small component which could be ascribed to postglacial change in the

[1] "Mount St. Elias and its glaciers," Am. Jour. Sci. (3), Vol. XLIII, pp. 169–182, with map, March, 1892.

temperature of this part of the earth's crust on account of the departure of the ice would be practically insignificant in comparison with the direct effects of the removal of the ice weight; and its small proportion in the whole result would be to diminish instead of to increase its amount. Upon this district, therefore, it seems well-nigh certain that no other important movement of elevation or of depression has taken place in connection with that dependent on relief from the previously existing ice load.

But a fraction of the changes in the levels of this basin was due to the diminution and final cessation of the ice attraction in its effect to draw water surfaces and the geoid level upward in the direction of the ice mass. The proportion of this element may apparently have been as large as a sixth or a quarter of the measured changes of levels; but its supposed amount, so far as I am able to indicate it, is derived from estimates of the volume of the ice-sheet, rather than from a discrimination of this part from that due to elevation of the land. The two agencies of change were nearly synchronous in their action upon the levels of the old shores, their effects were distributed in the same manner in their relationship to time and space, and both had almost ceased within this basin when the ice barrier of the glacial lake was melted away.

After progressively uplifting the area of Lake Agassiz, first chiefly in its southern half and afterward mostly at the north, but nearly ending their work here while the glacial lake yet existed, these agencies have since been elevating the basin of Hudson and James bays. The latter part of their labor remains unfinished, but during each century approaches considerably toward its completion, which will fully restore equilibrium or isostasy to this portion of the earth's crust.



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MAP SHOWING THE DISTRIBUTION AND DEPTHS OF ARTESIAN WELLS IN THE RED RIVER VALLEY.

Scale, about 42 miles to an inch.

Artesian Wells wholly in the Drift   Artesian Wells and other Borings reaching to the Bed Rocks

Depths are noted in feet below the surface. For their relationship to the sea level, see Plate X.

CHAPTER X.

ARTESIAN AND COMMON WELLS OF THE RED RIVER VALLEY.

On the broad, fertile plain called the Red River Valley, which was the central and deepest portion of the bed of the glacial Lake Agassiz, many artesian wells have been obtained within the thick drift sheet, deriving their supply of water from porous beds or veins of sand and gravel beneath, and frequently between, deposits of bowlder-clay or till. The depths of these wells vary from 40 feet, or rarely less, to about 250 feet, or rarely 300 feet, while a few others penetrate deeper, passing into the underlying Cretaceous beds, or northward into Silurian strata. The height to which the water is capable of rising above the surface of the ground is often only a few feet and seldom more than 25 to 50 feet. Hundreds of these flowing wells, commonly 1 to 2 inches in diameter of pipe, are in use on farms, at grain elevators, and for the supply of towns, on both the Minnesota and North Dakota sides of the Red River. Their distribution and range of depth, both in the United States and in Manitoba, are shown in Pl. XXXVII. Some tracts of considerable area within this valley, however, fail to find artesian water, but even these generally encounter water-bearing layers at depths corresponding with those of the artesian wells, from which water rises nearly to the surface.

Common wells throughout the whole area of Lake Agassiz and upon the adjoining country usually obtain a supply of water sufficient for ordinary farm and domestic uses within depths ranging from 10 feet to 50 feet or occasionally more. But the quality of their water, as also of the artesian wells, is often disagreeable. The fame of the Red River Valley for its large harvests of "No. 1 hard" wheat, averaging 20 bushels to the acre, is nearly equaled by the unenviable reputation of the water supplied by its wells. The drift here contains much of the carbonates and sulphates of lime and magnesia, derived from the Cretaceous strata which covered this area and were plowed up by the ice-sheet, mixed with much drift from the region of granites, gneiss, and crystalline schists on the northeast, and redeposited as till. The soluble alkaline ingredients of the soil impregnate all the waters of wells, springs, and streams in this region; and in the dry season they are often seen forming a white or gray efflorescence on the surface of the land, resembling frost, sometimes a quarter of an inch thick, being the residue from the evaporation of moisture rising through the porous ground.[1]

Wheat thrives better where the soil contains a considerable proportion of these alkaline salts, so that their presence throughout the Red River Valley is one principal cause of its superiority in wheat raising; and this, grown year after year, gradually takes away these ingredients and prepares the land for other crops. But their effect as dissolved everywhere in wells and streams partly offsets this benefit, and makes the water of all this region objectionably hard, and sometimes in wells and springs noticeably bitter or salt.

The hardness of the water, on account of which it will not dissolve soap, is produced by the carbonates of lime and magnesia, which it has taken up in soaking through the ground. The best way to provide water satisfactory for washing with soap is by collecting the rain from roofs. By the construction of cisterns, this soft water, which also is preferable for drinking and cooking, may be kept constantly on hand, there being generally a good supply of rain in all seasons excepting winter, when it falls as snow.

The water of streams and wells in this district contains a small proportion of the alkaline sulphates of lime, soda, magnesia, and potassa, and carbonate of soda, though not usually enough to be perceptible to the

[1]An analysis, by Prof. James A. Dodge, of an "alkali" efflorescence from a surface of till in Murray County, southwestern Minnesota, showed it to be a hydrous sulphate of magnesia, with slight traces of soda, potash, and lime. The proportions of sulphur trioxide and magnesia were the same as in epsomite (epsom salt), but it had less than half the percentage of water of crystallization required by epsomite. (Geol. and Nat. Hist. Survey of Minnesota, Tenth Annual Report, for 1881, p. 202.)

Efflorescent saline matter from one of the alkaline lakes of the Missouri Coteau, analyzed by Dr. G. M. Dawson, contained of sulphate of magnesia, 49.06 per cent; sulphate of soda, 47.73 per cent; and chloride of sodium, 0.75 per cent. A similar saline incrustation from the Souris Valley, examined qualitatively by Dr. Dawson, showed only the magnesic and sodic sulphates. (Geology and Resources of the Forty-ninth Parallel, p. 293.)

taste. These waters, however, more readily than pure water, decompose the wooden curbing, which, being the most convenient and cheapest material, is too commonly used in this region, destitute of stone quarries. The wooden well-curbing, which is commonly pine, soon contaminates the water, and when such wells are left stagnant or only drawn from slightly, the water becomes too foul in smell and taste to be drunk, even by cattle, and it may be the cause of sickness, as intestinal diseases and typhoid fevers, before reaching this stage. Let such wells be pumped so as to fill them with new water every day, and these offensive qualities are principally removed. If bricks, stone, or cement pipe are used for lining wells, and the water in them is frequently renewed by being largely drawn from,

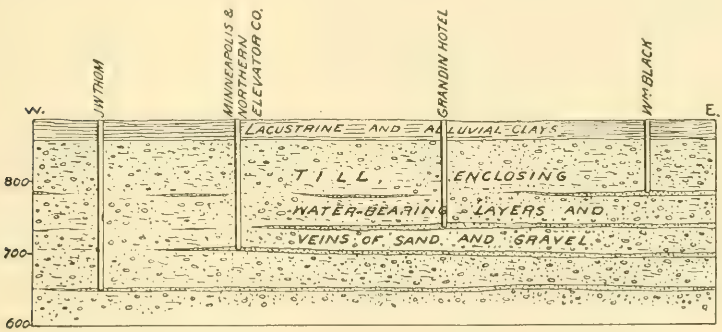

FIG. 31.—Diagram indicating the probable relationship of sources of artesian water at Grandin, N. Dak.

it is generally wholesome and palatable, and is well adapted for nearly all uses, excepting for washing with soap, as before mentioned, and for steam boilers, in which the large amount of scale deposited from it in evaporation is objectionable.[1]

SOURCES OF THE ARTESIAN WATERS.

The narrow areas that may be sometimes occupied by the sand and gravel layers in the drift sheet yielding artesian water, or the thin and in some places entirely deficient condition of these layers, is illustrated by the

[1] See two articles by Prof. N. H. Winchell, on "The water supply of the Red River Valley," Geol. and Nat. Hist. Survey of Minnesota, Sixth Annual Report, for 1877, pp. 9–12, and Ninth Annual Report, for 1880, pp. 166–174.

different depths at which a flow of water was first encountered by four wells in the village of Grandin, N. Dak. These wells, whose probable relationship in their supplies of water may be nearly as shown in fig. 31, are on an area only about 50 rods in extent, and their several depths are 105 feet, 158 feet, 187 feet, and 248 feet. Either the upper water-bearing beds here are narrow, like a stream course, so that they were not found by the deeper wells, or, if they exist as sheets of great width as well as length, they are in some parts thinned out, allowing the impervious till above to rest on that below. The experience in well-boring here is representative of inequalities in depths of flowing wells near together in many other places. More frequently, however, water is obtained from a nearly uniform depth throughout a considerable area, and it is then evidently derived from a single broadly continuous stratum.

FRESH WATER FROM POROUS BEDS OF THE DRIFT SHEET.

Though the water-bearing gravel and sand inclosed between deposits of till often occur in narrow veins or in beds which sometimes thin out, even near where they yield copious artesian flows, they must have a great extent in the direction from which the water supply is received, descending from levels higher than the Red River Valley plain, where the flowing wells are situated. At least, this must be the case where the water is fresh or only very slightly saline, as at Grandin and in all the southern part of the valley as far northward as the vicinity of Crookston, in Minnesota, and Blanchard, in North Dakota, and in a large district of Manitoba, including Winnipeg and the Mennonite reserve east of the Red River.

Upon the higher lands adjoining both sides of this valley the water of rains is partly absorbed by percolation into the drift sheet, chiefly through the most sandy and gravelly layers. Thence it passes in these porous veins and beds downward to the valley plain, where it is heavily pressed by the head of water filling their upper portions. When a boring penetrates the impervious overlying beds of alluvial and lacustrine clay and of till the water usually rises with a strong flow above the surface (fig. 32). If the height and pressure of its head are inadequate for this, it rises in the pipe to a permanent level, below which in most cases it can not be lowered by pumping, as a continual supply is received from the distant portions of the subterranean reservoir.

SALINE AND ALKALINE WATER FROM THE DAKOTA SANDSTONE.

North of Crookston and Blanchard to the international boundary and in the south edge of Manitoba the water of the artesian wells, almost without exception, tastes distinctly saline and alkaline. It seems very probable

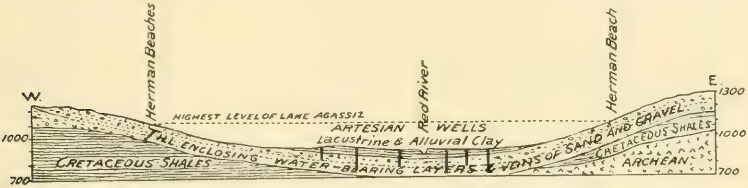

FIG. 32.—Section across the Red River Valley, showing the water supply of its fresh artesian wells. Horizontal scale, 15 miles to an inch.

that the water-bearing beds of that large portion of the Red River Valley differ widely in the origin of their water supply from the foregoing. Instead of deriving their water, like the fresh artesian wells, from rainfall upon higher parts of the drift surface contiguous to the Red River Valley, there seem to be good reasons for believing that the brackish water is mainly

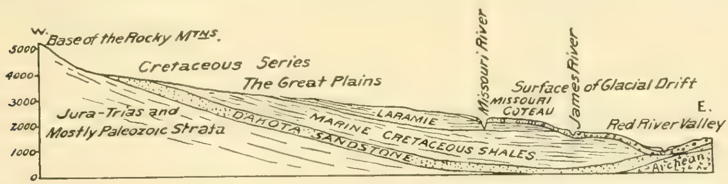

FIG. 33.—Section from the Rocky Mountains to the Red River Valley, showing the water supply of its saline artesian wells. Horizontal scale, 150 miles to an inch.

from the Dakota sandstone, which forms the base of the Cretaceous series in the upper Missouri, Assiniboine, and Saskatchewan basins, coming through that sandstone from its outcrops on the flanks of the Rocky Mountains and Black Hills, and permeating upward into the drift of the Red River Valley from areas where this sandstone is the underlying bed-rock (fig. 33). That the saline artesian waters found within the basin of Lake Agassiz come from these distant sources is indicated by the artesian wells obtained farther west in North and South Dakota, which also need to be somewhat particularly described here, since they are intimately related with the saline springs and flowing wells of the Red River Valley.

Relationship to the artesian wells of Devils Lake and the James River Valley.—Deep artesian wells of somewhat saline and alkaline water, like that of the part of the Red River Valley just described, are obtained on a belt that extends across North and South Dakota from Devils Lake to Yankton and Vermillion, including the greater part of the James River basin. Wherever borings along this belt have penetrated to the Dakota sandstone, the lowest Cretaceous formation in the upper Missouri region, artesian water has been found. Probably as many as 200 wells have been bored, their depths ranging from 900 to 1,550 feet, except in the southern part of the James and Vermillion valleys, where many wells are only 600 to 750 feet deep, and a few, the farthest southeast, are between 300 and 400 feet in depth. These wells are mostly 5 or 6 inches in diameter, and their strong pressure, commonly from 50 to 175 pounds per square inch at the surface, makes them valuable not only for fire hydrants but also to furnish power for manufacturing purposes. Several wells have been bored at Aberdeen, and five years ago fifteen wells were in use in Yankton. The pressure of the wells in Yankton is sufficient to raise the water 129 feet, and in numerous places along the middle portion of the James River Valley, as Huron, Redfield, and Aberdeen, the pressure corresponds to a rise of more than 400 feet above the surface.

The sections of these deep wells in North Dakota and on the high land between the James and Missouri rivers in South Dakota include, beneath the drift, the Fort Pierre, Niobrara, and Fort Benton divisions of the Cretaceous series; but along the lower part of the James River and on the Vermillion erosion during the Tertiary era removed the upper portion of these beds, leaving only the Fort Benton shales or a part of that formation over the Dakota sandstone.

At Devils Lake, where an artesian well was bored in 1889, about 6 feet above the depot, or 1,470 feet above the sea, the section was as follows:

Section of well at Devils Lake.

	Feet.
Glacial drift, till as on the surface	25
Dark shale, nearly alike through its whole thickness, including the Fort Pierre and Fort Benton formations, with no noticeable calcareous beds at the intermediate Niobrara horizon	1,403
Gravel, of granitic pebbles up to a half 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

From the sandstone, at the depth of 1,470 feet, brackish artesian water came up with a rush, but sand soon filled the pipe so that the supply became small. It is from this level that the present flow comes, through narrow slits cut in the pipe. The boring was continued 40 feet deeper, but no such strong flow was obtained below. In July, 1889, when the well was completed, it supplied 1,800 barrels of water in twenty-four hours, or about 40 gallons per minute, the diameter of the pipe being 8 inches, reduced to 3½ in the lower portion. The stream flowing away was then turbid with the exceedingly fine particles of sand brought up from the bottom.

The Jamestown well, bored in the winter of 1886–87, about 8 feet below the depot, or 1,400 feet above the sea, went through a similar section of about 1,400 feet of shales, with no distinctly different portion to indicate the place of the Niobrara formation.

At Deloraine, in Manitoba, 1,644 feet above the sea, situated close northwest of the Turtle Mountain and about 100 miles northwest from the city of Devils Lake, an unsuccessful boring for an artesian well has found, under a thickness of 94 feet of glacial drift, a somewhat uniform section of shales, largely calcareous in their lower half, extending to the total depth of 1,800 feet, according to Mr. J. B. Tyrrell, of the Geological Survey of Canada.[1] At that depth, which was bored during the years 1888 to 1890, the top of the Dakota sandstone had not been reached, so that it is known to be at least nearly 200 feet lower than at Devils Lake and more than 156 feet below the sea-level.

[1] Trans., Roy. Soc. Canada, Vol. IX, Sec. IV, 1891, pp. 91–97.

Artesian wells deriving water from the Dakota sandstone in North and South Dakota.

Locality.	Distance on latitude and longitude from the southeast corner of South Dakota.		Depth.	Pressure at surface per square inch.	Head above surface, computed from pressure.	Altitudes above the sea.		
	North.	West.				Source of water in upper part of the Dakota sandstone.	Surface, railroad at station.	Head, computed from pressure.
	Miles.	*Miles.*	*Feet.*	*Pounds.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Devils Lake	390	119	1,511	....	....	0	1,464	....
Jamestown	305	110	1,476	95	219	—76	1,408	1,619
Oakes	252	80	944	....	....	378	1,322	....
Ellendale	243	101	1,087	125	288	362	1,449	1,737
Britton	228	72	1,004	....	....	350	1,354	....
Columbia	216	92	965	175	404	339	1,304	1,708
Andover	202	72	1,070	90	208	406	1,476	1,684
Groton	204	82	960	[1] 187	432	344	1,304	1,736
Aberdeen	206	101	908	175	404	392	1,300	1,704
Ipswich	204	127	1,270	70	162	260	1,530	1,692
Mellette	186	101	900	....	....	400	1,300	....
Ashton	174	101	915	[1] 50	115	381	1,296	1,411
Doland	167	81	950	....	....	405	1,355	....
Redfield	166	103	900	175	404	395	1,295	1,699
Faulkton	176	132	1,210	....	....	363	1,573	....
Hitchcock	148	97	950	175	404	389	1,339	1,743
Huron	130	88	863	175	404	424	1,287	1,691
Miller	140	126	1,148	125	288	439	1,587	1,875
Highmore	141	148	1,552	25	58	338	1,890	1,948
Harold	141	163	1,453	80	185	348	1,801	1,986
Woonsocket	108	91	750	153	353	558	1,308	1,661
Letcher	97	85	600	....	....	700	1,300	....
Mitchell	84	79	600	....	....	701	1,301	....
Plankinton	85	102	750	140	323	778	1,528	1,851
Kimball	87	126	1,068	95	219	720	1,788	2,007
Vermillion	20	24	365	15	35	785	1,150	1,185
Meckling	23	31	338	....	....	818	1,156	....
Yankton	27	46	610	56	129	586	1,196	1,325
Tyndall	34	71	730	....	....	688	....	....
Fort Randall	38	106	600	45	104	660	[2] 1,260	1,364

[1] The pressure reported at Ashton is 100 or 125 pounds less than would be expected in proportion with other localities, and at Groton it is somewhat more. The discrepancy of the latter, however, is no greater than may be due to the superior permeability of the water-bearing stratum.

[2] Approximate altitude of high water of the Missouri River at Fort Randall.

For the greater part of my notes of the artesian wells of South Dakota, also of Ellendale and Oakes, in North Dakota, I am indebted to "Resources of Dakota," published by the Territorial commissioner of immigration in 1887, and to recent correspondence with Prof. G. E. Culver, then of the University of South Dakota, and with Prof. C. W. Hall, of the University of Minnesota. These data, with those obtained by me at Devils Lake and Jamestown, I have placed in tabular form for convenient comparison, showing (1 and 2) the distances of the localities north and west from the mouth of the Big Sioux River at the southeast corner of South Dakota; (3) depths of the wells; (4) their pressure at the surface, wherever it has been obtainable, in pounds per square inch; (5) the corresponding height or head to which the water would rise above the surface; (6) the altitude, with reference to the sea-level, of the source of the artesian water in the Dakota sandstone; (7) the altitude of the surface; and (8) the height of the computed head of water above the sea.

The flow of water from the Dakota sandstone at Devils Lake is found exactly at the sea-level, but the top of the sandstone formation is 39 feet higher. At Jamestown the flow rises from a depth of 76 feet below the sea-level, indicating that the top of the Dakota sandstone there sinks slightly lower than at Devils Lake. Along the distance of 85 miles from north to south between these points its level is probably nearly constant, and borings at intervening towns, as New Rockford and Carrington, will doubtless find artesian water at or slightly below the sea-level. Farther south the top of the sandstone and its water supply are found throughout a large district of South Dakota and the south edge of North Dakota at a plane from 250 to 450 feet above the sea. Continuing still southward, from Woonsocket to the Missouri River the water-bearing stratum rises to altitudes from 558 to 818 feet above the sea, the highest levels being at Meckling and Vermillion, the most southeastern localities of this list.

The same southeastward ascent of the Dakota sandstone reaches to its outcrops on the southwest side of the Missouri in Dakota County, Nebr., whence its name is derived, opposite to the southeast corner of South Dakota. There, and at other extensive outcrops in western Iowa and eastern Nebraska, having approximately the same elevations as the surface at Vermillion and Yankton, the water coursing through this sandstone finds outlet in springs; and these avenues of discharge explain the gradual reduction in the altitude of the head of water above the sea-level as the series of wells is followed from north to south and from west to east. Somewhat uniform altitudes of 1,619 to 1,743 feet are recorded as the heights to which water would rise in pipes for all the wells where pressure is reported, from Jamestown to Huron and Woonsocket, excepting those west of Huron, which will be considered later, and the well at Ashton, where the reported pressure is probably erroneous, lacking 100 pounds or more of its true amount. At Hitchcock the head of water has a computed altitude of 1,743 feet above the sea; 18 miles to the south, at Huron, it is 1,691 feet; 22 miles farther south, at Woonsocket, it is 1,661 feet; and 81 miles still farther south, at Yankton, it is only 1,325 feet. Fig. 34 illus-

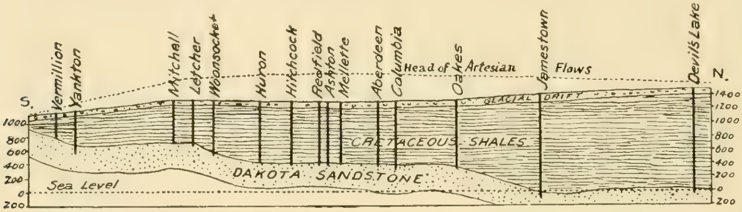

FIG. 34.—Section showing the series of artesian wells from Devils Lake and Jamestown southward to Yankton and Vermillion. Horizontal scale, 75 miles to an inch.

trates this relationship of the series of artesian wells extending from north to south in the James River Valley.

Equally distinct gradients of the plane of water head are found descending from west to east on and near the latitudes of Huron and Yankton. Thus at Harold, 75 miles west of Huron, the head is 1,986 feet above the sea; at Highmore, 15 miles east of Harold, it is 1,948 feet; at Miller it

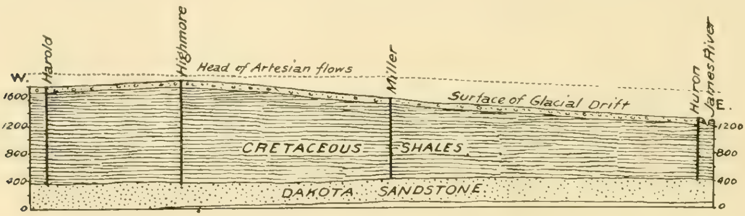

FIG. 35.—Section showing the series of artesian wells from Harold eastward to Huron. Horizontal scale, 15 miles to an inch.

has declined 73 feet in a distance of 22 miles farther to the east; and in the 38 miles thence to Huron it falls 184 feet more. The relationship of the wells at these places is shown in Fig. 35. From Kimball to Plankinton, in 24 miles from west to east, the water head declines 156 feet. Between Fort Randall and Yankton, in a distance of 60 miles from west to east, this plane descends at least 40 feet, but the descent is more if the well at Fort Randall is at a considerable height above the Missouri River. In 25 miles from Tyndall eastward to Yankton, the water head sinks probably 150 or 200 feet. In the next 22 miles eastward to Vermillion the descent is 140 feet. This feature of the artesian water supply is caused, as before stated, by its outlets through springs in outcrops of the Dakota sandstone, which begin 30 to 40 miles southeast of Vermillion and extend thence southeast and south.

All the eastern outcrops of the Dakota sandstone are lower than the upper portions of the James River basin and the wells farther west at Highmore and Harold. These outcrops, therefore, can not be the sources from which the sandstone receives its artesian water, but, as we have seen, they are the avenues of its natural outflow. We must look instead to the western outcrops of this formation, where it skirts the Black Hills and exposes its upturned edges along the base of the Rocky Mountain ranges, for the areas upon which the water is carried downward into the sandstone. Thence we know this stratum to be continuous beneath the plains to the James River Valley, for there are no nearer or other inlets from which the copious supply of the artesian wells can come. At a plane of similar or greater depth an artesian reservoir exists beneath much, if not all, of the country westward to the mountains. The gradients of the altitudes to which the water of wells is capable of rising along east-to-west lines in South Dakota, as at Huron, Miller, and Highmore, are approximately the same as the average westward ascent of the country, demonstrating this western origin of the water supply, and indicating that such wells may be obtained upon an extensive region of the arid plains.

The quantities of alkaline matter and salt dissolved in the water of these wells usually give it a brackish taste, and make it unfit for drinking by people and for ordinary domestic uses; but it is drunk freely by cattle and horses, with no unfavorable effects. These mineral ingredients seem to have been derived from the Cretaceous shales, and probably in part from beds in the Dakota formation, with which the water has been in contact during its slow percolation hundreds of miles through the sandstone. They are the same in kind and similar in amount with the mineral matter of Devils

Lake, concentrated by evaporation without outlet from the water of inflowing streams and springs, which bring very small amounts of these salts dissolved from the drift and Cretaceous shale of the adjoining country.

Much shale gravel and detritus, rich in sulphates, are present in the glacial drift over nearly the entire Red River basin, and the percolating rain water found by the fresh artesian wells in the drift of the southern and northern ends of the Red River Valley has acquired minute quantities of alkaline and saline matter. But where its proportion is large, as in the brackish water of the wells from Crookston and Blanchard northward to the edge of Manitoba, it seems impossible that so remarkable difference can be due to diversity in the material of the drift, or to longer time and better opportunity afforded to the water for such impregnation while percolating through porous beds or veins in the drift. The saline and alkaline artesian waters of the drift gravel and sand along this central portion of the Red River Valley therefore appear to be received mainly from the same Dakota sandstone which supplies the deep wells of the James River Valley.

Several wells in the vicinity of Casselton, Blanchard, and Mayville, ranging from 317 to 404 feet in depth, pass through the drift and enter a very fine white sandstone, probably the Dakota formation, from which they obtain flows of brackish water. About a dozen miles east of Blanchard the drift was found to have a total thickness of 310 feet, below which a boring went 107 feet into exceedingly fine white sandstone, finding, however, no artesian water, apparently because of the very close texture of the rock. The top of the sandstone in these wells is 650 to 575 feet above the sea. If it is the Dakota sandstone, as seems probable and nearly certain, it has an ascent of about 600 feet in 75 miles east from the meridian of Devils Lake and Jamestown, rising in its approach toward the Silurian, Cambrian, and Archean areas of Minnesota and Manitoba. Along a line about 13 miles north of the international boundary the top of the Dakota sandstone ascends eastward from a depth at Deloraine exceeding 156 feet below the sea-level to a depth of only 320 feet below the surface at Morden, where it is encountered 658 feet above the sea.[1] The Dakota sandstone

[1] J. B. Tyrrell, "Three deep wells in Manitoba," Trans., Roy. Soc. Canada, Vol. IX, Sec. IV, 1891, pp. 91–104.

there rises more than 800 feet in a distance of 106 miles from west to east. It appears thus to be the bed rock, on which the drift is deposited, beneath extensive tracts in the middle part and on the western border of the Red River Valley, discharging there its alkaline and saline artesian water into the permeable beds of gravel and sand in the drift sheet, whence it rises in the brackish wells of that district.

Relationship to artesian wells at Tower City and Grafton, N. Dak., Humboldt, Minn., and Morden (not artesian) and Rosenfeld, Manitoba.—An artesian well at Tower City, 50 miles east of Jamestown, is 4 feet lower than the depot, being 1,168 feet above the sea. Its depth is 670 feet, through drift, 163 feet; Cretaceous shales, with occasional beds of sandstone, 502 feet; and quicksand, into which the boring advanced only 5 feet. Salty and alkaline water outflows $9\frac{1}{2}$ gallons per minute, and is capable of rising 33 feet above the surface. The scanty flow and low head of this well suggest that the water-bearing stratum may be inclosed within the Fort Benton shales; but its altitude, 500 feet above the sea-level, accords with that of the sandstone reached by wells at Blanchard and Mayville, so that more probably it is the top of the Dakota formation. The plane of the head of water supplied from this formation would show a marked descent northeastward, as is thus indicated at Tower City, still more distinctly at Morden (page 81), and in less degree at Devils Lake, in comparison with Jamestown and Ellendale, if there are abundant natural outlets of this artesian water along the Red River Valley, as appears to be true, by springs rising through the drift. These brackish springs occur on many of the streams tributary to the Red River both in North Dakota and Minnesota, the most remarkable being on Forest and Park rivers, which therefore were formerly called the Big and Little Salt rivers.[1]

Beneath the central part and western side of the Red River Valley, the Dakota sandstone, forming the base of the great Cretaceous series which is penetrated by the wells at Deloraine, Devils Lake, and Jamestown, probably abuts in many places, with horizontal or only slightly inclined stratification, upon the eroded western edges of the similarly almost horizontally bedded Silurian rocks. Undoubtedly a part of the salt contained

[1]Translations of their Ojibway names, according to Rev. J. A. Gilfillan, Fifteenth Annual Report, Geol. and Nat. Hist. Survey of Minnesota, for 1886, p. 463.

in the water of the artesian wells in the drift of the Red River Valley, as well as of its saline springs, has been supplied directly from the underlying Silurian formations, which, as stated in Chapter III, yield an artesian flow of brackish water at Grafton, N. Dak, and flows of rather strong brine at Humboldt, Minn., and Rosenfeld, Manitoba. The relationship of these rocks to the adjacent Dakota sandstone suggests a question whether possibly some of the salt in the water of this sandstone at Morden, Tower City, Devils Lake, and along the James River Valley may have come from the same source. The gradients of the head of the artesian wells of North and South Dakota show, however, by their descent toward the east and southeast, that the currents of water running through the Dakota sandstone come from the Rocky Mountains and Black Hills, and that they find egress by springs in the Red River Valley and in the valley of the Missouri southeast of Yankton. On account of the greater weight of saline than of fresh water, this subterranean drainage of the vast western plains may have contributed much to the quantity and strength of the brine contained in the deep reservoir of the Silurian strata beneath the bed of Lake Agassiz. It seems to me, therefore, more likely that the Dakota sandstone has been chiefly a giver rather than a recipient of salt, in its relation to the Silurian formations penetrated by the Humboldt and Rosenfeld wells.

ANALYSES OF WATERS FROM WELLS, STREAMS, AND LAKES IN THE RED RIVER VALLEY AND THE ADJOINING REGION.

The following analyses show the composition of the mineral matter which had been held in solution and was left after evaporation by the waters of several wells, streams, and lakes in this region. The first column in each analysis gives the proportion of the several ingredients to the weight of the natural water in parts per million. In the second column their percentages are stated, and the third notes the weight of each in grains per standard gallon of the United States, containing 231 cubic inches. Nos. 1, 3 to 7, and 10 to 12 were analyzed under the direction of Prof. James A. Dodge, of the University of Minnesota, by his assistants, Mr. C. F. Sidener[1] and Prof. William A. Noyes.[2] No. 2 was analyzed by Mr. G. Christian Hoffman,[3] and Nos. 8 and 9 by Mr. Frank D. Adams,[4] of the Geological Survey of Canada. The hardness of these waters, when noted, is in degrees of Wanklyn's scale.

1. Brine from the artesian well at Humboldt, Minn. *(pages 74–76)*.

Ingredients dissolved in the water.	Parts per million.	Percentage.	Grains per gallon.
Silica	208.5	0.4	12.15
Alumina	40.9	0.1	2.38
Carbonate of iron	18.5	....	1.08
Sulphate of lime	1,990.2	3.5	116.08
Sulphate of magnesia	1,236.4	2.1	71.12
Carbonate of magnesia	1,347.5	2.4	78.60
Chloride of magnesium	1,567.6	2.7	91.44
Chloride of calcium	2,684.0	4.7	156.55
Chloride of potassium	724.3	1.3	42.26
Chloride of sodium	47,402.5	82.8	2,764.99
Phosphoric acid	Traces.	....	....
Total	57,220.4	100.0	3,336.65

The proportion of common salt in the total dissolved solids of this water is 82.8 per cent, or about five-sixths. "This gives it," as Prof. N. H. Winchell remarks, "more than the average per cent of chloride of sodium found in the Michigan brines, while the total solid matter in solution is only from one-third to one-half as much."[5]

[1]Geol. and Nat. Hist. Survey of Minnesota, Thirteenth Annual Report, pp. 43, 98, 101, 102 (Nos. 1, 10, and 11); and Fourteenth Annual Report, p. 345 (No. 4). Am. Geologist, Vol. VI, p. 218 (No. 3).

[2]Geol. and Nat. Hist. Survey of Minnesota, Eleventh Annual Report, pp. 172–175 (Nos. 5, 6, 7, and 12).

[3]Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. I, pp. 13–15 M.

[4]Ibid., Report of Progress for 1878–79, pp. 8–11 H. (Reduced to refer to United States standard gallon. Compare pp. 7–12 C.)

[5]Geol. and Nat. Hist. Survey of Minnesota, Thirteenth Annual Report, p. 43.

2. Brine from the artesian well at Rosenfeld, Manitoba (pages 78–80).

Ingredients dissolved in the water.	Parts per million.	Percentage.	Grains per gallon.
Silica	12.6	....	0.73
Carbonate of iron	Traces.	....	....
Carbonate of lime	77.7	0.2	4.53
Sulphate of lime	4,151.1	9.6	242.05
Borate of soda	Traces.	....	....
Chloride of magnesium	1,722.5	4.0	100.44
Chloride of calcium	398.2	0.9	23.22
Chloride of potassium	417.9	1.0	24.37
Chloride of sodium	36,497.1	84.3	2,128.15
Total	43,277.1	100.0	2,523.49

Bromine and iodine are both present, the former apparently exceeding the latter. The proportion of magnesium assumed to be in combination with them as bromide and iodide amounts to 59.6 parts per million. This brine is slightly purer than that of the Humboldt well, but its content of salt is one-fourth less.

3. Water from the artesian well at Jamestown, N. Dak. (page 529).

Ingredients dissolved in the water.	Parts per million.	Percentage.	Grains per gallon.
Silica	35.7	1.6	2.0823
Alumina	3.5	0.2	.2041
Carbonate of iron	2.2	0.1	.1283
Carbonate of lime	188.0	8.5	10.6743
Sulphate of lime	249.0	11.2	14.5241
Sulphate of magnesia	154.2	6.9	8.9944
Sulphate of soda	1,139.4	51.2	66.3602
Sulphate of potash	81.5	3.7	4.7523
Chloride of sodium	369.1	16.6	21.5296
Phosphates	Traces.	....	....
Total	2,222.6	100.0	129.2496

Hardness of this water, 21 degrees. In the test for the amount of its dissolved organic matter, by Tidy's permanganate method, the oxygen consumed in three hours was 0.7 part per million.

The water of the Jamestown well tastes strongly brackish, and is representative of many of the wells of the James River Valley deriving their supply from the Dakota sandstone; but some are less brackish and even palatable, while some others are more saline. According to Prof. Henry Montgomery, of the University of North Dakota, the water of the artesian well at Devils Lake (page 529) contains approximately 0.25 per cent of chloride of sodium (common salt), as compared with the whole weight of the water, or seven times more than the Jamestown water; and about 0.37 per cent of sulphate of soda (Glauber's salt), or nearly three and a half times more than is shown in the foregoing analysis.

4. *Water from the Miniwaste artesian well, Browns Valley, Minn. (page 89).*

Ingredients dissolved in the water.	Parts per million.	Percentage.	Grains per gallon.
Silica	13.0	0.5	0.7583
Alumina	0.4		.0233
Protoxide of iron	0.7		.0408
Sulphate of lime	51.8	2.1	3.0215
Sulphate of magnesia	27.9	1.1	1.6270
Sulphate of soda	1,452.6	59.0	84.7302
Phosphate of lime	5.0	0.2	.2916
Chloride of sodium	912.7	37.1	53.2378
Chloride of potassium	Traces.		
Carbonic acid	Traces.		
Nitrates	Traces.		
Total	2,464.1	100.0	143.7305

The test for organic matter, with permanganate of potash, showed 1.63 parts oxygen consumed per million. This water has a considerable reputation for its aperient and alterative medicinal properties. Its content of Glauber's salt is about one-fourth more than in the water of Jamestown, and it has two and a half times as much common salt.

5. Water from an artesian well at Carman, Polk County, Minn.

Ingredients dissolved in the water.	Parts per million.	Percentage.	Grains per gallon.
Silica	26.2	5.7	1.529
Alumina and oxide of iron	1.5	0.3	.087
Carbonate of lime	88.6	19.4	5.171
Carbonate of magnesia	52.9	11.6	3.087
Carbonate of lithia	Traces.		
Carbonate of potash	11.5	2.5	.671
Nitrate of potash	Traces.		
Carbonate of soda	73.8	16.2	4.308
Sulphate of soda	47.5	10.1	2.773
Borax	Traces.		
Chloride of sodium	156.5	34.2	9.134
Bromide of potassium	Traces.		
Iodide of potassium	Traces.		
Total	458.5	100.0	26.760

Nitrates, absent; phosphates, absent. The test with permanganate showed 0.85 parts oxygen consumed by organic matter per 1,000,000 water. Hardness, 12.5 degrees. This well is less saline and alkaline than many others on both sides of the Red River thence northward to the international boundary; but it is more so than most of the artesian wells southward in this valley.

6. Water from the Red River at Fergus Falls, Minn.

Ingredients dissolved in the water.	Parts per million.	Percentage.	Grains per gallon.
Silica	14.3	7.0	0.83412
Alumina and oxide of iron	1.2	0.6	.06999
Carbonate of lime	101.0	50.0	5.89133
Carbonate of magnesia	71.4	35.4	4.16476
Carbonate of lithia	Traces.		
Carbonate of potash	4.2	2.1	.24919
Bromide of potassium	Traces.		
Nitrate of potash	Traces.		
Nitrite of potash	Traces.		
Carbonate of soda	5.8	2.8	.33831
Sulphate of soda	1.8	0.9	.10499
Chloride of sodium	2.3	1.2	.13456
Total	202.0	100.0	11.78725

Iodine, absent; phosphoric acid, traces. The permanganate test showed 1.4 parts oxygen consumed by organic matter per 1,000,000 water. Hardness, 9.5 degrees.

7. Water from the Red River at St. Vincent, Minn.

Ingredients dissolved in the water.	Parts per million.	Percentage.	Grains per gallon.
Silica	13.0	4.6	0.75829
Oxide of iron and alumina	1.0	0.4	.05833
Carbonate of lime	97.8	34.3	5.70467
Sulphate of lime	35.7	12.6	2.08238
Nitrate of lime	1.1	0.4	.06416
Carbonate of magnesia	81.9	28.7	4.77723
Phosphate of lithia	0.6	0.2	.03499
Sulphate of potash	8.7	3.1	.50747
Nitrite of potash	Traces.		
Bromide of potassium	Traces.		
Sulphate of soda	21.7	7.6	1.26576
Chloride of sodium	22.9	8.1	1.33576
Total	284.4	100.0	16.58904

Iodine, absent. In the permanganate test the oxygen required for oxidation was 3.5 per million. Hardness, 19 degrees.

8. Water from the Red River one-fourth of a mile above the mouth of the Assiniboine.

Ingredients dissolved in the water.	Parts per million.	Percentage.	Grains per gallon.
Carbonate of lime	105.6	20.4	6.155
Carbonate of magnesia	154.3	29.8	8.996
Sulphate of lime	96.3	18.6	5.614
Sulphate of potash	14.5	2.8	.846
Sulphate of soda	67.4	13.0	3.938
Chloride of sodium	79.9	15.4	4.656
Total	518.0	100.0	30.205

The hardness of this water is 23.9 degrees.

9. Water from the Assiniboine River one-fourth of a mile above its junction with the Red River

Ingredients dissolved in the water.	Parts per million.	Percentage.	Grains per gallon.
Carbonate of lime	173.0	35.4	10.090
Carbonate of magnesia	137.7	28.2	8.027
Sulphate of potash	13.2	2.7	.769
Sulphate of soda	117.4	24.1	6.845
Chloride of sodium	46.8	9.6	2.730
Total	488.1	100.0	28.461

The hardness of this water was 20.6 degrees, being slightly less, like its total content of mineral matter, than in the water of the Red River at the confluence of the Assiniboine. The stage of rivers, whether in partial flood or at the low level of seasons of drought, decides to a large extent whether their dissolved ingredients are little or much. The amount of clayey mud and fine sand borne along mechanically suspended in the water of rivers is vastly increased by their rise and stronger currents in times of floods; but the amount of matter dissolved in the water, which is the only portion considered in these analyses, is then much less than at their lowest stages, when they hold little or no mud in suspension.

Although in the waters of the last two analyses the Red River had more dissolved matter, both mineral and organic, than the Assiniboine, the average proportion of the latter throughout the year is probably the greater. Samples of water from these streams, similarly collected by Dr. Robert Bell and analyzed by Dr. Baker Edwards, showed only about two-thirds as much of both mineral and organic matter in the Red River as in the Assiniboine.[1] These samples were collected October 18, 1873, and those of analyses 8 and 9 were taken on October 26, 1879. Recent rains in larger amount on one of these basins than on the other, or differences in their volume due to lack of rainfall, probably account for these different results of the analyses.

[1] Geol. and Nat. Hist. Survey of Canada, Report of Progress for 1878–79, pp. 7–12 C.

10. Water from Big Stone Lake.

Ingredients dissolved in the water.	Parts per million.	Percentage.	Grains per gallon.
Silica	106.50	19.2	6.2090
Carbonate of iron	2.20	0.4	.1283
Carbonate of lime	110.50	20.0	6.4455
Carbonate of magnesia	63.00	11.4	3.6748
Sulphate of magnesia	148.05	26.7	8.6358
Sulphate of potash	12.48	2.3	.7280
Sulphate of soda	95.63	17.3	5.5781
Chloride of sodium	15.12	2.7	.8819
Phosphates	Traces.		
Total	553.48	100.0	32.2814

Oxygen consumed by organic matter in the permanganate test, 1.32 parts per million. This water is remarkable for its large proportion of silica.

11. Water from the Mississippi River at Brainerd, Minn.

Ingredients dissolved in the water.	Parts per million.	Percentage.	Grains per gallon.
Silica	18.2	9.3	1.0616
Alumina	3.9	2.0	.2275
Carbonate of iron	4.2	2.2	.2453
Carbonate of lime	111.1	57.1	6.4787
Carbonate of magnesia	27.7	14.2	1.6169
Carbonate of potash	6.0	3.1	.3499
Carbonate of soda	19.4	9.9	1.1292
Sulphate of soda	3.0	1.5	.1749
Chloride of sodium	1.5	0.7	.0875
Nitrates	Traces.		
Phosphates	(1)		
Total	195.0	100.0	11.3715

[1] Slight traces.

Oxygen required for the oxidation of organic matter by the permanganate test, 1.28 parts per million.

12. Water from Lake Superior, collected at Grand Marais, Minn.

Ingredients dissolved in the water.	Parts per million.	Percentage.	Grains per gallon.
Silica	0.5	1.1	0.02917
Alumina and oxide of iron	Traces.		
Carbonate of lime	30.8	67.4	1.79656
Carbonate of magnesia	9.1	19.9	.53080
Carbonate of lithia	Traces.		
Carbonate of potash	1.9	4.2	.11083
Nitrate of potash	0.2	0.5	.01167
Nitrite of potash	[1]		
Carbonate of soda	0.5	1.1	.02917
Sulphate of soda	0.6	1.3	.03499
Chloride of sodium	2.1	4.5	.12249
Total	45.7	100.0	2.66568

[1] Minute traces.

Iodine and bromine, absent; phosphates and borates, absent. The test with permanganate showed 0.35 parts oxygen consumed by organic matter per 1,000,000 water.

Hardness, 3.5 degrees, so low amount being less than the average of "soft" well and spring waters.

This analysis of the very pure water of Lake Superior (perhaps even more remarkable for its small content of organic than of mineral matter) is presented for comparison with the waters of the Red River Valley. It contains less than one-fourth as much mineral matter, and only slightly more than this proportion of organic matter, as compared with the water of the Upper Mississippi River at Brainerd. These proportions, in comparison with the water of Big Stone Lake, are respectively one-twelfth and about one-fourth. The Red River at Fergus Falls has about four and a half times as much mineral matter as Lake Superior, and four times as much organic matter; but at St. Vincent these proportions are increased respectively to 6 and 10, and the former is still further raised to 11 at the mouth of the Assiniboine and the city of Winnipeg.

The artesian water at Carman has ten times as much mineral matter and two and a half times as much organic matter as Lake Superior, and these proportions for the Jamestown artesian well are respectively about

49 and 2. But a far greater contrast is afforded by the water of the Humboldt artesian well, which contains about 1,250 times more dissolved mineral matter than Lake Superior, while the ratio of their salinity is 22,572 to 1.

It should be remarked, however, that these comparisons are made with one of the purest lakes of the world. Few analyses of the natural waters of lakes and streams show so little dissolved mineral and organic matter. Reindeer Lake, lying in the great Archean area of central Canada, north of Lake Winnipeg, is one of these, for it has only about three-fifths as much dissolved matter as Lake Superior; and an equally small amount, or even slightly less, is found in the waters of Bala Lake, in Wales, and Loch Katrine, in Scotland.[1]

USE OF ARTESIAN WATER FOR IRRIGATION.

Within the agricultural eastern half of both North and South Dakota, occasional years, and sometimes two or three years in succession, have much less rainfall than the average. These years of drought and consequent complete or partial failure of crops have been exceedingly discouraging to the people of these States, checking the immigration which poured in rapidly during a series of comparatively wet years, with magnificent crops, from 1880 to 1885. The great fertility of the soil, however, when supplied with sufficient moisture, causes the questions to be asked: Can artificial irrigation be provided during seasons of drought on this area? and, Can artesian wells be profitably used for this purpose?

These questions are not of so great importance for the Red River Valley, where no drought has severely affected the crops during the fifteen or twenty years since the earliest settlement and development of farming, as for the closely adjacent country on the west, from the vicinity of Devils Lake southward along the Sheyenne and James rivers, where many farmers sowing 50 to 200 acres or more in wheat harvested little or nothing during the very dry years of 1887 to 1889. But within the Red River Valley portions of the summers of these and other years have been so dry that artificial irrigation would have benefited the grain fields. In a few instances

[1] Geol. and Nat. Hist. Survey of Canada, Report of Progress for 1880-81-82, pp. 6, 7 H.

and on a small scale the water of artesian wells in this valley has been applied to patches of garden vegetables and other crops near dwellings.

Will it be profitable, on a larger scale, to store the water of artesian wells in reservoirs for use in the season of growing crops, and especially during severe droughts? To this inquiry we may reply by computing the amount of water needed for irrigating a given space, as a quarter-section of 160 acres, the usual area of a homestead. Allowing a depth of 12 inches of water for this use during the growing season, the year's supply of water from a well flowing 100 gallons per minute is required, without allowance being made for leakage or evaporation from the reservoir. The Devils Lake well would, therefore, irrigate only 64 acres, and the Jamestown well, flowing 375 gallons per minute, will water less than a section 1 mile square. But each of these wells cost about $7,000, to which must be added the cost of the construction of reservoirs and irrigating ditches, placing the expense of such water supply far beyond its prospective value for ordinary agriculture.

Unusual difficulties were encountered in boring these wells, which are the deepest, excepting only the well at Highmore, in the list on page 530. With the experience now acquired, they might probably be bored for half as great expense; and shallower wells, from 600 to 1,000 feet deep, as at Yankton, Woonsocket, and Aberdeen, may be bored and piped at a cost ranging from $800 to $1,500. The still shallower artesian wells in the drift of the Red River Valley, varying in depth from 35 feet to 250 or 300 feet, cost from $50 to $200 or $300. Each of these wells could supply water sufficient for the irrigation of a few acres, and those having the most copious flow would irrigate 50 acres or more if their water were stored in reservoirs for use only during the summer.

An important objection, however, against the use of this water for irrigation seems to lie in its dissolved alkaline and saline matter, which must be left in the soil. After continued use during many years, the residuum from the water would quite certainly prove injurious to crops, so that the land would become worthless. Such results have attended irrigation with only very slightly saline water on the alluvial plains of the arid northwestern provinces of India. The proportion of sulphate of soda in streams flowing down from the Himalayan range and in canals taking water from them varies from 9 to 43 parts in a million, and the proportion of common salt is from 0.23 to 15 parts; yet under the dry climate of northwestern India the natural evaporation of so nearly pure water, and its use in irrigation, have caused extensive tracts of land formerly productive to become barren.[1]

Neither the water of the Red River at St. Vincent nor that of the very slightly brackish artesian well at Carman is more suitable for irrigation than the Himalayan waters mentioned; while the bitter water of the Jamestown and Devils Lake artesian wells, on account of its larger content of common salt and of Glauber's and Epsom salts (sulphates of soda and of magnesia), would be far worse for the land, in which saline and alkaline matter would be accumulated by the evaporation of the water.

Concerning the results following the use of artesian water for irrigation in the Red River Valley, Prof. C. W. Hall, of the University of Minnesota, writes me as follows, under date of January 14, 1891:

> Officers of our agricultural experiment station say that in the Red River Valley experiments already show that ground watered from artesian wells is, after three or four years, almost wholly unsuited to raising the current crops. Several large farmers in that region have sunk wells to secure a supply of water for gardens, and have found that very soon their garden patches must be moved to other places.

In many portions of the great arid region of the western plains and the Cordilleran mountain belt sufficiently pure water for irrigation is furnished by streams, especially where they flow from neighboring mountains, and less frequently by artesian wells. But it must be reluctantly said that within the agricultural area of Lake Agassiz, and upon the adjoining district of North and South Dakota, neither the rivers nor artesian wells can supply water well adapted for application to the land during a long series of years. Fortunately, irrigation is not greatly needed in any part of this lacustrine area; and on the adjoining region the bountiful harvests of the years of copious rainfall may fully offset the occasional failure of crops.[2]

[1] Medlicott and Blanford, Manual of the Geology of India, pp. 413–415.

[2] See Report of the Special Committee of the United States Senate on the Irrigation and Reclamation of Arid Lands, four volumes (bound in two), Washington, 1890.

NOTES OF ARTESIAN AND COMMON WELLS.

The following notes present many sections, showing in detail the character and order of the drift deposits penetrated by artesian and common wells in the Red River Valley and on the contiguous higher eastern and western borders of Lake Agassiz. A few of these wells pass through the drift and afford information of the underlying Cretaceous and Lower Silurian strata. Among the many records of wells gathered during the survey of the shore-lines of Lake Agassiz, this list selects in general the most noteworthy, as those remarkable for their depth, for abundant flow or sudden rise of water, or for their sections of the drift and older formations. At the same time the ordinary or average depth, or the range in depth of other wells, and the quantity and quality of their water supply, are often stated, with the prevailing character of the drift, lacustrine, and alluvial beds.

Two classes of wells, peculiar respectively to the beach ridges and the deltas, may be here described once for all, so that no examples of them will appear in the following pages. Many farmers, in selecting the site for their dwellings, have wisely placed them on the beautifully rounded, wave-like ridges of gravel and sand which mark the former shores of Lake Agassiz. Their houses have dry cellars, and their wells, after passing 10 to 15 feet through the gravel of the beach to the underlying till, usually obtain an ample supply of excellent water, healthful for people, horses, and cattle to drink. The water is hard, or unfit for washing with soap, because of the presence of the carbonates of lime and magnesia dissolved from the gravel, sand, and till; but it is usually free from alkaline matter, such as is often contained in the water of this district when it has percolated through the till and its inclosed sand and gravel beds for longer distances.

On the deltas of Lake Agassiz wells also usually have water of the same good quality, but it is found at a greater depth. Usually on these tracts the depth to water ranges from 20 to 50 feet; but on the Pembina delta and near the outer border of the Assiniboine delta a thickness exceeding 100 feet in their porous sand and gravel deposits must be penetrated before the plane of saturation or of water running through their basal portion is reached. Along the foot of the frontal slope of the delta, or on the banks of the river which has cut through it, this water issues in large springs.

The deepest well of this class noted was on the Pembina delta, close north of the river, in the northeast quarter of section 36, township 163, range 57, where T. R. McLaughlin had dug 145 feet and bored 30 feet farther, in all 175 feet, not yet obtaining any water. The material of the section was all water-deposited sand and gravel, some layers having pebbles as large as 3 or 4 inches in diameter, but mostly sand. A well only a half mile to the north, on the same delta, has a good supply of water at the depth of 30 feet, and in some places springs issue only halfway down the bluffs inclosing the Pembina River, which flows some 225 feet below the delta plateau upon which these wells are situated. Here and there somewhat clayey layers in the delta, or otherwise comparatively impervious beds, cause water to be found by wells before reaching the bottom of the sand or the general plane of its saturation. More frequently wells must go to that plane, lying in the Pembina delta mostly at a great depth, as exemplified also by the wells mentioned on page 359.

The arrangement of these notes is in three divisions, under the States of Minnesota and North Dakota and the Province of Manitoba. In each of the two States the counties are taken separately, in their order from south to north. In each county the geographic order of the townships whose wells are described is from south to north, and secondarily from east to west; and in any township where several wells are noted they are given in the numerical order of the sections (as shown on page 11).

It has been found most convenient to note in the same list both the artesian and the common wells. The artesian water often flows only to the surface or a few feet above it; and many other wells obtain water which rises from a deep source to within a few feet below the surface, coming evidently from the same beds that elsewhere supply the flowing wells. Among the common wells of less depth and not so nearly related with the artesian, the water often, and, indeed, usually, rises several feet above the porous bed or vein in which it is found. The shallow wells, however, of which there are many only 10 to 15 or 20 feet deep, generally are supplied by the seepage of surface water.

WELLS ON THE AREA OF LAKE AGASSIZ IN MINNESOTA

TRAVERSE COUNTY.

Browns Valley.—The section of the artesian well in this village has been given on page 89, and an analysis of its water on page 539.

Doleysmount.—Rudolph Heidelberger, southeast quarter of section 6: Well, 36 feet deep; till, 22 feet; and sand with water, not rising, 14 feet, to the bottom and continuing lower.

Emil Heidelberger, northeast quarter of section 6: Artesian well, 79 feet deep, in drift, chiefly till; flow scanty.

Croke.—Cyrus B. Stevens, northeast quarter of section 12: Well, 60 feet deep; soil, gravel, and sand, 5 feet; till, 50 feet; and quicksand, penetrated 5 feet and continuing lower, so soft that the auger fell 3 or 4 feet. Water, so alkaline that it can not be used, rose from this sand to 3 feet below the surface.

Clifton.—William McClymond, in section 13, has two artesian wells, each about 85 feet deep, in drift. There are several other flowing wells, 60 to 75 feet deep, in this northeastern part of the township.

J. T. Blaisdell, in section 31, has two flowing wells. The one at the farmhouse is 119 feet deep, bored all the way in till, yellowish for 25 or 30 feet, and dark bluish below, hardest in its lowest 6 or 8 feet, beneath which water was struck in coarse gravel, and rises to the surface, overflowing; a good supply. The other well, nearly a mile northeast from the foregoing, is 182 feet deep. Water rises from quicksand at the bottom, and is of good quality, but only a small supply. This well was bored after that at the farmhouse, so that water was expected at 119 feet, but none was found, nor was any layer of gravel and sand noticed at that depth.

Wheaton.—Common wells at Wheaton are 25 to 35 feet deep, in till; water usually rises to 10 or 15 feet below the surface, and is mostly alkaline; but the town well, in the middle of the street, 30 feet deep, drained every day by its general use, has fairly good water.

Boring for an artesian town well went to the depth of 300 feet, obtaining no flow at the surface. This well found at 200 feet a large supply of good water, which rose to 15 feet below the surface. It came from the top of a bed of sand and gravel about 10 feet thick, and rose with such force that it filled 40 feet of the pipe with sand. Next below was clay, probably till, about 65 feet, lying on Cretaceous shale, into which the boring was continued about 25 feet.

Another unsuccessful boring for artesian water was done in this village at T. E. Dunn's livery stable, to a depth of 390 feet. Till extended from the surface to a depth of 280 feet, inclosing layers of sand and gravel at 130 feet and at other depths to 200 feet. The lower 110 feet were hard, dark bluish shale, probably belonging to the Fort Benton division of the Cretaceous series.

Tintah.—Several shallow wells in this township have ample flows of good water from the drift. The well at the railway tank is 48 feet deep, with water rising only to the surface. J. E. Henry has three or more artesian wells at his extensive farm buildings near Tintah railway station. The well at the farmhouse is 45 feet deep, with water rising nearly to the surface, but not overflowing. At the barns, about 50 rods southeast, a well 67 feet deep flows 6 inches above the surface. Another well, about halfway between these two, is 45 feet deep, with water rising 6 feet above the surface.

Taylor.—In the north edge of this township, and near the Bois des Sioux River, Mr. Bruce has an artesian well 106 feet deep, flowing 3 gallons per minute.

C. M. Harmon, northwest quarter of section 3: Well, 73 feet deep; till extends to the depth of 70 feet, being yellowish for its first 15 feet, and dark bluish below, yielding much alkaline water at 18 feet, also some seeping water from lower gravelly streaks. At the bottom, water of excellent quality was found in a bed of gravel and sand, and rose within a few minutes to a level 6 feet below the surface. This water-bearing bed is only 3 or 4 feet thick, as was shown by boring deeper, when the pipe shut off the water, and was therefore lifted back.

David Warriner, section 31: A boring at the farmhouse went 165 feet in till, finding no supply of water. About 15 rods distant to the north, on land 6 feet lower, another well went 50 feet in till, to gravel and sand yielding a large supply of good water, which quickly rose to a permanent level 14 feet below the surface.

A large number of other wells in this county are described in Geology of Minnesota, Vol. II, pp. 530, 531.

WILKIN COUNTY.

Champion.—This township has probably as many as thirty artesian wells, ranging from 50 to 110 feet in depth, in the drift. One of the earliest bored and most copious in flow is on the Fountain Valley Farm, section 3, owned by Col. C. H. Brush & Co. This well is 66 feet deep, being till, 56 feet, and sand, 10 feet, and continuing deeper, from which the artesian flow is obtained. The diameter of the pipe is 1 foot, reduced below to 7 inches. A large stream of very clear, cold water constantly flows from this well, its estimated volume being 7 or 8 barrels per minute, or about 250 gallons. The water is of excellent quality for house and farm use, but is hard and slightly irony, and deposits a rusty sediment in the channel of the stream. Its temperature is 46° F.

In section 11, nearly 2 miles southeast from the foregoing, a well was bored to the depth of about 50 feet, and was left dry by the workmen when they stopped at night; but in the morning it was found overflowing and flooding the surrounding land. In 1887 this well had been thus running six years, baffling all efforts to shut it off, and spoiling or damaging a tract equal to half a section by its inundation.

George Barnes, northwest quarter of section 14: Artesian well, 83 feet deep, in till, to quicksand at the bottom, into which the auger fell suddenly 2 or 3 feet, obtaining a very powerful flow of water.

George W. Mace, southeast quarter of section 22: Well, 107 feet deep; water rises 5 feet above the surface, but has only a feeble flow.

T. B. Bushnell, southwest quarter of section 23, about 40 rods east of the last and on land several feet higher: Well, 105 feet; artesian water rises with much force, probably sufficient to carry it to a height of 40 feet. It flows 22 gallons per minute from a pipe 1 inch in diameter.

Nash Brothers, northwest quarter of section 26, about a half mile south of the last: Well also 105 feet; water, found at 95 feet, rises with similar force, bringing up quicksand. It has a temperature of 48° F., and is of the best quality, being softer than the water of neighboring shallow wells.

In the southeast quarter of section 34, near Tintah, a well 95 feet deep found much lignite in the upper part of a water-bearing bed of sand, into which the boring went 5 feet, obtaining water that rises nearly to the surface.

Campbell.—The railroad well in the village, 260 feet deep, went all the way in till, excepting occasional layers of sand and gravel, mostly thin, but at one place 8 feet thick, from 165 to 173 feet below the top. Numerous fragments of lignite were found in the till of this well, especially from 125 to 150 feet, and they were abundantly mixed with the thick bed of sand mentioned, making about 10 per cent of the deposit. Some of its pieces brought up from the depth of 173 feet were incrusted with pyrite. The lower portion of the pipe becoming filled with mud, it was found necessary to puncture the pipe and admit water above the clay filling. This was done at 176 feet. The water rose within 4 feet of the surface. Higher water-bearing veins were encountered in boring the well at 125, 150, and 165 feet.

F. W. Maechler, of Campbell, who has bored nearly a hundred deep wells within a radius of 5 miles, states that shallow wells, which are dug 10 to 25 feet deep, have, almost without exception, disagreeable alkaline water; but that the bored wells, 50 to 100 feet, or occasionally more, in depth, have very good water, frequently artesian. At Mr. Maechler's house the well is 55 feet deep; till, 20 feet; sand, with some layers of fine gravel, 35 feet, and continuing lower; water rises to 3 feet below the surface. This exceptionally thick bed of sand also supplies water to several other wells in the village; but some of the wells here, including the railroad well before noted, are wholly till, inclosing no important sand or gravel layer and having no inflow of water, for a depth of 100 to 125 feet.

W. D. Cross, 1 mile northwest from Campbell village: Boring, 176 feet, entirely in till, less stony in its lower half and there containing streaks of gravel and sand 6 to 12 inches thick; no supply of water. Another well, however, 124 feet deep, bored only a few hundred feet distant, was quite different, being till, 81 feet; sand and gravel, 31 feet, and sandy clay, 12 feet, continuing lower. This well obtains artesian water, just flowing to the surface; but it is found to be inexhaustible, and can be lowered only a few feet by pumping.

In section 22 a boring for Charles Mullen went 272 feet, obtaining no water. A mile to the southwest, at Mr. Maechler's farmhouse, in the northwest quarter of section 27, a well 88 feet deep has water which rises to 18 inches below the surface and can not be lowered by pumping.

Bradford.—Charles Covell, southeast quarter of section 10: Artesian well, 50 feet deep; water rises 15 feet above the surface.

W. H. Fish, southeast quarter of section 12, on land 20 feet above the foregoing: Well, 49 feet, wholly in till; water, slightly alkaline, rose from gravel and sand at the bottom to a permanent level 3 feet below the surface. This well was dug with a diameter of 5 feet, and was thus filled almost to overflowing within ten minutes after the water was reached.

Henry Poor, northeast quarter of section 14: Artesian well, 48 feet deep, bored 2 inches in diameter; very copious flow, not under control, rising in a bowl-like spring about 6 feet across, and running away in shallow depressions of the adjoining prairie.

Edward H. Boustead, southwest quarter of section 18: Artesian well, 85 feet deep; water of good quality, pleasant in taste, and found to be healthful, but peculiar in containing gas. Immediately after the water reaches the surface the gas collects into very minute bubbles, so that the water for about a minute seems to be filled with light gray dust particles, after which it quickly becomes clear, as it also was on first flowing from the pipe.

C. W. Keyes, in the southwest quarter of section 31, about a mile northeast of Campbell, has a flowing well of good water, 64 feet deep. Previous to this boring, a well dug 61 feet in till, supplied mainly with surface water of inferior quality from a thin bed of gravel and sand at 21 feet, had been used several years.

Breckenridge.—Borings for artesian wells in this town have been unsuccessful. The drift-sheet, chiefly till, inclosing only few and thin layers of sand and gravel, is found to have a thickness of 202 feet, underlain by dark Cretaceous shale, probably the Fort Benton formation. The shallow wells are mostly alkaline, and the water of the Red River, which is better, has been generally used.

Andrea.—The drift in this township is commonly till to the depth of 40 or 50 feet or more, its lowest 4 or 5 feet being very hard; then quicksand, 5 to 10 feet or more, into which the boring must go a few feet, as in the following examples of artesian wells, to get a good supply of water.

L. Manske, northeast quarter of section 10: Flowing well, 50 feet deep.

P. H. Funkley, southeast quarter of section 26: Well, 60 feet; large flow; rising 10 feet above the surface.

R. McIntosh, southeast quarter of section 27: Flowing well, 86 feet deep.

P. Heider, northwest quarter of section 34: Well, 43 feet; water rises 4 feet above the surface.

Akron.—Albert Lutti, northeast quarter of section 34: Artesian well, 36 feet deep; in till, to gravel and sand at the bottom; water of good quality rises 4 feet above the surface. Another flowing well in the southeast quarter of this section is only 34 feet deep.

McCauleyville.—The two following wells are in the village, about 25 feet above the low-water stage of the Red River, whose alluvium is thus known to reach some 20 feet below that level.

James Nolan: Well, 33½ feet deep; soil, 2½ feet; brownish yellow alluvial clay, 26 feet; dark quicksand, 4 feet; gravel containing shells, like the bottom of a lake, with water, 1 foot and continuing lower.

In Cyril Boutiette's well, alluvial clay extended to the depth of 45 feet, where was found a layer of abundant remains of rushes and sedges, some of them having their flowering and fruiting panicles and spikes distinctly preserved.

Mitchell.—C. R. Gleason, northeast quarter of section 28: Well, 27 feet; soil, 2; yellowish gray till, 6; gray sand, ½ inch; much harder dark bluish till, 18 feet, containing plentiful rock fragments up to 6 inches in diameter; underlain by sandy black mud, in which were many small gasteropod shells. This doubtless interglacial fossiliferous layer, and an interglacial forest bed found under 12 feet of till at Barnesville, in Clay County, both within the area that was covered by Lake Agassiz, show that there was a sufficiently long warm epoch in the midst of the great Ice age to cause the ice-sheet to retreat northward beyond Barnesville.

The recession of the ice seems referable, as indicated on page 280, to the Aftonian stage of the Glacial period, between the Kansan and Iowan stages of ice accumulation. The upper part of the great channel occupied by Lakes Traverse and Big Stone and the Minnesota River was probably eroded by southward outflow from the Red River Valley at that time to a depth somewhat below the level of the upper or Herman beach of Lake Agassiz, and was not subsequently filled with drift when the ice-sheet again covered the land far southward to its Iowan limits. This interglacial erosion may have reached below the levels of the fossiliferous layers in the wells of Mitchell and Barnesville, allowing these parts of the Red River Valley to have a land surface, while its deeper central part held a lake; or, more probably, as I think, the valley may then have sloped southward, on account of differential northward elevation of the region, so that no lake would be formed during the Aftonian glacial recession in this basin.[1]

Atherton.—In the southwest quarter of section 9, a well 37 feet deep has water which rises 3 feet above the surface.

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[1] Am. Geologist, Vol. XV, pp. 279-282, May, 1895.

Michael Starrs, southeast quarter of section 20: Well, 45 feet deep, in till, to gravel at the bottom, from which water rises to 4 feet below the surface, and flows away by a ditch to the Deerhorn Creek, only about 50 feet distant.

Charles Funkhandel, in the northeast quarter of section 35, has a well only 11 feet deep, which yields a copious artesian flow.

Descriptions of many other wells in this county are given in Geology of Minnesota, Vol. II, pages 527–530.

CLAY COUNTY.

Barnesville.—This city has no artesian wells, and the common wells are 12 to 40 feet deep, mostly in till which incloses beds of gravel and sand. A boring by John Marth to the depth of 150 feet, on the west side of the main street, found no artesian water.

Mr. Marth has a shallow well, 13 feet deep, which is remarkable for its interglacial forest bed. The section was soil (the blackened surface of the till), 2 feet; yellowish till, 10 feet; then quicksand, 1 foot, containing several branches and trunks of trees, thought to be tamarack, up to 8 inches in diameter, lying across the well, which, together with the inflow of water, prevented further digging.

Rudolph Sieber, in the southwest quarter of section 12, Barnesville Township, close north of a small creek, has an artesian well 35 feet deep, from which water rises with a strong flow to a height of 16 feet or more above the surface.

Sabin.—Angus Murray: Well, about 80 feet in till, to gravel, from which water of excellent quality rose to a level only 3 or 4 feet below the surface. The Minneapolis and Northern Elevator Company has a similar water supply in a well 90 feet deep. Other wells about 20 feet deep in this village, dug mostly in beach sand, have good water.

A. E. Henderson, on the Pleasant Ridge Farm, 1 mile north of Sabin, has a well 72 feet deep, with water rising almost to the surface.

Glyndon.—In the southern part of this township, 3 to 5 miles northeast of Sabin, there are several artesian wells 50 to 75 feet deep.

Two borings at the elevator of G. S. Barnes & Co., in Glyndon Village, failed to obtain water, and the augers were broken in the till, called "hardpan," at the bottom. In the deeper one of these borings a depth of 125 feet was reached, the section being reported as soil, 3 feet; quicksand, 22 feet; dark clay, free from stones, 75 feet; very hard yellowish till, 15 feet; and softer till, 10 feet. The till in these borings is said to have been so hard that only a tenth as fast progress could be made in it as in the dark alluvial clay above. A log of wood, which was called "cedar," about a foot in diameter, was encountered by one of these borings in the dark alluvium, 35 feet below the surface; and the other boring, about 12 feet distant, found "rotten chips" of wood at the same depth. In the well at the railroad engine house, somewhat farther west, vegetable deposits, including sheets of turf and drift wood, were found at the depth of 13 to 18 feet.

Moorhead.—An unsuccessful boring done in 1889 by this city, in the hope of obtaining artesian water or gas, went to the depth of 1,750 feet. From comparison and combination of notes published by Prof. N. H. Winchell,[1] with others supplied by Mr. John T. Gray and Prof. C. W. Hall, the section appears to have been as follows: Alluvial and lacustrine deposits, chiefly fine clayey silt, 55 feet; pebbly clay, apparently till, 55 feet; gravel and sand, 35 feet, yielding water which rose nearly to the surface; till, with occasional layers of sand, 75 feet, extending to the base of the drift at 220 feet; bluish and greenish shales, with beds of sand, 145 feet, probably belonging to the Fort Benton formation, of Cretaceous age; and granitoid and gneissic rocks, doubtless of Archean age, beginning at 365 feet, of which a thickness of 1,385 feet was penetrated.

Artesian wells in the drift have been obtained here as follows:

At J. G. Burgquist's brickyard a well 165 feet deep flows 8 inches above the surface.

Minneapolis and Northern Elevator Company: Well, 200 feet deep, with water rising 5 feet above the surface. In another well, 200 feet deep, at Lamb Bros.' brickyard, the water rises only to a level 6 feet below the surface.

These deep wells have water of good quality, excepting its hardness, while the water of shallow wells, 10 to 25 feet deep, coming from a bed of sand 3 to 10 feet thick, inclosed above and below by the alluvial clay, is somewhat alkaline. Most of the water used for domestic purposes in both Moorhead and Fargo is taken from the Red River by waterworks.

At the Artesian stock farm of W. R. Tanner & Co., section 24, Moorhead, a well 228 feet deep found water in a bed of sand forming the lowest 3 feet of the section, and rises 2½ feet above the surface. It is free from any saline and alkaline taste, and can be used for washing with soap. Two previous borings here were stopped at the depth of about 180 feet by encountering bowlders in the till. Most of the deep wells within a few miles about this farm get water in layers of gravel and sand inclosed in the till at depths from 160 to 200 feet, from which the water rises to a few feet below the surface, not overflowing.

Kragnes.—Minneapolis and Northern Elevator Company: Artesian well, 155 feet deep; water rises 4 feet above the surface, there flowing only 30 barrels in twenty-four hours from a 2-inch pipe; but this well, when pumped, supplies an abundance of water, and can not be reduced more than 20 feet below the surface.

Common wells on farms around Kragnes are 15 to 30 feet deep.

[1] Geol. and Nat. Hist. Survey of Minnesota, Bulletin No. 5, "Natural gas in Minnesota," 1889, pp. 27-31.

Georgetown.—C. B. Hill, Osborne Farm, southeast quarter of section 33: Artesian well, 180 feet deep; the water, rising 4 feet above the surface, is of good quality, but not so suitable for use in the boilers of steam engines as the river water.

Several flowing wells in the northern part of this township range from 165 to 180 feet in depth.

Numerous other records of wells in Clay County are noted in Geology of Minnesota, Vol. II, pages 667–669.

NORMAN COUNTY.

Perley.– The Minneapolis and Northern Elevator Company has an artesian well about 200 feet deep. Another of similar depth is at A. T. Aabye's house.

Lake Ida.—Ferdinand Burkhardt, southwest quarter of section 2: Well, 80 feet deep; yellow till, 10 feet; blue till, 70 feet; water seeps, filling the well to about 25 feet below the surface.

Ada.—The town well, 217 feet deep, 4 inches in diameter, supplies a stream which partly fills a 1-inch pipe. It was bored in 1881, and has since been running at the rate of about 100 barrels per day. This water is very clear, and forms no irony sediment. Its cool temperature (47° F.) and its excellent quality for drinking and domestic uses, being called soft water, nearly equal to rain water for washing, make this a very satisfactory investment for the town. Its cost was about $500.

Common wells of Ada and its vicinity are 10 to 20 feet deep. Their water is hard, but is considered healthful for drinking.

Henry Downs, one-fourth of a mile west of Ada, has a flowing well about 90 feet deep.

McDonaldsville.—S. A. Farnsworth, southeast quarter of section 4: Well, 75 feet; soil, 3 feet; yellow alluvial clay, 10 feet; blue clay, alluvial in its upper part, but doubtless including a considerable depth of till below, 56 feet; a harder portion of the till, called "hardpan," 5 feet; gravel, 1 foot, and extending lower; artesian water, of similar quality and amount of flow as the Ada town well.

Pleasant View.—Two artesian wells, similar in their sections to the last, but more feeble in flow, were noted in this township, namely, one, 65 feet deep, on William Hein's farm, in the southwest quarter of section 2, and the other, 76 feet deep, at F. S. Flower's, in the southeast quarter of section 22.

Anthony.—Ole B. Halvorson, section 19: Well, 12 feet; soil, 2 feet; yellow till, 10 feet; water comes from a layer of sand 6 inches thick at the bottom, rising 6 feet to its permanent level in a half day. Mr. Halvorson has also bored down 65 feet, finding the section wholly till, dark bluish below the first 12 feet; no layers of sand and no additional supply of water. Common wells in this vicinity range from 12 or 15 feet to 30 feet in depth. The water is slightly alkaline, but is quite tolerable and apparently healthful when the supply is daily renewed by pumping.

Halstad.—The Minneapolis and Northern Elevator Company has an artesian well, which is reported to be about 250 feet deep. The common wells are similar to those of Anthony in their depths and quality of water.

Lockhart.—This township and others adjoining it have many flowing wells, varying from 100 to 200 feet in depth.

On William Fisher's farm, in section 5, three artesian wells are each about 130 feet deep. Their water, which rises 4 feet above the surface, is free from any alkaline or saline taste.

Leo Gnadt, section 6: Artesian well, 165 feet deep, from which good water rises 3 feet above the surface.

At the buildings of the Lockhart Farm, in section 29, a well 5 inches in diameter was bored to the depth of 142 feet in the autumn of 1880, the section being as follows: Soil, 2 feet; yellow alluvial clay, or perhaps in part till, about 10 feet; blue till, 130 feet, to sand at the bottom, from which water of excellent quality rose to the surface with a powerful flow. The water was allowed to run in its full amount during a month or more, flooding a considerable tract for a mile northward. With the water much sand was brought up and deposited by the stream in a neighboring slough, its estimated volume being approximately 300 cubic yards, spread on the average a foot thick over a space about 100 feet in diameter. The flow of this well was reduced after a time by a cap and gauge to a small stream; but in the following December it ceased, because the bottom of the pipe for about 20 feet had been compactly filled with sand.

In July, 1881, a second well of similar diameter was bored a short distance south of the preceding. Till extended to a depth of 141 feet, below which the boring went into a bed of sand 16 feet, from which water rose to 15 feet above the surface, flowing through an inch pipe about 60 barrels per day. Many fragments of lignite, up to 3 inches long, were found in several layers in the sand bed, probably a half bushel of it in all being brought up as the boring progressed, but no lignite was encountered in the till. One piece of wood 3 or 4 inches long, with numerous smaller fragments of wood, was also found in the sand.

Several other artesian wells similar to these have since been bored on this farm. One of these, about 700 feet distant from the first well, struck water at 137 feet, which rose with a much stronger and alarming flow, and soon found vent also alongside the pipe, making a large hole and inundating the vicinity of the farm buildings and much adjoining land. To carry away this water many laborers were quickly set to digging ditches along a distance of several miles to the west. After some two weeks, however, the heavy flow mostly ceased, becoming principally confined to the pipe, with only a moderate and controllable quantity coming to the surface outside the pipe.

Shely.—Iver Nilson, in section 14, has a well 219 feet deep, with water at first rising to the surface, but afterward to about 4 feet below the surface. This well goes wholly through drift, nearly all till, but including occasional thin beds of gravel and sand. The last 5 or 6 feet were quicksand, extending also deeper, from which the water came. One and a half miles south of this a well 225 feet deep has water rising to 3 or 4 feet below the surface; and a half mile farther south a well with similar water supply is 209 feet deep. Most of the flowing or very deep wells in this township and northward are slightly saline, but Mr. Nilson's has no such taste, and is well adapted for washing with soap, being said to be "as soft as rain water."

The common wells of this region (a belt of morainic till crossing the Red River Valley from east to west) are 10 to 25 feet deep, obtaining water which seeps from the upper part of the till. The water, though hard and slightly alkaline, is not generally unhealthful for farm and house use, excepting in wells that are contaminated by the decay of wooden curbing. When these wells are allowed to remain stagnant, without being frequently drawn from in large amount, the water becomes very offensive in odor and taste.

POLK COUNTY.

Liberty.—Jacob Stambaugh, northeast quarter of section 33: Well, 52 feet; soil, 2 feet; gravel and sand of the McCauleyville beach, 16 feet; bluish-gray till, very hard, 34 feet, to quicksand, from which water, of good quality but hard, rose 24 feet in ten minutes, to its permanent level. Several pieces of wood were found in the till of this well. Another well here, only 17 feet deep, finds an ample supply of water at the base of the beach gravel and sand.

Reis.—At Beltrami station the Red River Valley Elevator Company has an artesian well 140 feet deep, from which water rises 12 feet above the surface. It has no saline nor alkaline taste, and is less hard than the water of the neighboring shallow wells.

George C. Reis, northeast quarter of section 32: Artesian well, 147 feet deep; soil, 2 feet; yellow till, partly so hard as to need to be dug with a pick, 8 feet; and dark-bluish till, also very hard, 137 feet, containing occasional layers of sand and gravel up to 6 inches in thickness. Water, of the same excellent quality as at Beltrami, rises 12 feet above the surface. This well is 5 inches in diameter, reduced at the top to a 1-inch pipe, from which the flow amounts to about 3 gallons per minute, or 150 barrels in twenty-four hours.

Russia.—Eric Bjerk, northeast quarter of section 2: Well, 60 feet deep; soil, 2 feet; till, dark bluish, excepting near the surface, so soft that it could be all spaded, 58 feet, to dark sand which extends at least 2 feet. At this depth the well was left dry by the workmen at the end of their day's labor, but in the morning it was filled with water and overflowing.

L. T. Soule, the Russia Farm, section 19: Well, 124 feet; soil, 2 feet; yellow alluvial clay, 3 feet; quicksand, 1 foot; dark bluish till, 104 feet, with no layers of sand or gravel; sand, fine above and growing coarser downward, 13 feet; and gravel, 1 foot and continuing below. All the sand bed yields a feeble artesian flow, and a strong flow comes from the gravel. It is hard water, but excellent for drinking, having no alkaline taste.

Hammond.—W. S. Rattray, northeast quarter of section 15: Well, 12 feet; soil, 2 feet; yellow alluvial clay, 7 feet; sand, 3 feet, underlain by dark blue clay. Good water, becoming 3 feet deep, issues from the lowest foot of the sand. Other wells in this township are 10 to 15 feet deep, many of them having objectionably alkaline water.

Fairfax.—In the west part of section 28 a well 80 feet deep has water which rises 8 feet above the surface. There are also several other flowing wells within 2 or 3 miles eastward and southward, ranging from 80 to 112 feet in depth.

Nine flowing wells in the northeast quarter of section 18 range from 185 to 205 feet in depth; and one in the southwest quarter of this section is 173 feet deep.

Andover.—E. S. Corser, Southside Farm, section 3: A boring 205 feet deep in drift, mostly till, obtained no artesian water.

In the northeast quarter of section 23 an unsuccessful boring to the depth of 111 feet went through black soil 1½ feet, alluvial clay 18 feet; a vegetal deposit of leaves and partially decayed wood 3 feet; and then clay, probably mostly till, to the bottom.

Carman.—The artesian well at E. S. Corser's elevator, in this village, is 191 feet deep, being yellowish alluvial clay, 11 feet; yellowish quicksand, 3 feet, in which shallow wells get an ample supply of water, slightly alkaline; and dark bluish clay, alluvial at the top, but soon changing to till, 177 feet, containing occasional thin layers of sand below the depth of 160 feet from the surface. A bed of fine gravel and sand was reached at the bottom, from which water rose to the height of 10 feet above the surface, and flows at the rate of 100 barrels a day. The water, of which an analysis is given on page 540, is very good for drinking and for all farm and domestic uses. For washing with soap and for use in engine boilers, it is much better than the water of the river. The cost of the well, bored 5 inches in diameter, was $600.

Crookston.—Nels Swanson, in the south edge of the city, south of the Red Lake River: Artesian well, 185 feet deep in till; alluvial clay above and till below for the greater part of its depth, with occasional thin veins of sand and gravel; water of good quality.

Another flowing well, owned by B. Sampson, about 20 rods north of the preceding, is also 185 feet deep, its lowest 6 feet being sand.

S. M. McKee, southwest quarter of section 3: Well, 230 feet, with water rising from the bottom to 12 feet below the surface.

H. A. Wyand, southwest quarter of section 5: Well, 236 feet; till, 155 feet; a harder deposit of till, called "hardpan," 14 feet; fine gravel and sand, 23 feet, with water rising from its top to 8 feet below the surface; again till, in part moister and softer than the higher till, 38 feet; and quicksand, 6 feet, also continuing lower, from which water rises to 1½ feet below the surface.

Harvey Cook, southwest quarter of section 8: Artesian well, about 180 feet deep; water rises $1\frac{1}{2}$ feet above the surface.

There are many artesian wells, probably not less than a hundred, within a radius of 10 miles around Crookston, ranging from 165 to 285 feet in depth, wholly in the drift. Most of them have excellent water, free from any saline or alkaline taste.

Fisher.—Red Lake Mills, in the village: Well, 190 feet deep; soil, 2 feet; yellowish alluvial clay, 12 feet; quicksand, about 1 foot, yielding water of sufficient amount and good quality for common wells; dark bluish clay, mostly till, through all the remaining depth below, except that it incloses infrequent layers of sand 6 to 12 inches thick, from one of which, at the depth of about 125 feet, water rose to 6 feet below the surface, but no artesian flow was found.

L. Freeman, in the north edge of the village: Well, 198 feet; alluvial clay, 40 feet; and till, inclosing occasional seams of sand and gravel up to 1 foot in thickness, extended thence to the bottom. Water of good quality rises to 9 feet below the surface. By tapping the pipe at a slightly lower level it flows to the milk house and barnyard, which are situated near the well, on the slope descending to the river.

Hugh Thompson and F. S. De Mers, in the south part of the village: Artesian well, 285 feet deep, mainly till, but beds of gravel and sand containing fresh water were encountered at 133 feet and 190 feet, each of these beds being about 10 feet thick. Brackish water from sand at the bottom rises to 1 foot below the surface. Though perceptibly saline, it is relished by horses and cattle and is found to agree with them.

It seems very significant that this well, the first noted with considerable salt water in proceeding northward on the Minnesota side of the Red River, is close to a boring by C. W. Webster in the southwest quarter of section 14, about a mile east of Fisher, which at a depth of 300 feet reached a very fine-grained white sandstone, doubtless the Dakota sandstone, as that formation is encountered at a similar depth by numerous wells on the opposite side of this valley plain in North Dakota. This sandstone, as stated in the earlier part of this chapter, is probably the source of the saline water commonly obtained by deep wells in the drift northward from the vicinity of Crookston and Fisher to southern Manitoba.

St. Hilaire.—An artesian well 146 feet deep, wholly in the drift, chiefly till, was bored about three-fourths of a mile south of the depot, near where the Crookston road and railway turn southwestward; good water, but scanty flow.

Euclid.—Two miles northeast of Euclid, Mr. Allen has a flowing well about 75 feet deep; water rising only a little above the surface.

In the village common wells obtain an inexhaustible supply of good water at the depth of 12 to 18 feet, the section being soil, 2 feet; yellow till, spaded, 6 to 10 feet; and gray till, darker and much harder, requiring to be picked, several feet, to a bed of quicksand from which the water rises to a permanent level 6 to 8 feet below the surface.

Keystone.—The first artesian well at the buildings of the Keystone Farm, in section 23, was bored in 1881, having a depth of 110 feet. The section was soil, 2 feet; yellow alluvial clay, 12 feet; sand, yielding considerable water, about 2 inches; dark bluish till, 71 feet; and sand and gravel, 25 feet. Water of excellent quality, without salty taste and so soft that it can be used for washing with soap, flows at the rate of 40 barrels per day, or nearly a gallon per minute, the diameter of the well pipe being 5 inches. During all the boring below 85 feet water rose to the surface, but only in very small quantity, until a hard layer of gravel was reached at the bottom. Seven other artesian wells, all obtaining good water in the drift, have since been bored here, ranging in depth from 95 to 150 feet.

Another well on this farm, sunk to the depth of 250 feet, reached the Dakota sandstone, the very fine white sand coming up with the water and giving it a milky appearance. It yielded a copious artesian flow of brackish water, and was therefore abandoned.

Angus.—Several borings 200 to 300 feet deep in Angus village and its vicinity have found no artesian water.

A. D. Andrews, southwest quarter of section 10: Well, 82 feet; soil, 2 feet; alluvial sandy silt, 5 feet; hard, dark bluish till, mostly picked, 43 feet; much harder till, with more frequent bowlders, 28 feet; soft sand and gravel, 4 feet and continuing lower, from which good but hard water rose immediately to its permanent level, 20 feet below the surface.

A. O. Bailey, section 27: Well, 253 feet; soil, 2 feet; mainly till below, with no important beds or veins of sand and gravel before reaching the bottom, whence an ample supply of good water, like that of the less deep artesian wells on the Keystone Farm, rose to 10 feet below the surface.

Tabor.—The depths of two flowing wells in the southeast part of this township are reported to be about 45 and 70 feet. Common wells are mostly 10 to 15 feet deep, with copious supply of healthful water from sandy layers in the alluvial clay.

Farley.—Furlong & Ramsey; southeast quarter of section 27: Two borings to depths of about 165 feet and 200 feet obtained salt water, which rose nearly to the surface, but is not used. This large farm takes its water supply from two shallow wells, each 12 feet deep, and from surface pools dug a few feet deep.

MARSHALL COUNTY.

Warren.—At the elevator of the Warren Manufacturing Company a well 130 feet deep has slightly saline water, which rises from the bottom to 5 feet below the surface. Its section was alluvial clay, 50 feet, or quite probably the lower part of this is till; then a bed of gravel, 10 feet, with much water, which does not rise to the surface; dark bluish till, 50 feet; and sand and gravel, 20 feet and continuing lower.

The boring for a town well showed a great thickness of till beneath this section, extending to the depth of 260 feet.

L. Loughridge, in the village: Well, 96 feet; water rises to 4 feet below the surface, and is capable of supplying about 25 barrels daily.

Pembina Farming Company, 1 mile southeast of Warren: Well, 180 feet, obtaining excellent water, not saline, which rises to 20 feet below the surface.

March & Spalding, 1 mile west of the village: Well, 143 feet; water rises to 4 feet below the surface, supplying 75 barrels in twenty-four hours.

The common wells of this vicinity are 10 to 30 feet deep, obtaining usually an abundant supply of water, which is very hard, but has little or no alkaline taste.

Argyle.—A boring for a town well in this village, 150 feet deep in drift, chiefly till, was stopped at this depth by a bowlder, having found no considerable supply of water. Gas which could be ignited issued from the depth of 70 to 100 feet.

Minneapolis and Northern Elevator Company: Flowing well, 155 feet deep, with water rising only slightly above the surface, but yielding a large supply when pumped. It is saline, but is used for the engine boiler.

Middle River.—William Carrese, section 22, 1 mile south of Argyle: Flowing well, 285 feet deep; brackish water rises 2 feet above the surface.

O. D. Ford, Stone Farm, section 33: Flowing well, 218 feet deep; water, found at 185 feet, rises 2 feet above the surface; brackish, but good for cattle.

Bloomer.—On the Argyle Farm, section 23, a boring 200 feet or more in depth obtained no artesian water.

Wanger.—In the northeast quarter of section 10 a boring found combustible gas at 80 feet.

James Headrick, southeast quarter of section 28: Well, 28 feet deep, dug 26 feet, there finding a cavity 2 feet deep, full of running water, which passes through the well with a southwestward current estimated at 2 miles per hour. A bucket dipping water is apt to be swept away under the southwest side of the well. The water runs over a bed of fine gravel and forms sand bars in the bottom of the well, which therefore needs to be frequently cleared out. The section was soil, 2 feet; clay, 4 feet; sand and gravel, 2 feet; and till, 18 feet. Along the course of the Tamarack River for 8 miles thence westward to Stephen it receives many small springs, issuing nearly on a level with the river; and some of these are probably formed by the stream that flows through this well.

Tamarack.—C. W. Culbertson, section 31: Flowing well, 74 feet deep; water rises 10 feet above the surface; saline, but good for stock.

Stephen.—Town well, about 240 feet deep; water rises 3 or 4 feet above the surface, but it is not a large supply, even when pumped from at 10 feet below the surface; too saline for any use.

On the Stephen Farm, owned by Charles M. Ramsey, another saline artesian well, unused, is 220 feet deep.

Parker.—J. Q. Cronkhite, section 25: Flowing well, 95 feet deep, quite salty water, rising about 10 feet above the surface.

Augsburg.—Wheeler & Culbertson, section 32: Boring about 300 feet deep; no supply of water.

Sinnott.—John Hughes, northeast quarter of section 28: Well, 42 feet; soil, 2 feet; soft, stratified alluvial clay, yellowish above, but dark bluish for the greater part of its thickness, 38 feet; very hard, yellowish gray till, dug into only 2 feet, containing sandy veins or layers, from which water seeping into the well filled it 7 feet in a half day. Within two weeks in the dry season, when it was dug, the water rose to a depth of 30 feet. It is of good quality, hard, but with no saline taste.

KITTSON COUNTY.

Donaldson.—E. N. Davis, in the northwest quarter of section 29, Davis, close east of Donaldson station, has a flowing well 45 feet deep, which was bored in 1880 in a quarter of a day with an ordinary 2-inch auger. Its flow ever since that time has been nearly constant, at the rate of about 8 gallons a minute, or more than 300 barrels daily. The section was soil, 1½ feet; yellowish gray alluvial clay, 10 feet; dark bluish alluvial clay, 28 feet; hard dark gray till, 5 feet; and a very hard ferruginous layer, one-half foot, from beneath which the water rose quickly to the surface, bringing up sand and gravel. The temperature of the water is 42° F. Though salty to the taste, farm stock thrive with this as their only supply of water, which they drink very freely; and it has been used by people, with no apparent injury, as the only water for drinking and cooking through several weeks of drought. The height to which it will rise is known to be more than 23 feet, at which height the flow seemed to be undiminished. On stopping the pipe of this well the water issued as a spring several rods distant.

Kennedy.—A boring by the Kennedy Land and Town Company went to the depth of 225 feet, obtaining no artesian water. Below the alluvial clay of the surface the section was chiefly till. Bowlders were observed at the depth of 45 feet, and bowlders and gravel in the till were encountered thence to the bottom. Water from layers or veins of sand and gravel rose nearly to the surface, but was too saline to be used.

Skane.—The Fort Donaldson Farm, in section 20, has an artesian well 95 feet deep, with water likewise so salty that it can not be used. But some other deep wells in this township obtain fresh water of good quality, as Lars Lundgren's well, in the southeast quarter of section 7, which is 119 feet deep, with water rising just to the surface, not overflowing.

Hallock.—Eklund elevator: Well, 125 feet deep; alluvial clay above, succeeded by till below for nearly all the depth; very saline water rises from gravel and sand at the bottom to a permanent level 4 or 5 feet below the surface.

L. N. Eklund, a sixth of a mile east of the depot and elevator: Well, 90 feet deep; also very salty water, rising to 5 feet below the surface. Another well, only 2 rods distant, obtained saline water at 80 feet, which rose immediately just to the surface, not overflowing.

L. B. Riddell, close west of Hallock village: Well, 71 feet deep; saline water, not used, rises to 4 feet below the surface.

Granville.—W. J. Ross, in section 7, has a flowing well of fresh water, only 30 feet deep. John Jenkins, jr., in section 18, a mile south of the last, also has a flowing well of similar depth and good quality of water.

Northcote.—Peter Daly, in this village, bored 75 feet, obtaining no water. The North Branch of Two Rivers supplies the water used here, which is healthful, but very hard. A mile west of Northcote a salt spring issues in the bed of this stream. Salt springs also occur in the channel of the South Branch of Two Rivers, about 5 miles west of Hallock.

Humboldt.—The section of the deep artesian well on the farm of D. H. Valentine, at this station, has been given on page 75, and an analysis of its water on page 537. This water has never been utilized.

St. Vincent.—A well 165 feet deep was bored by the railway company about three-fourths of a mile east of St. Vincent in the winter of 1878–79. It yielded very saline water, not used, which rose 10 feet above the surface. The section was alluvial clay and till to the depth of 120 feet, and gravel and sand thence to the bottom, 45 feet.

The common wells of this county are 10 to 30 feet deep, generally obtaining water which is slightly alkaline, but may be used for all farm and domestic purposes, if the wells are drawn from plentifully so as to insure new inflow every day.

WELLS ON THE AREA OF LAKE AGASSIZ IN NORTH DAKOTA.

RICHLAND COUNTY.

Wahpeton.—No artesian water was found in a boring 120 feet deep at the Richland County court-house, the section being till, which incloses thin layers of sand and gravel. A deeper boring passed through the drift to Cretaceous shale, probably the Fort Benton formation, at 195 feet.

The city is furnished with water by a system of waterworks, which pumps its supply from the Red River, above Breckenridge, at the upper end of a long ox-bow or horseshoe-like circuit of the river.

Fifteen or more flowing wells are reported in the German settlement along the Wild Rice River, within 10 miles southwest of Wahpeton, ranging in depth from 70 feet to 305 feet.

Farmington.—A. D. Ellsworth, 1 mile southwest of Farmington station: Flowing well, 93 feet deep, almost wholly in till; water of good quality, called "soft," rises 7 feet above the surface. There are several other flowing wells of similar depth in this vicinity.

Fairview.—On the Fairview Farm an artesian well 240 feet deep, bored wholly in alluvial, lacustrine, and drift deposits, has a powerful flow.

Mooreton.—Artesian wells at the Mooreton Roller Mills and at the Central Hotel are about 135 feet deep, obtaining moderate flows of good water, about 4 gallons per minute from an inch pipe.

On the Minneapolis Farm, owned by Bull & Menage, about 2 miles northwest of Mooreton, a well 150 feet deep flows 7 gallons per minute from a three-fourths inch pipe. At 11 feet above the surface it shows no perceptible decrease in the force of the flow.

The Antelope Farm, owned by Hugh Moore, about 3 miles farther northwest, has an artesian well 173 feet deep, with two-thirds as strong flow as the last.

Wyndmere.—The Northern Pacific Elevator Company bored to the depth of 267 feet, obtaining no artesian water. The thickness of the alluvial, lacustrine, and drift formations was in total 218 feet, below which the boring went 49 feet in dark Cretaceous shale.

Dwight.—Ten artesian wells, from 85 to 105 feet deep, are within a radius of 5 miles around this village. Their water is good, not at all saline, but slightly alkaline, though less so than that of the common wells, which are 10 to 25 feet deep.

Colfax.—H. E. Crandall, Headquarters Hotel: Artesian well, 85 feet deep; soil and delta sand, 6 feet; till, 79 feet, to sand and gravel at the bottom.

Depths of other artesian wells in Colfax village, all obtaining good water in the drift, are as follows: At Cargill Bros.' elevator, 125 feet; at the Red River Valley mill, 128 feet; and at the railway tank, 135 feet.

Two flowing wells, 55 and 60 feet deep, are reported within a few miles east of this village.

Walcott.—Minnesota and Dakota Elevator Company: Flowing well, 120 feet deep; the water, which is of excellent quality, rises only 1 foot above the surface.

The artesian town well, 25 rods east of the preceding, is 110 feet deep. It ceases flowing when the larger pipe of the elevator well, 4 inches in diameter, is opened to its full size.

An artesian well 1 mile north of Walcott, 227 feet deep, obtains good water, called "soft," which rises only to the surface. About 2 miles farther north a well 104 feet deep flows about 50 barrels daily, rising 5 feet above the surface. Another flowing well, 2 miles north of the last, is 131 feet deep.

Common wells in all this region obtain ample supplies of water at depths ranging from 10 to 30 feet, and no salt taste is noticeable in the water of either the common or the artesian wells.

CASS COUNTY.

Kindred.—No artesian wells. The common wells are 10 to 15 feet deep, in fine loamy silt, obtaining slightly alkaline water from a layer of sand 1 foot thick at the bottom.

Davenport.—The town well is 70 feet deep, in alluvial and lacustrine beds, and has about 10 feet depth of water. Several other wells in this village are similar; none artesian.

Leonard.—Wells here, on the Sheyenne delta of Lake Agassiz, obtain a copious supply of excellent water at 18 to 20 feet. The section is all sand, which continues beyond the depth of the well bored or driven 46 feet by the Northern Pacific Elevator Company.

Warren.—At the buildings of the Leech Bros.' farm, in the southeast quarter of section 17, a boring 475 feet deep, finding no artesian water, went through the lacustrine clay, till, and probably a considerable thickness of Cretaceous shale; and its lowest 75 feet were in a fine white sandstone, very hard and compact, doubtless the Dakota sandstone, which here, as occasionally farther north, is so close grained in its upper portion as to be almost impervious to water.

Durbin.—Cargill Bros.' elevator: Artesian well, 160 feet; water chalybeate, at first a copious flow, diminished later by sand filling the lower part of the pipe.

Common wells in this village and its vicinity are about 30 feet deep.

Everest.—At the Cargill Bros.' elevator a well 160 feet deep derives water from gravel at the bottom, rising nearly to the surface. The common wells are 40 to 50 feet deep, with good water from gravel, filling the wells to the depth of 20 to 30 feet.

Gill.—An artesian well on the farm of J. C. Gill, in the northwest quarter of section 35, is about 260 feet deep, with water rising 15 feet or more above the surface.

Fargo.—The alluvial and lacustrine beds and the glacial drift are together 220 feet thick, being, in descending order, stratified clay, 95 feet; sand and gravel, 10 feet, yielding water which rises nearly to the surface; and till, 115 feet, inclosing occasional layers and veins of water-bearing sand and gravel. Below the drift a boring went 42 feet farther, probably in Cretaceous strata referable to the Fort Benton formation, being soft, dark blue shale, 32 feet; coarse sand rock, 6 feet; and a second shale, 4 feet, in which the boring stopped at a total depth of 262 feet. Water rose from the sand rock to 10 or 12 feet below the surface, apparently a good supply.[1]

Pillsbury & Hulbert elevator: Well, 150 feet; water rises to 8 feet below the surface, in so copious supply that it can not be lowered by pumping; it is of excellent quality, softer than the water of the river.

Most of the water used throughout the city is taken from the river by a system of waterworks.

[1] U. S. Geol. Survey of the Territories, 1872, p. 301.

Mapleton.—Wells in this village are 60 to 80 feet deep, in alluvial and lacustrine clayey silt, obtaining slightly alkaline water from sandy beds at the bottom, whence it rises to be 30 to 40 feet deep.

Dalrymple.—Cass & Cheeney Elevator Company: Well, 60 feet; water seeps, scanty, alkaline.

Casselton.—The city artesian well is 327 feet deep, its section being yellowish alluvial clay, 25 feet; darker bluish clay and sand, alluvial and lacustrine, 45 feet; till, 180 feet, inclosing thin seams and veins of sand and gravel; and very fine-grained sandstone, probably the Dakota sandstone, in some portions containing fragments of lignite, 77 feet, in which the boring ceased. The same section, to the depth of 317 feet, was also found by the well at Capt. C. May's flouring mill. Both these wells obtain slightly brackish water, which rises 40 feet above the surface.

Smith Stemmel, 3 miles west of Casselton, has a similar flowing well about 350 feet deep.

Northern Pacific Elevator Company: Well, 100 feet; water, somewhat saline, rises from a layer of sand to 6 feet below the surface.

The common wells of Casselton and its vicinity vary in depth from 20 to 70 feet, the deepest obtaining good water at the top of the till, whence it usually rises to fill the lower half of the well.

Wheatland.—Slightly alkaline water is supplied by most of the wells in the village, which are 20 to 30 feet deep in till; but water of excellent quality is obtained on the Campbell beach, in the east edge of the village, by wells 15 to 20 feet deep in the beach gravel and sand.

Tower City.—The city artesian well has been described on page 535.

Reed.—C. H. Welton, southeast quarter of section 17: Flowing well, 153 feet deep, in alluvial and lacustrine deposits for its upper part, with much till below. Water, fresh, and soft enough for washing with soap, rises 4 feet above the surface.

B. P. Reynolds, northeast quarter of section 20, about 40 rods southeast from the last: Well, similarly flowing, only 130 feet deep. Probably these two wells are supplied by separate water-bearing layers.

Raymond.—E. Porrett, southwest quarter of section 6: Well, 80 feet, in alluvial clay and till, the latter containing fragments of lignite; the water, somewhat alkaline, rises to 1 foot below the surface.

H. G. Roberts, in the northeast quarter of section 23, close north of the Maple River, has a flowing well 190 feet deep.

Harwood.—Minneapolis and Northern Elevator Company: Flowing well, 117 feet deep; water rises from sand and gravel to 10 feet above the surface; it is fresh, good for drinking, and called "soft" for washing.

Argusville.—The Minneapolis and Northern Elevator Company has three artesian wells, one 158 feet deep; another, 20 feet distant, 157 feet; and a third, about 35 rods distant, 147 feet. Below a small depth of alluvial and lacustrine clay these go through till with bowlders. The water, very good for drinking, comes from a bed of gravel and sand 5 to 7 feet thick, which was passed through to till beneath in one of these wells.

Berlin.—Two flowing wells in the northeastern part of this township are 87 feet and about 100 feet deep. The common wells are 40 to 60 feet deep, with water rising to 10 or 15 feet below the surface.

Amenia.—The artesian well at the elevator of the Amenia and Sharon Land Company is 279 feet deep; water rises 5 feet above the surface, not a copious flow. Another boring went to the depth of 400 feet, finding no lower artesian water. The section was soil, 2 feet; yellowish gray till, 30 feet; harder dark bluish till, about 200 feet, inclosing occasional water-bearing layers of sand and gravel; and Cretaceous beds below, the last 100 feet or more being very fine-grained white sandstone and nearly white shale, probably the Dakota formation.

Edward McNeill, a half mile east of Amenia, has an artesian well 215 feet deep, yielding a large supply of water. On Lee E. Clark's farm, some 4 miles distant to the northeast, the copiously flowing water of a well about 275 feet deep rises 30 feet above the surface. All these deep wells at and near Amenia have slightly brackish, hard water.

William Hinkle Smith, in section 32, has bored 290 feet, obtaining no artesian water. The well most used by this large farm is 75 feet deep, with a very abundant supply of good water, which rises to 20 feet below the surface.

On the farm of Gage & Davis, in the southeast quarter of section 9, a well 155 feet deep has water which rises from the bottom to 5 feet below the surface. This water, like that of Mr. Boustead's well, noted on page 553, contains gas which is not visible when the water first flows from the pump, but shows in very minute bubbles, as fine as dust, from one-fourth to three-fourths of a minute later, then disappearing so that the water is left clear. It is called excellent water for drinking and for engine boilers.

Ripon.—A railway boring to the depth of 280 feet found no artesian water. Common wells mostly are 20 to 40 feet deep, obtaining a copious supply from sand and gravel beds inclosed in the till.

Gardner.—Minneapolis and Northern Elevator Company: Well, 125 feet; water rises 12 feet above the surface.

S. C. Dalrymple, section 6: Artesian well about 230 feet deep; strong flow. There are ten or more other flowing wells within a few miles around Gardner, ranging from 96 feet to 250 feet in depth. Their water is slightly brackish.

Grandin.—The village of Grandin has four artesian wells within an extreme distance of 50 rods from east to west and half as much from south to north, as follows: William Black, 105 feet deep, with water at first rising 12 feet, now 8 feet; the

Grandin Hotel, P. C. Weisbecker, 158 feet, water rising 15 feet; the Minneapolis and Northern Elevator Company, 187 feet, water rising 12 feet; and J. W. Thom, at his store, 248 feet, water rising only 2 feet. All these wells are slightly saline, but are called good for drinking and cooking, except in making tea. It is remarkable that they obtain water at four distinct levels, showing that at least the upper water-bearing deposits of gravel and sand are narrow veins, as of stream courses; or, if they form broad sheets, those above are pinched out in places, so that the deposits of overlying and underlying till come together. (See pages 525, 526.)

TRAILL COUNTY.

Elm River.—Robert Young, about a mile west of Quincy, has an artesian well 213 feet deep; water copious, slightly saline.

Alexander Armstrong's well, a half mile south of Mr. Young's, is 110 feet deep, with very strong flow, having scarcely any perceptible saline taste.

Kelso.—St. Anthony and Dakota Elevator Company: Well, 110 feet; mostly in till, below a considerable thickness of alluvial and lacustrine clay; water at first overflowed, but now stands a few feet below the surface; it is capable of supplying 200 barrels in twelve hours, the diameter of the pipe being 2 inches.

Minneapolis and Northern Elevator Company: Well, 109 feet; water overflows slightly; ample supply for pumping. The water of both these wells is slightly salty, but is not harmful for drinking; it rapidly rusts through the plate of engine boilers in which it is used.

James Johnson, section 3: Artesian well, 175 feet deep; the water flows from the pipe, which is 2 inches in diameter, at the rate of about 2 barrels per minute, forming a considerable brook; when confined in the pipe, it rose 20 feet above the surface, and flowed with little apparent diminution. The water is saline, but both cattle and people prefer it rather than the water of the adjoining creek, the North Branch of the Elm River. This well was bored only about 150 feet deep, the section having been nearly all till; then, within fifteen or twenty minutes, the pipe sank about 20 feet in quicksand, and it settled more during the following night. When the sand filling the lower part of the pipe was cleared out, the water rose with such force as to bring up gravel stones from 1 to 1½ inches in diameter in the 2-inch pipe, showing that it had sunk to a bed of gravel. In this well a feeble artesian flow was noted at about 110 feet, as in the wells of Kelso village, 1½ miles distant. There are several other flowing wells within 1 or 2 miles around Mr. Johnson's, some being about 110 feet deep, and others having nearly the same depth as his well.

S. A. Dalrymple, southeast corner of section 1: Artesian well, 180 feet deep; 2-inch pipe, flowing a stream a half inch in diameter at 3 feet above the surface; water slightly brackish.

Alexander Smart, southeast quarter of section 12: Boring 417 feet deep, obtaining no artesian water; the alluvial and lacustrine beds of the surface have an undetermined thickness, probably less than 60 feet; next below, till extends about 250 feet, inclosing occasional thin beds of sand and gravel, to the base of the drift at 310 feet. Thence the boring went 107 feet in a very fine-grained white sandstone, in part very hard, but in other parts less so than the till. The drillings from this formation, believed to be the Dakota sandstone, are mostly similar to flour in their fineness, but usually they also contain many small, rounded quartz grains, from a hundredth to a fiftieth of an inch in diameter.

Bohnsack.—R. M. Cunningham, southeast quarter of section 5, township 144, range 52: Well, 140 feet deep, wholly in till; water rises from sand and gravel at the bottom to 30 feet below the surface.

Hague.—On Farm No. 1 of the Grandin and Dalrymple Farming Company, at Hague post-office, northwest quarter of section 25, township 145, range 49, are two artesian wells, 160 feet and 210 feet deep; water, slightly saline, rises from each to a height of 10 feet or more above the surface. The well on Farm No. 3, in the northeast quarter of section 9, township 144, range 49 (Elm River), is 160 feet deep, with water rising just to the surface. From another artesian well, on Farm No. 6, in the southeast quarter of section 33, township 145, range 49, also 160 feet deep, the water rises 6 feet.

Hillsboro.—In the city of Hillsboro and within a distance of 5 miles there are probably thirty or more artesian wells, mostly between 100 and 200 feet deep, all obtaining somewhat saline and alkaline water. Notes of several in Hillsboro are as follows:

W. H. York, in the northeast part of the city: 105 feet deep; flow about 200 barrels daily; water slightly brackish, softer than the water of the deeper wells.

City well, at the intersection of the two principal streets: 185 feet deep; flow about 75 barrels daily, through 6-inch pipe; strongly brackish, used only for watering horses and cattle.

S. C. Sherwood, in the north part of the city: About 190 feet deep; flow estimated at 400 barrels daily, through 2-inch pipe. The water of this well, with largest flow in the town, though salty, is employed for all uses of the house and stable, including drinking and cooking. But in general throughout the city the principal supply for domestic uses is taken from the Goose River.

Minneapolis and Northern Elevator Company: 195 feet deep.

J. R. Nunn's livery stable: 198 feet deep.

Florence Mill Company: 195 feet deep; flow, 250 barrels daily.

At the North Dakota Roller Mill, in the south part of the city, several borings have been made, in all of which combustible gas has been found at the depth of 105 to 120 feet. The deepest of these borings went 630 feet, obtaining no artesian water.

A considerable thickness of Cretaceous beds, apparently the Fort Benton shales and the Dakota sandstone, were penetrated, reaching "quartzite" at 620 feet.

Blanchard.—Again, probably as many as thirty artesian wells exist in Blanchard village and within a radius of 5 miles around, varying in their depth from 150 to 404 feet. The glacial drift extends to a depth of about 200 feet, below which these wells pass into Cretaceous shale and very fine-grained sandstone, probably the Dakota formation. The following are two of the deepest borings:

S. S. Blanchard, section 11, township 145, range 52: Well, 375 feet; brackish water, good for stock throughout the year and used in engine boilers, rises 15 feet above the surface.

Emerson & Wild, southwest quarter of section 19, township 145, range 51, a half mile north of Blanchard Village: Well, 404 feet deep; brackish water, capable of rising 40 feet or more above the surface, flows at the rate of 30 gallons per minute from a 2½-inch pipe.

Norman.—On Jones & Brinker's farm, in section 13, an artesian well about 350 feet deep has a strong flow of saline water.

Mayville.—Goose River Mill, owned by Gibbs & Edwards: Artesian well, 395 feet deep, in drift about 200 feet and below in Cretaceous shale and sandstone; water brackish.

The city artesian well, 355 feet deep, has a strong flow of brackish water, which rises 22 feet above the surface, its rate of flow being about 85 gallons per minute.

Common wells in Mayville and its vicinity are 20 to 40 feet deep, in alluvial clayey silt and till, obtaining somewhat alkaline water. The supply needed for drinking and cooking is taken from the Goose River, excepting by those who have rain-water cisterns.

Portland.—A boring for the railway tank is said to have gone to the depth of 275 feet, obtaining no artesian water.

Minnesota and Dakota Elevator Company: Well, 90 feet; water rises to 20 feet below the surface; it is brackish, and forms much scale on the boilers of engines.

The common wells in Portland are 15 to 40 feet deep in till, from which water seeps, somewhat alkaline.

Hatton.—Cargill Bros.' elevator: Well, 254 feet; delta silt, about 20 feet; till, inclosing occasional sand and gravel layers, about 200 feet; and sand, 34 feet. Excellent water, which makes but little scale on the engine boilers, rises to 6 feet below the surface.

Common wells here are only 10 to 12 feet deep, obtaining plentiful and good water in the fine sand of the Elk Valley delta.

About 3 miles southwest of Hatton, in section 25, Newburg, Steele County, a boring on the farm of Smith & Mills went to the depth of 553 feet, obtaining a strong artesian flow, which, however, soon ceased because the lower part of the pipe became filled with sand. The bottom of this boring is at nearly the same elevation above the sea as that of the deep artesian wells of Blanchard and Mayville, being, like them, doubtless, in the Dakota sandstone.

GRAND FORKS COUNTY.

Northwood.—Red River Valley Elevator Company: Well, 20 feet deep, in delta sand; water usually 10 to 15 feet deep, overflowing in the spring. Common wells here are 15 to 18 feet deep, supplying good water, which forms little scale on engine boilers.

Kempton.—Wells in the vicinity of Kempton are about 20 feet deep, the section being soil, 2 feet; fine clayey sand, 10 feet; a harder bed of sand, 2 feet; and quicksand below, which contains an ample supply of excellent water.

Grand Forks.—A railway well bored near the depot in 1881 to the depth of 265 feet, 5 inches in diameter, reduced below to 3½ inches, yielded in August of that year, probably after the lower part of the pipe had become filled with sand, only a very scanty overflow; water saline, not used.

C. J. Alloway, in the north edge of the city: Artesian well, 270 feet; alluvial and lacustrine clay, 30 feet; till, inclosing occasional beds of sand and gravel, 220 feet; and sand, 20 feet; the water, too saline to be used, rises 2 feet above the surface.

The common wells of Grand Forks, 20 to 30 feet deep, have water of fair quality, but the city is mainly supplied through waterworks which pump from the river.

Brenna.—Lawrence Kennedy, in the north part of this township, about halfway between Grand Forks and Ojata, has a flowing well of brackish water 90 feet deep.

Ojata.—Minneapolis and Northern Elevator Company: Flowing well, 115 feet deep; water saline, unfit for engine boilers, though it has been so used. Similar artesian water was also found by this well at the depth of about 70 feet. Common wells are mostly 15 to 18 feet deep, obtaining water that is slightly alkaline, though not perceptibly so to the taste. When dug deeper they get bitter or salty water.

Emerado.—Wells in this village and its vicinity are 15 to 20 feet deep, in till, with thin veins and layers of sand; good water. One well, bored 70 feet deep, near the depot, found no water supply, while another well 10 rods east found plenty of water at 20 feet.

The well of the railway tank was dug 53 feet deep in a dry season, and the workmen at night left their tools at the bottom, which gave no sign of water; but the next morning it was full of water to 8 feet below the surface.

Arvilla.—Common wells at and near Arvilla are 15 to 30 feet deep, in till, obtaining somewhat alkaline water. The first boring for a town well went nearly 200 feet in the till, obtaining no sufficient water supply. A second boring found abundance of good water at 85 feet, whence it rises to about 30 feet below the surface and is not lowered by vigorous pumping.

Larimore.—The well at the Sherman House, 60 feet deep in the fine silt and sand of the Elk Valley delta, and other shallower wells, are noted on pages 334, 335. The water is copious and of good quality, forming little scale on engine boilers.

Manvel.—Joseph Colosky, Manvel Hotel: Artesian well, 166 feet deep, in alluvial and lacustrine silt and till, inclosing occasional layers of sand and fine gravel. A large flow of saline water was found in such a layer at 107 feet. The second flow, at 166 feet, is very strong, running from the 2-inch pipe at the rate of about 40 gallons per minute.

Minneapolis and Northern Elevator Company: Artesian well, 175 feet; the water is capable of rising more than 45 feet above the surface, there flowing from an inch pipe (reduced from the diameter of the well, which is 2 inches) at the rate of about 6 gallons per minute. In 1887 this well had been running five years and showed no diminution of flow. The water contains much sulphate of magnesia, not being so salt as that at 107 feet. In engine boilers it forms a powdery precipitate, which is easily blown out by the engineer, not being so troublesome as the usual scale.

Turtle River.—Richard Forrest, northeast quarter of section 28: A boring, seen when it was in progress at 150 feet, had brackish artesian water flowing feebly from sand all the way below 100 feet.

Johnstown.—William Stratton, section 22: Well in alluvial clay, which at the depth of 19 feet contained a log 10 inches in diameter, thought to be birch. It was chopped off to permit the well to go deeper. Another well in the southwest part of this township found two similar tree trunks 16 feet below the surface.

WALSH COUNTY.

Ardoch.—Minneapolis and Northern Elevator Company: Artesian well, 164 feet, the section being mostly till; large flow of saline water.

Brooks Bros.' elevator: Well, 42 feet deep, 8 feet in diameter, with plenty of water. A boring below this to the total depth of 100 feet from the surface was stopped by a bowlder. The section was alluvial clay, 15 feet; sand and gravel, ½ foot; and till, easy to dig and bore, 85 feet. Alkaline water seeps, much coming from the gravel at 15 feet.

Common wells at Ardoch are 15 to 20 feet deep, most of them obtaining tolerably good water. The town has two public wells or cisterns, each 13 feet deep and 13 feet in diameter, and another measuring 15 feet in these dimensions, for fire protection.

Minto.—Minneapolis and Northern Elevator Company: Artesian well, 200 feet deep; alluvial, lacustrine, and drift deposits, 190 feet, the lower two-thirds being till, with no important water-bearing veins or layers; then sand and gravel, 10 feet and extending below. The water rushed up with such force as to bring pebbles an inch in diameter, and rises when confined in pipes to a height of 60 feet above the surface.

It is quite brackish, but some persons have drunk it freely and almost solely during several years, thinking it favorable for their health.

Brooks Bros.' elevator: Well, 196 feet deep, with similar strong flow as the foregoing.

The common wells are 15 to 20 feet deep, in yellow alluvial clay, to blue clay which is not dug into; water seeping, slightly alkaline.

Grafton.—The deep artesian well of the city, passing through Lower Silurian strata below the drift, and obtaining a powerful flow of brackish water, has been described on pages 77, 78.

The Minneapolis and Northern Elevator Company and the Brooks Bros.' elevator had artesian wells, each 156 feet deep, but their water was so saline and scanty that they are disused.

The water of the common wells here, 12 to 25 feet deep, is slightly alkaline, but is considered healthful.

About 5 miles northeast of Grafton a well is reported to have found in the alluvial clay, at the depth of 35 feet, a log about a foot in diameter, which was chopped off at both sides of the well.

Conway.—The depths of the common wells range from 20 to 60 feet, in till.

Park River.—Wells 15 to 40 feet deep, in till, obtaining a plentiful supply of good water.

PEMBINA COUNTY.

St. Thomas.—Minneapolis and Northern Elevator Company: Artesian well, 175 feet deep, mostly in till; water saline, but used in the engine boiler. The Brooks Bros.' elevator is supplied by a well only 18 feet deep.

The common wells are 15 to 20 feet deep, in alluvial clay; water slightly alkaline.

Glasston.—The Minneapolis and Northern Elevator Company has a flowing well about 200 feet deep, with water rising only 2 feet above the surface, but yielding an inexhaustible supply when pumped. It is brackish, but is drunk freely by stock and by some people, who soon like it, and no injurious effects attend its use.

Common wells, mostly 14 to 20 feet deep, have somewhat alkaline water. Several other wells within a few miles east of the railway between St. Thomas and Glasston, and about the latter station, go 90 to 150 feet through till to gravel and sand, from which water, slightly brackish, rises immediately to a permanent level 10 to 20 feet below the surface.

Hamilton.—Minneapolis and Northern Elevator Company: Artesian well, 179 feet; water brackish.

Rand & Norton's livery stable: Artesian well, 175 feet; also brackish, but agreeing with horses and cattle.

The common wells of Hamilton are 12 to 20 feet deep, usually having good water. Many other wells have been bored in this vicinity 75 to 150 feet deep, only rarely obtaining artesian flows; but water, found in gravel and sand at the bottom generally rises nearly to the surface. In some wells the water is too salty or bitter to be used, but others equally deep have fresh water. The former probably derive their water supply from great distances through beds of sandstone underlying the drift, while the latter receive their water from rains on neighboring areas, percolating only through porous sand and gravel beds of the drift sheet.

Bathgate.—The artesian well of the Minneapolis and Northern Elevator Company is 143 feet deep, passing through alluvial and lacustrine clay and till to coarse sand, whence a very copious flow of water rises to 6 feet above the surface. It is somewhat saline and alkaline, but its mineral matter is chiefly deposited as a powdery sediment in the boilers of engines, which can be easily blown out.

During the year 1887 eleven artesian wells, ranging from 130 to 160 feet in depth, were bored within a radius of 5 miles about Bathgate.

There are no shallow wells in this town, as the seeping surface water is too alkaline. The water of the Tongue River is used for ordinary domestic purposes.

Neche.—Minneapolis and Northern Elevator Company: Well, about 175 feet deep; water saline, rising to a few feet below the surface; unfit for any use.

Akra.—Abner French, at center of section 18, township 161, range 55, 6 rods southeast of the Tongue River: Well, dug at first about 16 feet deep, having good water, which seeped from the alluvial clay. In an unusually dry season it was dug 4 feet deeper, and found a layer of sand from which water of inferior quality soon rose 6 feet, to the level of the river.

WELLS ON THE AREA OF LAKE AGASSIZ IN MANITOBA.

Artesian or flowing wells are obtained at many localities in Manitoba near the Red River, as in Winnipeg and southward, where water often rises to the surface from layers of sand and gravel in the drift.

Winnipeg.—About 40 wells have been bored by the city authorities of Winnipeg, for supplying water for domestic use. Mr. H. N. Ruttan, the city engineer, states that about a dozen of these wells go into the bed-rock, which is limestone, while the others derive their water from layers of quicksand in or beneath the till. Several of them in the west part of the city are artesian, but eastward the water rises only to 5 or 10 feet below the surface. The water is considered of good quality for drinking and cooking, but it contains much mineral matter in solution, chiefly the sulphates of lime and magnesia.

Alluvial stratified clay extends to a depth that varies from 3 to 10 feet or more. This is underlain by the glacial till or bowlder-clay, which incloses thin veins and layers of fine gravel and sand, and frequently is underlain by sand and gravel, but in many places extends to the limestone. The upper part of the till here shows an imperfect stratification, due to its deposition in Lake Agassiz, and contains a less proportion of bowlders and gravel than its lower part, which is very hard, and is therefore commonly denominated "hardpan." The depth to the limestone varies from 30 to 60 feet in the west part of the city, and increases to about 75 feet eastward.

One of these wells, bored in the west edge of the city, close north of the Assiniboine and 1½ miles west of the Osborne street bridge, went 32 feet in stratified clay and till, and then 100 feet in limestone, mostly of light buff or cream color, obtaining water of good quality at 132 feet, which rose to 5 feet below the surface. The bed-rock is nearly like that which outcrops at Lower Fort Garry and East Selkirk.

A general section of the superficial deposits at Winnipeg is noted by J. Hoyes Panton as follows, from information supplied by Mr. Piper, known as having an extensive experience in well boring throughout the city:

1. Surface mold, 1 to 4 feet thick, dark color, and exceedingly fertile.

2. "Yellow gumbo," 2 to 3 feet; a very sticky form of yellowish clay, which usually holds considerable water.

3. Dark gray clay, 30 to 50 feet thick, with bowlders scattered throughout, some of them 4 feet in diameter and chiefly gneissoid, and no doubt derived from Laurentian rocks.

4. Light-colored clay, 1 to 3 feet, containing many small stones.

5. Hardpan, 2 to 10 feet, a very solid and compact form of clay.

6. Sand, gravel, and bowlders, 5 to 25 feet.

7. Angular fragments, 1 to 3 feet, usually limestone, and largely derived from the solid rock which lies immediately below it.

This loose material is far from being uniform, and varies so much in its arrangements that scarcely any two borings show the same distribution. Sometimes there is little or no hardpan, while in other parts it is several feet thick. However, as a usual thing, these seven forms of strata are passed through in boring, and varying in thickness to the number of feet already mentioned.[1]

St. Boniface.—Wells in St. Boniface are nearly the same as in Winnipeg, on the opposite side of the river. The deepest learned of is on the exhibition ground, 156 feet deep, being stratified clay and till, 36 feet, its lowest 10 feet very hard and compact; sand, 44 feet, to the bed-rock at 80 feet; then limestone, of light cream color or nearly white, penetrated 76 feet and extending below.

Niverville.—Thomas W. Craven, hotel: Well, 65 feet deep, in alluvium and till; water rises to 15 feet below the surface. Other wells in this village have nearly the same depth or less, none coming to the bed-rock; but it was reached by a well a third of a mile east, at a depth of about 100 feet.

Four miles south-southeast of Niverville, in the northeast quarter of section 5, in this same township 7, range 4 east, Cornelius Freesen's well, situated on the Niverville beach, passed through alluvium and glacial drift, 65 feet, and shale, 30 feet, obtaining an ample artesian flow of excellent water.

In the southwest quarter of this section, a half mile from the foregoing, Adam Freesen has a similar flowing well, 107 feet deep, which went 37 feet into the shale.

[1] Report of the Department of Agriculture and Statistics, Manitoba, for 1882, p. 176.

This is said to be the deepest of about twenty flowing wells in this Mennonite Reserve, their range of depth being from 40 to 107 feet.

Dominion City.—James Spence, Victoria Flour Mills: Flowing well, 170 feet deep, in alluvial clay and till, the latter very hard below the depth of 120 feet; bed-rock not reached; water brackish, flowing feebly, not used.

The common wells of this village, 12 to 16 feet deep, have good water which seeps from the alluvial clay.

The Roseau River has much softer water than the wells and most of the short streams of this region, so that the railway tank at Dominion City, taking water from the Roseau, is preferred by the locomotive engineers above any other source of water on this branch line.

Emerson.—Wells in Emerson range from 10 to 25 feet in depth, in alluvial clay, and obtain water tolerably good for drinking and cooking, but it is very hard and unsuited for laundry use.

West Lynne.—Hudson Bay Company's steam flouring mill: Well, 108 feet deep, dug 68 feet in alluvial and lacustrine clay, and bored 40 feet lower, apparently in the same deposit. The only water found, not enough to supply the engine, is that which seeps from the clay, coming almost wholly within the first 20 feet below the surface. The ordinary wells in this village, 14 to 18 feet deep, obtain good water, seeping in sufficient amount for domestic use.

Artesian wells near Letellier and on the Low Farm.—An artesian well on the French Reserve at the center of township 2, range 1 east, near Letellier, 12 miles northwest from Emerson and West Lynne, is 250 feet deep, not reaching the bed-rock. It supplies brackish water, which is drunk by cattle. Another artesian well of similar depth is on the Low Farm, about 12 miles west of Morris, the water of which is strongly saline.

West Selkirk.—The well at the Lisgar House, 100 feet deep, reached the bed-rock, which is limestone, at 65 feet.

Stonewall.—J. B. Rutherford's flouring mill: Well, 82 feet deep, consisting of beach gravel and sand, 10 feet; till, 2 feet; and limestone, including red shaly beds, 70 feet, to the bottom, where the drill fell 1 foot and water rose immediately to 22 feet below the surface. Several other wells in Stonewall have had a similar experience, obtaining water which rises from hollows in the limestone.

Township 15, range 2 east.—William Andrew, southeast quarter of section 7: Well, 94 feet deep; till at the surface and to a depth of 11 feet; and limestone, 83 feet, mostly hard and of light buff color, but inclosing some 25 feet of reddish shaly beds between the depths of 45 and 70 feet. There are several such wells in the same vicinity.

Between Pleasant Home and Gimli.—Mr. Andrew states that about 25 miles northeast from the last a well between Pleasant Home and Gimli has been sunk 120 feet, wholly in the glacial drift, not reaching the bed-rock.

Rosser.—The railway well at Rosser is 29 feet deep, in till, which forms the surface there and east to Little Stony Mountain; water rises 15 feet from a sandy layer at the bottom.

Township 11, range 1 east.—Robert D. Bathgate, section 27: Well, 60 feet deep; till, 24 feet, from which alkaline water seeps; and light buff, hard limestone, 36 feet, and continuing lower; water of good quality rises from the bottom to 20 feet below the surface. Other wells in this vicinity mostly get good water in veins or thin layers of sand and gravel contained in the till.

St. François Xavier.—On Mr. Nanton's ranch, about 10 miles west of Headingly and a quarter of a mile south of the Assiniboine, a well 114 feet deep passed through alluvial clay, 14 feet; till, 34 feet; limestone of light cream color, 47 feet; and reddish limestone, 19 feet. Brackish water rises from the bottom to 14 feet below the surface.

Meadow Lea.[1]—Section 30, township 13, range 2: Wells in this vicinity range from 20 to 95 feet in depth, and are wholly in till, not reaching the bed-rock.

Township 13, range 6.—Charles Cuthbert, section 21, 10 miles north-northeast from Portage la Prairie: Well, 16 feet deep; soil and loamy silt, to water in quicksand and fine gravel. The surface here is only a few feet above the high-water level of Lake Manitoba.

Portage la Prairie.—The common wells are 12 to 16 feet deep, being black soil, 2 to 4 feet; then yellowish-gray, loamy silt, the alluvium of the Assiniboine, in which fragments of driftwood, as small limbs of trees, are occasionally found, to water in quicksand and fine gravel. The deepest well here is that of the Manitoba and Northwestern Railway tank, which reaches 30 feet, to till at the bottom, obtaining a very large supply of water.

Township 12, range 8.—Kenneth McKenzie, jr., in the north edge of section 2, close west of Rat Creek: Well, dug 86 and bored 72 feet, to a total depth of 158 feet; soil, 2 feet; sand, 4 to 5 feet; yellow till, 4 feet; blue till, 76 feet, easy to excavate, with scanty intermixture of gravel, but containing occasional stones up to 1 foot or more in diameter, undoubtedly true till, for the surface generally through the south part of this township has plentiful embedded bowlders up to 2 or 3 feet in diameter; below was "hardpan," a more indurated deposit of till, very hard to dig or pick, bored or drilled 72 feet, and found to vary much in its hardness through this depth, some portions being much softer than where the boring began. A seam of sand and fine gravel, about an inch thick, was noticed between the upper part of the till, which was dug, and the harder lower portion. At the bottom the drill struck a harder layer, which was called rock. It was probably shale, for the drill, being dropped a few times upon it, seemed in danger of becoming stuck so that it could not be removed. Water rose from the bottom within the first day to a depth of 20 or 30 feet in the portion of the

[1] Here and onward, through the following pages, the ranges are numbered westward from the reference meridian.

well that was dug, and within a few days it reached its permanent level, about 20 feet below the surface. It does not sink below this level in dry seasons, but in wet seasons it rises to 7 feet below the surface, near the bottom of the sand. It is somewhat salty, so that it is not suitable for house use, but it is drunk freely, and with no ill effect, by horses and cattle during the entire winter.

A quarter of a mile south of this Mr. McKenzie's father has a similar well as to its depth and succession of deposits passed through to rock, but it obtains a less ample supply of water. Both wells are 864 feet, approximately, above the sea; and the top of the bed-rock is accordingly about 706 feet above the sea-level.

Gladstone.—Wells vary from 10 to 15 feet in depth, in sandy, fine silt. Water abundant and of excellent quality.

Arden.—In the vicinity of Arden wells are 10 to 50 feet deep, the section being till, excepting where this is overlain by beach deposits from 5 to 15 feet thick.

Neepawa.—John A. Davidson & Co., store: Well, 60 feet, the deepest in the town; soil, 2 feet; gravel and sand of the Assiniboine delta, 12 feet; and till, dark bluish, with the usual proportion of gravel and bowlders, 46 feet, and extending below; water good. Other wells, mostly 15 to 25 feet deep, reach till at nearly the same depth.

Township 13, range 16.—The deepest wells in this township go 50 to 70 feet, wholly in till; but commonly a sufficient supply of water is found within 30 feet or less.

Carberry.—Wells 10 to 20 feet deep in sand, the Assiniboine delta; plenty of good water.

Chater.—At the elevator, 42 feet, and at the hotel, 31 feet, wholly in till, yellowish above and dark bluish below; water rose several feet.

Brandon.—Wells 10 to 30 feet deep, in delta gravel, underlain by till; good water.

Carman.—Depths 10 to 15 feet, in alluvial clay, with sandy layers; good water. Two miles south of Carman, James Stewart's and George E. Laidlaw's wells are, respectively, about 100 and 120 feet deep, probably passing through the alluvial and lacustrine clays and glacial drift to underlying Cretaceous shales. The water of the deeper of these is too brackish for house use, but is drunk by cattle.

Treherne.—In the vicinity of Treherne wells vary from 15 to 50 feet in depth, the section being beach and delta deposits of stratified gravel and sand; excellent water.

Holland.—Wells at Holland are 10 to 20 feet deep, in till to shale, which is reached at about 10 feet; water good, generally better from the shale than from the drift. Shale is not encountered by wells farther north, on the Assiniboine delta. In the adjoining Tiger Hills, on the south, the depth to shale varies commonly from 2 or 3 to 10 or 15 feet.

Cypress River and Glenboro.—Depths, 10 to 17 feet, in fine silt, the delta of the Assiniboine; water good, issuing from quicksand.

Township 8, range 18.—Rounthwaite post-office, section 14: Well, 20 feet deep; soil, 2 feet; yellowish gray till, 13 feet; harder blue till, 5 feet and lower; water seeps, plentiful and good.

Township 7, range 17.—Williamson, Dignum & Co., farmhouse in section 3: Well, dug 30 feet and bored 32 feet more; seen while the boring was in progress at depth of 62 feet; all till, mostly yellowish, to that depth. This is half a mile north of the northern base of the Tiger Hills, at an elevation of about 1,350 feet above the sea.

Langs Valley.—Langvale post-office, at James Lang's house, section 2, township 6, range 18: Well, 18 feet deep; all gravel and sand, with quicksand at the bottom. This is on the bed of the channel of outflow to the Pembina from the glacial lake in the Souris basin.

Plum Creek.—Wells in this village, at the junction of Plum Creek with the Souris, are 10 to 30 feet deep, in till, not reaching bed-rock; but outcrops of the Fort Pierre shale occur on the Souris, near by.

Gretna.—Common wells, 10 to 20 feet deep, in alluvial and lacustrine clay, obtaining a scanty supply of water. A boring is said to have been made here for the railway tank, to a depth of 150 feet, without finding a supply of water, and it is now pumped from the Pembina River.

Rheinland.—Wells 15 to 20 feet deep, in somewhat sandy lacustrine clay; excellent water.

Township 2, range 5.—John Johnston, section 3: Well, 22 feet; soil, 2 feet; yellowish till, containing bowlders up to 5 feet in diameter, 20 feet; to gravel with water which rises from it 2 or 3 feet. This is between the Campbell and Tintah beaches, on the low terrace at the foot of the Pembina Mountain escarpment. Other wells near show that this terrace consists of the Fort Pierre shale, thinly covered with glacial drift.

Morden and Nelson.—The deep boring recently made unsuccessfully for artesian water at Morden has been described on page 81.

Common wells in Morden and Nelson are 10 to 25 feet deep, in alluvial silt and underlying till; water frequently alkaline.

CHAPTER XI.

AGRICULTURAL AND MATERIAL RESOURCES OF THE AREA OF LAKE AGASSIZ.

Agriculture must evidently be always the chief industry and source of wealth throughout the prairie portion of the area of Lake Agassiz, attended, in villages and towns, by needed branches of trade and manufactures. The great fertility of this district and its capabilities for agriculture depend largely on the character of the underlying alluvial, lacustrine, and drift formations, which in their diverse development upon different tracts give considerable variety to the soils. Beyond and above the inherent qualities of the land, its value to the farmer and herdsman is further dependent in a very large degree on the climatic conditions which are brought by the changing seasons of the year. Both these factors of agricultural prosperity had expression, before the land was cultivated or pastured, in the native flora of the country and in its former herds of elk, antelopes, and buffaloes. After the consideration of these sources, conditions, and natural evidences of the adaptation of this district for diversified and successful agriculture, the development of this industry is shown by a partly statistical review of its rapid progress in the production of wheat and other crops and in stock raising and dairying.

The more strictly geologic resources of this region are next noticed, comprising its building stone, lime, and bricks, all of which, and especially the last, have much economic importance. Mention is also given to its salt springs, lignite, and natural gas, none of which, however, occurs in such amount that it can be profitably utilized.

Lastly, the water power and other natural aids for the development of manufactures within the area of this glacial lake are considered. Some of its streams, as the Red Lake and Clearwater rivers, the upper part of the Red River before it enters this lacustrine area, and especially the Winnipeg

River, are unsurpassed in the value of their water power, which can be made uniform throughout the year by using the lakes tributary to these streams for reservoirs. Probably much of the wooded portion of the country that was covered by Lake Agassiz will be cleared and used as farming land; while the waterfalls and rapids which abound on rivers within the Archean part of the wooded district will become the sites of manufacturing villages and cities.

VARIETY AND DISTRIBUTION OF THE SOILS.

Over nearly the entire prairie district of Lake Agassiz and upon the higher and more undulating or rolling country that stretches thence westward, a sandy clay, often with some intermixture of gravel and occasional bowlders, forms the soil, which has been colored black to a depth of 1 or 2 feet below the surface by decaying vegetation. The alluvial and lacustrine beds, or the glacial drift, the same as the soil, excepting that they are not enriched and blackened by organic decay, continue below, being usually yellowish gray to a depth of 10 or 15 feet, but darker and bluish beyond, as seen in wells. The glacial drift contains many fragments of Cretaceous shale, magnesian limestone, granites, and crystalline schists; and its fine detritus and the silty deposits carried into Lake Agassiz by its tributaries are mixtures of these pulverized rocks, presenting in the most advantageous proportions the elements needed by growing plants.

The till or glacial drift of this region is remarkably contrasted with that of New England and the other Northern States westward to the Mississippi River by its containing a smaller proportion of bowlders, cobbles, or comparatively small rock fragments and gravel. On an average the surface of the till in this southwestern part of the area of Lake Agassiz has probably not more than one-twentieth as many bowlders as the average in the States farther east. They are so few that they present no obstacle to the cultivation of the soil, except on the occasional morainic belts, where bowlders are plentiful, often strewing the ground upon limited tracts, which usually are knolly and hilly. These tracts can not be profitably subjected to tillage, but have generally a fertile soil and afford excellent pasturage. The smooth, gently undulating or nearly flat areas of till, which are far more extensive than the morainic belts, can be plowed often across a distance of several miles, bounded only by stream courses, without encountering a bowlder or tree or bush to require the plow to deviate from its straight and continuous furrow. The few bowlders which are found on these lands, seldom exceeding 3 to 5 feet in diameter and varying in numbers from perhaps one to five or ten per acre, are scarcely so many as the farmer desires for the construction of cellar walls, foundations of buildings, and for other uses.

Large portions of the deltas of Lake Agassiz, and the whole of the broad, flat expanses of lacustrine and alluvial silt which adjoin the Red River, have no bowlders nor gravel. Here the ideal conditions are found for the cultivation of single fields of grain occupying hundreds or thousands of acres. Though the subsoil of many arable tracts of the Red River Valley is saturated with moisture throughout the year at the depth of only a few feet below the surface, even these moist areas have sufficient slopes to drain away the water of snow-melting and the rains of spring in season for early sowing. While the soil of both the till and the lacustrine and alluvial deposits is prevailingly clayey, it yet is nearly everywhere sufficiently sandy and porous to permit a part of these waters and a large proportion of the summer rains to be absorbed by it. Whenever a temporary drought comes, the water thus received and stored at a moderate depth in the subsoil is raised by capillary attraction to the surface. The roots of vegetation are thus nourished, and the growth of the crops is continued without check or a bountiful harvest is often matured without the aid of rainfall during a month or more.

Some tracts of the Red River Valley are marsh, owing to the flatness of the land and the depression of these tracts a few feet below their natural avenues of drainage. The marshes vary in extent from patches of a few hundred acres up to 50 square miles.

An enumeration of the most noteworthy of these boggy, partially inundated areas in Minnesota includes the marsh, 6 miles in diameter, occupying the greater part of Winchester, Norman County, in crossing which the south branch of the Wild Rice River becomes diffused and lost, until it is gathered again on the western border of the marsh by the union of the waters of many rills, brooklets, and springs; the marshy grounds in Anthony and Halstad townships, also in Norman County, lying on each side of the Marsh River; the great swamp in southwestern Polk County, in which the Sand Hill River is lost for about 8 miles, being again formed by many brooks that flow from the western edge of the swamp along a distance of 5 miles from south to north; the Snake River marsh in Sandsville, on the north line of Polk County; the marsh in Bloomer, Parker, and Big Woods, Marshall County, in which the Middle River is lost for 5 miles next above its junction with the Snake River; and the large swamp in the northern edge of this county, extending also into Kittson County, formed by the outspread waters of the Tamarack River, which is thus lost across a distance of 8 miles.

Excavation of channels for these rivers through their marshes and for a distance of several miles below them to the depth of 5 to 10 feet below the present waterways, with the cutting of side ditches in the marshes, will drain these wet lands, which will then have a very deep and fertile soil, sufficiently dry for tillage, being doubtless the best and most enduring in productiveness among all the rich lands of this valley plain. A survey for a plan of drainage of the eastern side of the Red River Valley, lying in Minnesota, was made in 1886; and the estimate by Mr. C. G. Elliott, the engineer in charge, for the expenditure needed to provide the main ditches and to deepen the existing watercourses is $746,228. The number of acres to be benefited by the drainage is 808,600, showing an average cost of 92 cents per acre. Minor ditches, which will be dug on each side of the roads, following the section lines, are not included in this estimate.

The part of this flat valley in North Dakota is dotted here and there with many small marshes, but with very few that have so large an area as several square miles. The most considerable in size are the marsh, 2 to 3 miles across, in Berlin and Hammond, Cass County, in which the Rush River is lost; marshes adjoining Salt Lake, through which the Forest River flows in Ardoch, Walsh County; and a low meadow, mostly mown for its marsh hay, but in small part a permanent bog, extending 12 miles from south to north, with a width of a half mile to 2 miles, in the east part of Midland, Pembina County.

In both Minnesota and North Dakota these bogs are destitute of trees and shrubs, and are occupied mostly by rushes, sedges, and marsh grasses, which usually attain a very rank growth. No malarial diseases, however, are produced by the marshes in their present condition, and the principal injury to be charged against them is that they hinder or prevent the construction of roads which would be a public convenience. So long as they remain undrained, these lands are almost or quite worthless, but when well drained and brought under cultivation they will be a great addition to the wealth and resources of this fertile valley.

East of the Red River Valley, the wooded part of the area of Lake Agassiz in northern Minnesota contains frequent swamps, ranging from a few acres to many square miles in area, usually occupied by a sparse growth of tall and slender tamarack and black spruce trees, but in their central portions often destitute of trees and covered by peat mosses, in which there may be a pool or lakelet, either of clear water or filled with rushes. Extensive swamps of this kind, locally called muskegs, adjoin Red Lake, Mud and Thief lakes, the Lake of the Woods, and Roseau Lake. Indeed, they are reported as covering a large part of the country northeastward from Red Lake to the international boundary, forming a region which is well-nigh impassable excepting in winter, when the surface of the muskegs is frozen.

The vast forest region of Lake Agassiz comprised within Canadian territory has many scattered muskegs, but also much land with dry and rich soil, worthy to be cleared and cultivated, throughout all its extent from Rainy Lake and River and the Lake of the Woods northwestward by the great lakes of Manitoba to the Saskatchewan. During many years to come no attempt will probably be made to utilize the swamps or muskegs of the wooded country; but in Manitoba, as already noted in Minnesota, many of the marshes and swamps of the prairie region are being drained for agriculture. The main ditches are dug as a part of the public improvements by the Provincial Government, which is reimbursed by the sales of the marsh lands, worthless before they are drained, but afterward very valuable.

Several of the prairie marshes of Manitoba, lying west of the Red River and on both sides of the Assiniboine, range in extent from 20 to 75 square miles, namely, the marsh in which Tobacco Creek is spread out and lost east of Pomeroy; the great marsh similarly formed by the waters of the Boyne River and Elm Creek, extending 15 miles from west to east, with a width of 3 to 6 miles, overflowing southeastward to the Red River by the Rivière aux Gratias; the Squirrel Creek marsh, lying close south of the White Mud River, between Westbourne and Woodside, formed by Image, Beaver, Squirrel, Pine, and Silver creeks, which come from the northeastern slope of the Assiniboine delta; and the Big Grass marsh, extending more than 20 miles from south to north, with a width of 3 to 5 miles, in which the White Mud and Big Grass rivers are lost or flow sluggishly through a broad, quaking morass, with shallow, rush-filled lakes along its axial portion.

Commonly the water of the marshes is supplied almost wholly by inflowing streams and by rainfall, but in some instances they receive a large part of their water from springs. Multitudes of copious springs of fresh water, issuing from thick beds of sand and gravel which eastward are overlain by till, form the very remarkable boggy tract, a half mile to 1 mile wide, which extends about 9 miles from south to north along the highest shore of Lake Agassiz in Akron and Tanberg, Wilkin County, Minn. Unlike the level marshes before enumerated, this tract lies on a slope which descends 20 to 40 feet upon the width of the marshy ground from east to west. On such a slope the marsh can be maintained only by the constant issuance of spring water through all portions of its bed. (See pp. 286, 385.)

In several other marshes of smaller extent, as on the Salt Cooley and Salt River, near Ojata, tributary to the Turtle River, and on the Forest and Park rivers, it is known that saline springs come up within the area of the marshes, because, although the streams flowing into them are fresh, the outflowing water is brackish.

Throughout nearly all the part of the Red River Valley where brackish water is found by the artesian wells, and where it infrequently outflows in springs, as just noted and as observed in the channels of Two Rivers and other streams, there are noticed also occasional and rare patches of ground, usually no more than a few square rods, or at most a few acres, in extent, on which wheat, oats, or other crops, after germinating and beginning an apparently healthy growth, are soon dwarfed or killed, while closely adjoining land, sometimes scarcely distinguishable in the appearance of the soil, is yet divided from the preceding by rather definite boundaries, as shown by the healthful growth of vegetation and a satisfactory harvest. These peculiar spots fail year after year to produce any crop, and their exceptional character in fields which mainly have a bountiful growth of waving grain is a source of wonder and much conjecture to many farmers. They are very simply explainable, however, as the places to which the saline and alkaline artesian and spring water percolates upward through veins and layers of gravel and sand and somewhat porous or creviced tracts of the till and lacustrine and alluvial beds, until it comes to the surface and is there diffused through the soil of a small or somewhat large area, thus affecting vegetation, though not issuing in sufficient quantity to produce springs.

Although the bowlders of the till within the basin of the Red River are mostly Archean granite, gneiss, and crystalline schists, derived from the northeast and north, with few—probably on an average less than 1 per cent—of magnesian limestone, derived from Silurian and Devonian formations underlying the drift and outcropping northward in Manitoba, the latter forms a very considerable proportion, usually more than half, of the smaller rock fragments inclosed in the till and of the gravel in modified drift and alluvial deposits. Owing to the greater prevalence of joints in the limestone, it has been reduced more readily to the size of gravel, and it probably has contributed at least as much as the Archean rocks to the sandy and clayey matrix of the till, pulverized by the grinding action of the ice-sheet. The powdered limestone is one of the most important ingredients of the drift. Dissolved in the water of wells and springs, as noted in the preceding chapter, it makes them hard, diminishing their desirability for washing and for use in the boilers of steam engines, but not for drinking and cooking. On the other hand, this element contributes a large share toward making the very fertile soil of this district and producing the magnificent harvests of wheat which are its principal export and source of wealth.

A still larger proportion of the drift upon the prairie district of Lake Agassiz was supplied from the Fort Pierre, Niobrara, and Fort Benton shale formations of the Cretaceous series. They are mostly soft shales, however, and therefore have supplied no bowlders; nor are they usually represented conspicuously by pebbles of the till and in gravel deposits, excepting near the western border of the ancient lake, where the Pembina Mountain escarpment and plateau, the basal part of the Tiger Hills, and the Riding and Duck mountains, consist of these shales. Many streams flowing down from these highlands have cut deep ravines and valleys in their frontal escarpment, and have spread much shale gravel outward for several miles along the watercourses on the Red River Valley plain. The till or glacial drift on this western margin of the lacustrine area and on all the plateau country extending thence westward has also a considerable ingredient of shale gravel. But the greater part of the material contributed from these shale beds to the glacial drift is mingled with the pulverized Archean granite and gneiss and Paleozoic limestones, doubtless generally far surpassing these as a constituent of the finely comminuted rock flour which is the most abundant element of the bowlder-clay or till.

The portion of the till thus received from the Cretaceous beds has given to its soil the somewhat alkaline character which is perhaps the most noteworthy quality distinguishing the soil of this district and of the plains on the west, in contrast with the soil of the Northern States and Canadian provinces east of Lake Agassiz. The sulphates of magnesia and soda, with other soluble salts, together termed "alkali," which are present in considerable amount in the glacial drift of the Red River Valley and the western plains, are almost wholly due to the contribution of the Cretaceous shales to the drift. This soluble mineral matter was contained in the Cretaceous ocean, and much of it became imprisoned and stored up in the very fine clayey sediments of that time. On the areas of these shale formations beyond the limits of the glacial drift the soil is far more alkaline than within this region, where Archean, Paleozoic, and Cretaceous strata have joined in making up the drift through the grinding and kneading action of the ice-sheet

Foregoing descriptions and analyses of the waters of wells, lakes, and streams have sufficiently indicated the effects of this alkaline matter of the soil upon the water supply. At the same time, the result of evaporation from the soil during droughts, often producing on previously moist tracts a saline and alkaline efflorescence, was also noticed. Shallow and flat depressions, into which the alkaline matter is brought by drainage from higher adjoining land, thus may have many times more of the soluble salts in their soil than the average of the district; and when these tracts become dry and their moisture from a considerable depth is drawn upward and evaporated at the surface it leaves a whitish-gray alkaline incrustation. These low alkaline lands are unfit for agriculture until they have been well drained during several years, which may frequently be done by ditches only a few feet deep, leading into lower watercourses. Excepting such depressions and the marshes and sloughs before described, all the land of this district has at least the very slight slopes necessary for free drainage, and is well adapted for the cultivation of wheat, oats, and other cereals, and of the common garden vegetables and small fruits that are suited to the climate. The proportion of alkaline matter in the till soils wherever they have natural drainage is not prejudicial but rather advantageous for wheat and other grains.

Along the axial belt of the Red River Valley plain alluvial clayey silt usually borders the river to a distance of 5 to 10 miles on each side, and other tracts are covered by fine lacustrine sediments of nearly the same character, bordering the prominent delta plateaus. These areas have a somewhat porous soil, composed mostly of very fine sand or rock flour rather than true clay, being thus similar to the bowlder-clay or till; but they have a somewhat less proportion of the soluble alkaline salts, which in the process of aqueous deposition of these beds were partially removed and carried away by the rivers into the sea.

The deltas of sand and gravel, mainly modified drift washed away from the melting ice-sheet and amassed in the margin of Lake Agassiz by its tributary glacial rivers, also contain less alkaline matter than the till.

They have a large ingredient of limestone gravel, sand, and fine detritus, so that their soil is usually fertile, while the very porous subsoil permits early sowing and is favorable for the rapid growth and early maturing of crops.

The unique tracts of dunes, however, consisting of bare sand drifted by the winds, or partly or wholly covered with grasses and other herbage, bushes, and small trees, which occupy extensive portions of the Sand Hill, Sheyenne, and Assiniboine deltas, are themselves worthless for agricultural uses, and even afford only scanty pasturage. But many well-grassed patches of ground lie in the hollows among the dunes, where herds find good forage.

Probably the parts of this district that are worthless to the farmer, comprising the sand hills, the alkaline undrained depressions, permanently wet sloughs, the steep bluffs or banks of the watercourses, and very stony morainic tracts, amount together to no more than a fiftieth of the whole country. Elsewhere all this vast area is fertile and easily cultivated, with considerable diversity in the soils of its different portions, dependent on the nature of the drift, lacustrine, and alluvial formations, and on their conditions of drainage. The black soil has usually a thickness of 1 to 2 feet, this color being due to enrichment by the decaying vegetation of all the years and centuries since these deposits were formed during the Ice age and at its close.

Looking forward to no very distant time, it may be foreseen that nearly all the land here will be brought under successful cultivation, and that a farming population of probably a million people, perhaps even twice or thrice this number, will live on the prairie area of Lake Agassiz. Many of them will come as immigrants, and in their selection of this rich farming region for their future homes the most important inquiries next after those concerning the native quality of the land will relate to climate. The rainfall and the temperature not only affect very closely the health and comfort of the people, but they also determine whether the crops sown or planted in a naturally productive soil and tended with patient and faithful care shall bring forth an abundant or a scanty harvest.

CLIMATIC CONDITIONS.

Six stations at which continuous series of weather observations have been made are here selected for the purpose of exhibiting by their records the general climatic conditions of the southwestern part of the area of Lake Agassiz, which is fast becoming occupied by a dense population engaged in agriculture. Five are stations of the United States Signal Service, namely: St. Paul, where observations were begun November 1, 1870; Duluth, also having records since November 1, 1870; Moorhead, since January 1, 1881; St. Vincent, since September 5, 1880; and Bismarck, since September 15, 1874.[1] With these are also inserted the records of observations at Winnipeg for the Meteorological Bureau of the Dominion of Canada, beginning with the year 1871 and published up to the year 1887, inclusive.

RAINFALL AND SNOWFALL.

At these stations, of which three are situated on the Red River, the combined amount of rainfall and snowfall are as follows for their series of years, with the resultant means deduced from each series:

Annual and mean annual precipitation, in inches.

Stations.	1871.	1872.	1873.	1874.	1875.	1876.	1877.	1878.	1879.	1880.	1881.
St. Paul	30.63	....	34.75	35.51	30.66	23.67	28.80	22.78	32.39	29.76	39.16
Duluth	31.20	30.12	38.73	36.43	26.93	32.27	34.31	28.09	45.28	38.11	37.56
Moorhead	....	....	....	....	....	....	....	....	....	....	29.48
St. Vincent	....	....	....	....	....	....	....	....	....	....	15.51
Winnipeg	20.17	30.17	17.04	18.31	16.85	29.18	24.61	29.52	25.23	27.17	18.09
Bismarck	....	....	....	....	27.52	30.92	17.68	20.23	22.61	19.75	15.76
Mean for entire district	27.33	....	30.17	30.08	25.49	29.01	26.35	25.15	31.38	28.70	25.93

Stations.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	Mean annual.	
										Years.	Mean.
St. Paul	23.14	26.70	26.11	25.33	22.89	25.85	25.86	16.96	23.38	19	27.60
Duluth	38.02	23.20	35.85	19.96	33.37	28.56	27.31	32.04	24.09	20	32.07
Moorhead	34.01	24.96	28.50	22.68	26.76	21.97	16.50	17.07	21.79	10	24.37
St. Vincent	22.48	17.88	21.81	16.58	15.04	18.47	17.22	14.44	22.09	10	18.15
Winnipeg	20.75	19.22	25.13	16.52	14.84	17.98	....	....	....	17	21.81
Bismarck	21.33	15.66	23.36	13.08	13.26	16.33	16.51	11.03	15.75	16	18.80
Mean for entire district	26.62	21.68	27.13	19.53	22.26	22.24	20.68	18.31	21.42	....	23.80

[1] Annual Reports of the Chief Signal Officer, United States Army. (In the year 1891 the Weather Bureau was transferred to the United States Department of Agriculture.)

The amounts of the average or normal precipitation for each month at the five stations in the United States from the date of their establishment to the end of 1886, and at Winnipeg during the fifteen years 1871 to 1885, are noted in the following table:

Normal precipitation, in inches, for each month of the year.

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
St. Paul	1.03	0.97	1.52	2.25	3.34	4.85	3.26	3.67	3.38	2.05	1.37	1.30
Duluth	1.06	1.14	1.56	2.26	3.74	5.33	3.90	3.41	4.53	2.95	1.79	1.31
Moorhead	.77	.98	.88	2.38	3.04	4.47	4.59	3.42	2.42	2.77	1.25	.78
St. Vincent	.36	.40	.50	1.36	2.22	2.59	2.66	2.68	2.13	2.28	.56	.52
Winnipeg	.57	.97	.89	1.56	2.37	3.62	2.87	3.08	1.91	1.51	.86	1.00
Bismarck	.54	.64	1.05	2.78	2.91	3.40	2.28	2.60	1.24	1.19	.75	.77
Mean for entire district	.72	.85	1.07	2.10	2.94	4.04	3.26	3.14	2.60	2.12	1.10	.95

From these tables it is seen that the mean annual precipitation of moisture as rain and snow at different places in this district ranges from 18 to 32 inches. It is most upon the wooded country east and northeast of the Red River Valley; on that valley plain its average is about 22 inches; but westward it decreases to 19 inches at Bismarck.

The most plentiful precipitation is during the season of the growth of crops, increasing, on an average for the whole district, from about 2 inches in April to 3 inches in May and 4 inches in June, which is usually the most rainy month; and decreasing to about 3 inches in July, nearly the same in August, and 2½ inches in September. But many years depart widely from these averages, there being sometimes during several consecutive years an excess and during other isolated or consecutive years a deficiency of rainfall. During the fifteen to twenty years since agricultural settlements were first made in the Red River Valley south of the international boundary, the rainfall and temperature, though showing marked contrasts in different years, have always been so favorable for farming that there has been no instance of failure on this valley plain to secure at least a generally remunerative harvest; while most of the years have yielded very abundantly.

A large portion of the rainfall is brought by thunder showers, which may occur at any hour of the day or night. Terms of cloudy and more or less rainy weather, due to broad storms that sweep from west to east, occasionally occupy one, two, or three days, or very rarely a whole week; but on the average, in all seasons of the year, this region has a large majority of clear days with bright sunshine.

In addition to the recorded rainfall, seasons that have a considerable supply of rain, with at least a moderately humid atmosphere, receive much moisture in the form of the nightly dews, which greatly help the growth of crops; but in seasons of drought, with an arid atmosphere, when all vegetation gasps for moisture, the nights condense little or no dew.

In winter the snow is commonly about a foot deep during two or three months, from December or January to March. Sometimes it comes earlier or stays later, and very rarely it attains an average depth of 2 or 3 feet. Nearly every winter has from one to three or four severe storms, called blizzards, in which the snowfall is accompanied by a fierce wind and often by very low temperature. The air is filled with flying grains of snow, by which the view to any considerable distance is obscured and the traveler finds his eyes soon blinded in attempting to move or look in the direction from which the storm comes. The earliest snows, which, however, are likely to be soon melted away, usually fall during November, but very rarely they come as early as the middle of September; and the latest snows vary in time from March to May.

During a series of years of prevailingly copious rainfall and snowfall, extending from 1871 or earlier to 1884, agriculture was partially or generally successful upon a large area reaching westward from the southwestern borders of Lake Agassiz to the Missouri River. Then a series of five prevailingly dry years, with long terms of severe drought, extended to 1889, during which the crops of that area were mostly very scanty and for large tracts were several times an utter failure, bringing great distress and dismay to the people, many of whom were compelled to abandon their lands and homes and to remove to more favored portions of the country. A new cycle of plentiful rainfall appears to have begun in 1890, 1891, and 1892, giving again magnificent harvests in the region from Devils Lake to Bismarck and southward, which had suffered most severely by drought.

Fluctuations of lakes and streams.—Through the past hundred years maximum and minimum stages of the great Laurentian lakes have alternated in cycles of about a dozen years, during which comparatively scanty average rainfall for several years was followed by unusually abundant rainfall.[1] These fluctuations are similar with those just noted in the rainfall of North Dakota. Besides such short cycles, important secular changes of the mean annual precipitation in this State, occupying considerably longer periods, have caused remarkable changes in the levels of numerous lakes which have no outlets.

Devils Lake[2] thus shows evidence of having attained, about the year 1830, a level 16 feet higher than its low stage in 1889, reaching at or near the former date to the line that limits the large and dense timber of its bordering groves. Below that line are only smaller and scattered trees, of which Capt. E. E. Heerman informed me that the largest found by him and cut a few years ago had fifty-seven rings of annual growth. Within the twenty-five years since the building of Fort Totten this lake has fallen 9 or 10 feet, and it has fluctuated 4 feet under the influence of the changes in the average annual precipitation of rain and snow during the past dozen years.

The high stage reached by this lake about sixty years ago appears to have been limited by an avenue of discharge eastward into Stump Lake, which rose at the same time to within about 3 feet of this height. The latter and smaller lake, receiving no large tributary and lying in a basin that nowhere extends many miles from the lake, was prevented by evaporation from rising quite so high as Devils Lake, which during years of abundant rains and snows receives a large tributary, the Mauvaise Coulée, draining a broad area that stretches 60 miles northwestward to the Turtle Mountain. The outlet from Devils Lake into Stump Lake was nearly due eastward from Jerusalem, situated on Lamoreaux Bay at the most eastern portion of the entire lake shore. With an overflow at this point, Devils Lake may many times have been raised to this beach by the periodic variations in rainfall during the many centuries since the Ice age.[3]

[1] Charles Whittlesey, "On fluctuations of level in the North American lakes," in Smithsonian Contributions to Knowledge, Vol. XII, 1860, pp. 25, with 2 plates. G. M. Dawson, in Nature, Vol. IX, pp. 504–506, April 30, 1874. Bela Hubbard, in Popular Science Monthly, Vol. XXXII, pp. 373–387, Jan., 1888. G. K. Gilbert, in The Forum, Vol. V, pp. 417–428, June, 1888.

[2] See pp. 169–171, with Pl. XVIII.

[3] Compare with Mr. Gilbert's hypothetic explanation of the Stansbury shore-line of Lake Bonneville, U. S. Geol. Survey, Monograph I, p. 186.

At the time when the last ice-sheet retreated, however, the confluent waters of Devils and Stump lakes were raised to a shore-line which now has a slight ascent from west to east, lying 21 to 25 feet above the low stage of Devils Lake in 1889. This shore is traceable around both lakes, passing above the watershed that now divides them. At the same height, as shown by leveling, a well-marked watercourse is found running across the present watershed between the west part of Stump Lake and the Sheyenne River, in section 19, township 151, range 61. This glacial channel of outflow has a nearly flat bottom 150 feet wide, and is bordered on both sides by moderately steep morainic hills 50 to 75 feet high.

While the ice border was retreating across these lake basins the inflow from its melting produced a large outflowing stream, but there is no proof that any time since the departure of the ice has been so humid as to raise the lakes to this channel. The heavy growth of timber which in many places borders the lakes extends across the highest beach ridge or line of erosion to the next shore, which, as before noted, is the limit of the forest, and therefore is believed to have been the lake margin since the beginning of this century. Though the climate so lately had during a considerable term of years more rainfall than now, it was yet surely less than the average amount in the region of the Laurentian lakes and in New England, else the levels of both lakes must have been raised to overflowing—that is, to the continuous highest shore-line and channel of discharge southwest of Stump Lake.

The following are notes of the elevations of these lakes, of their former shore-lines above their present levels, and of this outlet. A slight differential uplifting, like that which gave to the beaches of Lake Agassiz their northward and eastward ascents, is shown by the glacial shore-line, which is now level through its western 18 miles from Minnewaukan to the city of Devils Lake, but thence rises eastward about 3 feet in a distance of 16 miles to Jerusalem, and 1 foot more in the next 6 miles southeast to the channel of outlet.

Notes of leveling in the vicinity of Devils and Stump lakes.

	Feet above the sea.
Railway at passenger station, city of Devils Lake	1,464
Railway at passenger station, Minnewaukan	1,461
Devils Lake, surface of water August 8, 1887	1,431.6
Devils Lake in 1889	1,430
Devils Lake, highest and lowest stages during the years 1880 to 1889	1,434–1,430
Stump Lake, surface of water August 12, 1887	1,417
Former shore-lines of Devils Lake at Minnewaukan and the city of Devils Lake	1,451, 1,446, 1,439
Former shore-lines at Jerusalem on Lamoreaux Bay	1,454, 1,446, 1,439
Former shore-lines of Stump Lake	1,455, 1,443, 1,433, 1,426
Bottom of channel of outflow from Stump Lake to the Sheyenne River	1,454.6

The elevations of the former shores of Stump Lake were determined by leveling on the northern slope of a promontory of till, which was an island at the time of the higher shore-lines, rising to 1,458 feet, in the east part of section 21, township 151, range 61. Postglacial deposition of alluvium, brought from slight ravines gullied by rains on the adjoining morainic hills, may have raised the bed of the channel of overflow 1 to 3 feet, or possibly more. The outflowing river, like the River Warren, was evidently shallow during the greater part of each year, corresponding to the general level of Devils and Stump lakes, then confluent; and while the glacial melting was most rapid during the summer months, this somewhat extensive body of water and its outlet were probably raised no more than a few feet above their minimum winter stage.

Besides the formerly higher stages of these and other neighboring lakes, it is also known that they have stood continually lower than now, at least by several feet, during a long period, sufficient for the growth of large forests on the shores of Stump Lake, and of the North and South Washington lakes and Lake Coe, in township 149, range 63; for this is proved by submerged logs and stumps, the latter standing rooted in the soil where they grew. Many of these logs and stumps have been hauled out of the southeastern bay of Stump Lake by the neighboring farmers for use as fuel. This prolonged epoch of comparative desiccation may have coincided with the yet more arid conditions in the Great Basin, which, as shown by

Russell, appear to have entirely dried up Pyramid, Winnemucca, and other lakes of Nevada about three hundred years ago.[1] On the other hand, the high stage of Devils Lake before mentioned was near the time of the highest known flood of the Red River, in 1826, when its water rose 5 feet above the surface where Winnipeg is now built. Likewise it should be noted that the highest known stage of the Laurentian lakes was in 1838, when Lake Erie stood 6 feet above its lowest recorded stage, which was in the winter of 1819–20.

TEMPERATURE.

Owing to the geographic position of the basin of Lake Agassiz, in the central part of a large continent and nearly equidistant between the equator and the north pole, the difference between the mean temperatures of summer and winter is great, the winters being very cold and usually some portions of the summers very hot. The temperature, however, is mostly cool and invigorating through the six or seven months in which the land is worked and its harvest gathered.

In summer there are commonly only a few excessively hot days (80° to 100° F.) in a single heated term, which is preceded and followed by longer terms of agreeable coolness, even at midday. It is also important to note that, however hot the days may be, the nights, almost without exception, through the whole summer are cool and favorable for refreshing sleep.

In winter, though the temperature is continuously below zero of the Fahrenheit scale, even at midday, while the sun shines brightly, during days and occasionally weeks together, the dryness of the air makes the extreme cold (10° to 40° below zero) no more difficult to endure than a temperature 25° to 50° higher with the moist air of the region about the Laurentian lakes and on the Atlantic coast. Usually there is no considerable thawing at any time during two or three months of the winter. The ordinarily scanty snowfall, which gives a sheet of snow seldom exceeding a foot in average depth, is likely to serve well, if not too much drifted by gales at the time

[1] Geological History of Lake Lahontan, U. S. Geol. Survey, Monograph XI, pp. 223–237, 252. Compare G. K. Gilbert's Lake Bonneville, Monograph I, p. 258.

of its fall, for sleighing and sledding through this whole period of steady cold. This season, too, is more sharply demarked than in most other parts of the United States. It is begun by a sudden cold wave, generally during the first half of November, which freezes the ground and stops the late autumn work of plowing; and the return of warmth in spring is by a sudden transition which rapidly melts away the snow and soon thaws and dries the land sufficiently to prepare it for the seeding of the broad wheat fields.

The following table shows the mean temperatures at the six stations before noted. In the United States they were computed from the daily extremes of temperature during a period of nine years preceding the end of 1888. At Winnipeg, Manitoba, the average is drawn from observations begun in 1871 and extending through fifteen years.

Normal temperature, in degrees Fahrenheit, for each month and for the whole year.

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
St. Paul	7.9	15.6	27.4	46.2	58.6	68.1	72.4	69.6	60.1	48	31.3	18	43.6
Duluth	6	12.4	21.9	37.7	48.6	58	66	64.2	56.1	45.2	29.4	16.7	38.5
Moorhead	−4.8	4.2	18.6	40	53.8	64.3	67.8	65.3	56.2	43.1	24.8	9.7	36.9
St. Vincent	−9.6	−0.6	13.2	36.2	52	62.2	65.2	62.8	53.4	40	20.6	5	33.4
Winnipeg	−5.7	−0.1	11.5	33.7	52.1	61.5	65.8	63.6	51.7	39	16.7	2	33.2
Bismarck	1.4	9.6	20.8	41.4	55.7	65	69.5	67.2	57	43.9	27.4	13.8	39.4
Mean for entire district	−0.8	6.8	18.9	39.2	53.5	63.2	67.8	65.4	55.7	43.2	25	10.9	37.5

Ice on the Red River closed the season of navigation at Moorhead and Fargo in the years 1881 to 1888 at dates which range from the 11th to the 25th of November; and navigation was opened, with the breaking up and departure of the ice, at dates from the 12th to the 24th of April. Throughout the years 1889 and 1890 navigation was suspended because of the low stage of water.

The first severe frosts, destroying tender vegetation, occurred at Moorhead and Fargo in the years 1881 to 1890 at dates from August 25 to September 20; and the last severe frost there in spring during the same years ranged from May 2 to June 8. At St. Vincent these dates for the first were from August 4 to September 20, and for the last from April 29 to June 8.

WINDS.

The nearly level vast prairies are fully exposed to all currents of the air, and during the most windy months, which are in the spring and autumn, they seem very bleak to one who has previously lived only in districts where the surface mostly receives a partial shelter from the force of winds by the undulations of hills and vales and by the presence of forests and trees cultivated for ornament and shade. The movements of the atmosphere on the prairie district of Lake Agassiz do not appear, however, to exceed in their aggregate amount those on its wooded district, or on the basins of the Laurentian lakes, or on the Atlantic seaboard. Exposed places throughout these areas, as the tops of hills, are quite as severely swept by gales as the prairies, where they are so much more observed in the common experience of the people. One of the most desirable improvements of the prairie homestead is the cultivation of rows of trees, called wind-breaks, about the buildings.

Winds, usually light, but on many days heavy, are moving almost continually over this area, with variations in their direction to every point of the compass. From the hourly records of the velocity of the winds as measured by self-registering anemometers during the seven years from 1883 to 1889, inclusive, their mean velocity for this whole period was 6.58 miles per hour at St. Paul, 7.28 miles at Duluth, 8.81 miles at St. Vincent, and 8.39 miles at Bismarck.

With these means it will be instructive to compare the records of several stations in other parts of the country during the same time, which show for Boston, Mass., a mean velocity of 11.18 miles per hour; New York City, 9.30 miles; Washington, D. C., 5.39 miles; Savannah, 7.12 miles; Chicago, 9.01 miles; Cincinnati, 6.55 miles; St. Louis, 10.56 miles; New Orleans, 7.26 miles; Omaha, 8.05 miles; Denver, 6.99 miles; Salt Lake City, 5.18 miles; Portland, Oreg., 4.94 miles; San Francisco, 8.94 miles; and San Diego, Cal., 5.61 miles. Among sixty-six stations of the United States Signal Service thus tabulated, the maximum mean velocity of the wind is at Dodge City, Kans., 11.48 miles per hour, and the minimum is at Lynchburg, Va., 3.76 miles. The least windy station of the

United States, however, appears to be Phœnix, Ariz., where the records of the years 1879 to 1881, inclusive, showed a mean velocity of only 2.37 miles.

FLORA OF THE BASIN OF THE RED RIVER OF THE NORTH.

Upon every portion of the land area of the globe, the flora, or assemblage of species constituting its mantle of vegetation, is a very sensitive register of its aggregate climatic conditions and of the value of its soil for agriculture. In almost an equal degree, also, the fauna, or representation of animal life, testifies what the capabilities of the country will be for pasturage and stock raising, and what crops will be successfully cultivated by the farmer, even before the coming of the axman to fell the forest and of the plowman to draw the first furrow on the prairie. The vast herds of buffalo[1] and the frequent droves of antelope and elk which roamed over this district previous to the advent of the white man were a prognostication of the present ranchman's wealth of cattle, horses, and sheep, feeding in the valleys and on the plains from which the native tall game and the aboriginal huntsman have so recently vanished. The nutritious and abundant grasses and other herbage on which the wild herds fed are now succeeded by luxurant fields of grain, or, growing in the yet unbroken sward, they now fatten the beef, rear the broncho and thoroughbred horses, and produce the wool, which are exported to Chicago and more eastern markets.

Though no strongly defined line of division can be drawn between different portions of the flora and fauna of the country from the Atlantic to the Rocky Mountains and from the Gulf of Mexico to the Arctic Sea, it is

[1] The early immigrants found the bones of buffaloes scattered here and there throughout the whole prairie region. On account of their commercial value for sugar refining and for the manufacture of superphosphate, these bones were collected and sold at the railway stations during the first two or three years after the railway was built into any new part of the country. A heap of buffalo bones which I saw beside the railway awaiting shipment at Langdon, N. Dak., in August, 1889, measured 100 feet by 20 feet in area, with an average height of 4 feet, representing probably two or three thousand animals. During the same month I saw a much larger pile of bones at Minot, in the same State, its contents being estimated as equal to 200 feet by 30 feet by 4 feet. The dealer informed me that the weight of this pile was about 600 tons, and that during the preceding part of the year he had purchased and already shipped some 1,200 tons, the average price paid being $8 per ton. During the one forenoon when I was there, ten or more wagonloads of bones were brought in by the farmers from the region around. Probably nearly all that could be found in the vicinity were collected during that year. (Compare page 139, and Geology of Minnesota, Vol. II, p. 516.)

nevertheless true that great contrasts exist between the eastern region, with its plentiful rainfall, and the dry western plains, as also between the almost tropical southern margin of the United States and the tundras beneath the Arctic Circle. In traveling from the once wholly forest-covered country of the eastern States across the prairies to the far western plains, bearing cacti and sagebrush, there is observed a gradual change in the flora, until a very large proportion of the eastern species is left behind, and their places are taken by others capable of enduring more arid conditions. Likewise in going from St. Augustine or New Orleans to Chicago, St. Paul, Winnipeg, and Hudson Bay and Strait, the palmettoes, the evergreen live oak, bald cypress, southern pines, and the festooned Tillandsia or "Spanish moss," are left in passing from the southern to the northern States; and instead we find in the region of the Laurentian lakes the bur or mossy-cup oak, the canoe and yellow birches, the tamarack or American larch, the black spruce, balsam fir, and the white, red, and Banksian pines, while farther north the white spruce, beginning as a small tree in northern New England and on Lake Superior, attains a majestic growth on the lower Mackenzie in a more northern latitude than a large part of the moss-covered Barren Grounds which reach thence eastward to the northern part of Hudson Bay and Labrador. Thus, although no grand topographic barrier, like a high mountain range, impassable to species of the lowlands, divides this great region, the transition from a humid to an arid climate in passing westward, and the exchange of tropical warmth for polar cold in the journey from south to north, are accompanied by gradual changes of the flora by which in the aggregate its aspect is almost completely transformed.

In the central part of this large area, the basin of the Red River of the North, with my geologic exploration during a half dozen summers, I have given careful attention also to the geographic limits and relative abundance of the species making up the flora. It has been interesting to find there the intermingling and the boundaries of species whose principal homes or geographic range lie respectively in the directions of the four cardinal points, east and west, south and north.

FOREST TREES AND SHRUBS.

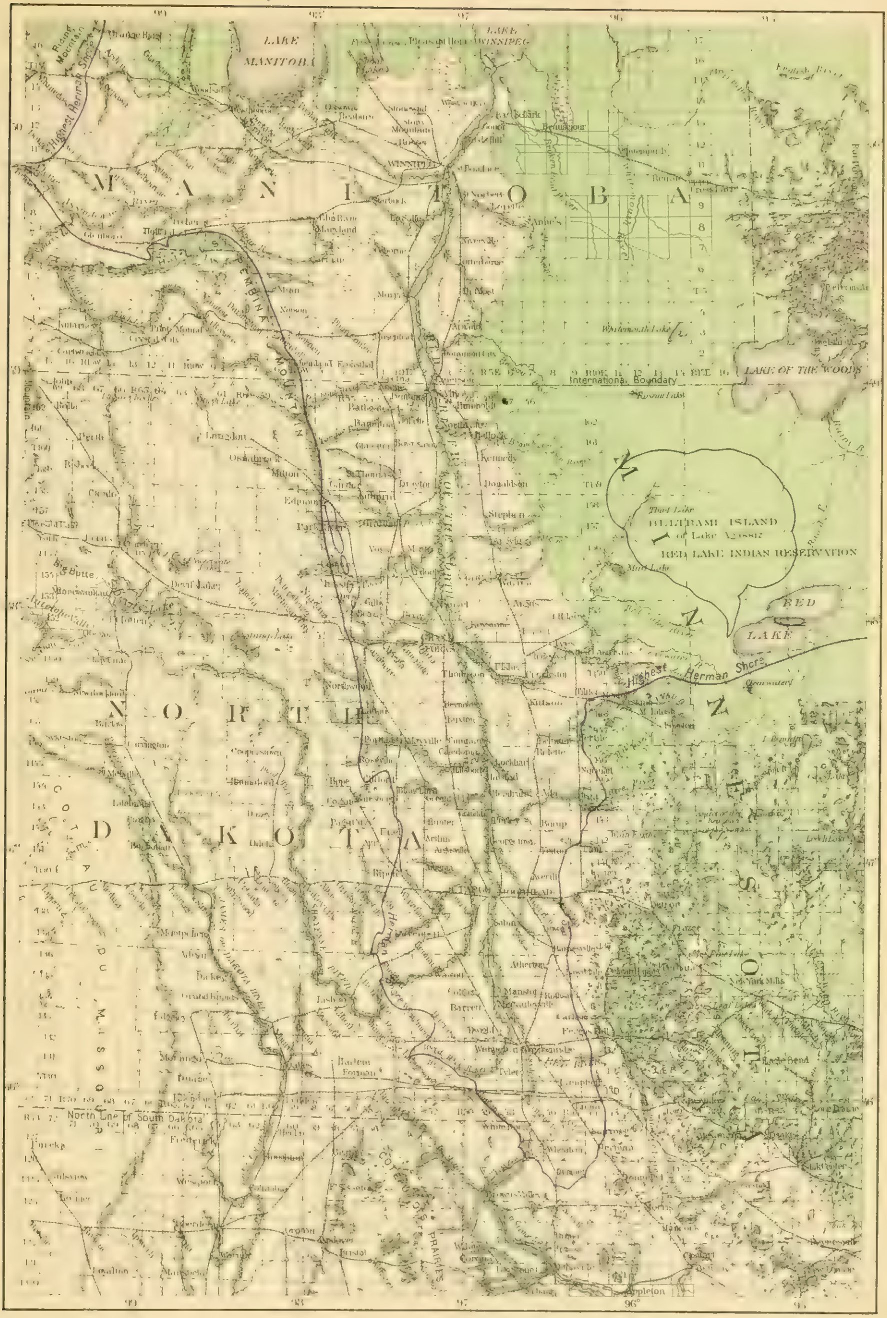
Many species of trees which together constitute a large part of the eastern forests extend to the Red River basin, reaching there the western or northwestern boundary of their range. Among these are the basswood, sugar maple, river maple, and red maple, the three species of white, red, and black ash, the red or slippery elm, and the rock or cork elm, the butternut, the white, bur, and black oaks, ironwood (*Ostrya virginica* Willd.), the American hornbeam (*Carpinus caroliniana* Walt.), the yellow birch, the large-toothed poplar, white and red pine, arbor-vitæ, and the red cedar or savin. A few species of far northern range find in this district their southern or southwestern limit, namely, our two species of mountain ash, the balsam poplar, Banksian or jack pine, the black and the white spruce, balsam fir, and tamarack.

Some of the eastern shrubs which make the undergrowth of our forests also attain here their western limits; but a larger proportion of these than of the forest trees continues west along the stream courses to the Saskatchewan region, the upper Missouri, and the Black Hills. Among the shrubs that reach to the borders of the Red River basin, but not farther westward, or at least southwestward, are the black alder or winterberry, the mountain holly, the staghorn sumach, the hardhack, the huckleberry, the dwarf blueberry and the tall or swamp blueberry, leatherwood, and sweet fern. Shrubs and woody climbers that have their northern or northwestern boundary in this basin include the prickly ash, staff tree or shrubby bittersweet, frost grape, Virginian creeper, and the four species of round-leaved, silky, panicled, and alternate-leaved cornel. On the other hand, shrubs of the north which reach their southern or southwestern limits in the Red River basin include the mountain maple, the few-flowered viburnum and withe-rod, several species of honeysuckle, the Canada blueberry, the cowberry, *Andromeda polifolia* L., *Kalmia glauca* Ait., Labrador tea, the Canadian shepherdia, sweet gale, the dwarf birch, green or mountain alder, beaked hazel-nut, *Salix balsamifera* Barratt, and *S. myrtilloides* L., var. *pedicellaris* Anders., black crowberry, creeping savin, and the American yew or ground hemlock.

No tree of exclusively western range extends east to the Red River basin, and it has only a few western species of shrubs, of which the most noteworthy are the alder-leaved Juneberry or service berry (in Manitoba commonly called "saskatoon"), the silverberry, and the buffalo-berry. To these are also to be added the shrubby *Œnothera albicaulis* Nutt., which occurs chiefly as an immigrant weed, and the small-leaved false indigo, which abounds on moist portions of the prairie. The silverberry (usually called "wolf willow" in the Red River Valley) is common or abundant from Clifford, N. Dak., and from Ada, Minn., northward, forming patches 10 to 20 rods long on the prairie, growing only about 2 feet high and fruiting plentifully, but in thickets becoming 5 to 10 feet high. Its silvery whitish foliage and fruit make this shrub a very conspicuous and characteristic element of the Red River flora.

The single species of true sagebrush belonging to this basin (*Artemisia cana* Pursh) extends east in North Dakota to the Heart Mound, 6 miles northwest of Walhalla, or 35 miles west of the Red River at Pembina, and to a hill close west of the Sheyenne River, about 8 miles south of Valley City, growing in both places on outcrops of the Fort Pierre shale. It attains a height of 1 to 3 feet, and the tough wood of its base is 1 to 1½ inches in diameter. *Artemisia frigida* Willd., called "pasture sagebrush" by Macoun, is abundant throughout a wide area westward, extending east locally to "the ridge" east of Emerson, Manitoba, the Falls of St. Anthony, and Lake Pepin.

Causes of limitation of the forest.—The boundary between the forest and the prairie, shown by Pl. XXXVIII, and the similarity of the two regions in their topographic features and drift deposits, have been noted in Chapter II (pp. 44–46). The usually abrupt transition from the timbered to the prairie country and the general absence of trees and shrubs in the prairie region have been often attributed to the effect of fires. Through many centuries fires have almost annually swept over these areas, generally destroying all seedling trees and shrubs, and sometimes extending the border of the prairie by adding tracts from which the forest had been burned. Late in autumn and again in the spring the dead grass of the prairie burns very rapidly, so that a fire within a few days sometimes spreads 50 or 100



MAP OF THE SOUTHERN PORTION OF LAKE AGASSIZ, SHOWING AREAS OF FOREST AND PRAIRIE.

Scale, about 42 miles to an inch.

Forest Area, and belts and patches of Timber on streams and lakes Prairie

miles. The groves that remain in the prairie region are usually in a more or less sheltered position, being on the borders of lakes and streams, and sometimes nearly surrounded by them, while areas that can not be reached by fires, as islands, are almost always wooded. If fires should fail to overrun the prairies in the future, it can hardly be doubted that much of that area would gradually and slowly be changed to forest.

Yet it does not appear that fires in the western portion of our great forest region are more frequent or destructive than eastward; and our inquiry must go back a step further to ask why fires east of the Appalachian Mountains had nowhere exterminated the forest, while so extensive areas of prairie have been guarded and maintained, though not apparently produced, by prairie fires here. Among the conditions which have led to this difference we must undoubtedly place first the greater amount and somewhat more equable distribution throughout the year of rain in the Eastern States.[1]

Evidence that an increase of moisture in the ground suffices to produce a heavy growth of forest trees in a principally prairie region, even without protection from the incursions of prairie fires, is afforded by the bluffs of the opposite sides of the valley of the Minnesota River, which was the course of the River Warren, outflowing from Lake Agassiz. Timber is found in a nearly continuous though often very narrow strip bordering this stream through almost its entire course, but generally leaving much of the bottom-land treeless. The bluffs on the northeast side of the river have for the most part only thin and scanty groves or scattered trees. The southwestern bluffs, on the contrary, are heavily wooded through Blue Earth and Brown counties, excepting 2 or 3 miles at New Ulm. They also are frequently well timbered in Redwood and Yellow Medicine counties, but in Lac qui Parle County they are mostly treeless and have only

[1] The dependence of forests on a greater supply of rainfall than is needed by the grasses and other herbaceous vegetation of the prairies is ably stated by Prof. James D. Dana, "On the origin of prairies," Am. Jour. Sci. (2), Vol. XL, 1865, pp. 293–304; and by Dr. George M. Dawson, with discussion of prairie fires and the benefits to be derived from tree culture, Geology and Resources of the Region in the Vicinity of the Forty-ninth Parallel, 1875, pp. 311–324. Effects of drought and of cold to set limits to forests, and, on the other hand, extension of prairies into formerly timbered areas through the agency of annual fires, kindled by the Indians for the purpose of driving the game toward the hunters or providing a better growth of grass on which buffaloes and deer would feed, are noted by Prof. N. S. Shaler, Aspects of the Earth, 1889, pp. 282–290. Other views which had been advanced by Whitney, A. Winchell, and Lesquereux, previous to Dana's paper on this subject, seem untenable.

occasional groves. The greater abundance of timber on the southwestern bluffs appears to be due to their being less exposed to the sun, and therefore more moist, than the bluffs at the opposite side of the valley. Above Montevideo the timber is mainly restricted to a narrow belt beside the river and to tributary valleys and ravines.

PRAIRIE GRASSES AND FLOWERS.

Among the fifteen hundred, more or less, indigenous species of herbaceous plants inhabiting the Red River basin, probably half are deserving of note for attaining their geographic limit upon this area, or at least the limit of their abundant or frequent occurrence. But thorough and detailed botanic exploration of all the great interior region of our continent westward to the Rocky Mountains and far northward will be requisite before we can speak with certainty concerning many of the less conspicuous species of our flora. We may here notice briefly some of those plants whose geographic range is best known, especially such as are useful for pasturage and hay.

In general, the flora of the prairie area of Lake Agassiz is mostly made up of species that are familiar to residents of the Eastern and Southern States, occurring also commonly or abundantly there; but many of these plants reach their western and northern limits along the Red River of the North.

On the other hand, seventy-six species[1] of northern range, some of them plentiful beneath the Arctic Circle, are known to extend south of the forty-ninth parallel in the Red River Valley, or on the east to the Lake of the Woods or into northern Minnesota, but not to the southern end of this valley at Lake Traverse. This northern element of the Red River flora includes thirteen species of Carex, and nine grasses, the latter being *Deyeuxia langsdorffii* Kunth, *Trisetum subspicatum* Beauv., var. *molle* Gray, *Danthonia intermedia* Vasey, *Poa alpina* L., *P. laxa* Hænke, *Agropyrum*

[1] Lists of these species and of the western species extending into this district, also a list of the weeds (troublesome to the farmer) observed in the district, both indigenous and introduced, with notes of their range and relative abundance, are given in my paper, "Geographic limits of species of plants in the basin of the Red River of the North," Proc., Boston Soc. of Nat. Hist., Vol. XXV, 1890, pp. 140–172.

dasystachyum Vasey, *A. tenerum* Vasey, *Elymus sibiricus* L., var. *americanus* Watson, and *E. mollis* Trin.

Another list of one hundred and two species comprises plants which are known to attain their eastern limits within the Red River basin, being common thence westward on the plains and often in the Rocky Mountains and to the Pacific. In this list are twenty Compositæ, most of them abundant and showy; four species of Carex; and twelve grasses, namely, *Beckmannia erucæformis* Host, var. *uniflora* Scribner, *Stipa spartea* Trin., *S. viridula* Trin., *Sporobolus cuspidatus* Torr., *Avena pratensis* L., var. *americana* Scribner, *Schedonnardus texanus* Steud., *Bouteloua oligostachya* Torr., *Distichlis maritima* Raf., var. *stricta* Thurber, *Poa tenuifolia* Nutt., *Festuca scabrella* Torr., *Agropyrum glaucum* R. & S., var. *occidentale* V. & S., and *Elymus sitanion* Schultes.

The most plentiful and valuable grasses in this northeastern part of the great prairie region of the continent are as follows, with notes of their habit of growth and comparative importance:

Spartina cynosuroides Willd., the prevailing and often the only grass of sloughs (which is the term commonly applied to miry depressions of the prairie), making good hay; also largely used as fuel by immigrants in many districts remote from timber and railways, and as thatch by Mennonite colonists in Manitoba.

Beckmannia erucæformis Host, var. *uniflora* Scribner, frequent or common on wet ground, where water stands a part of the year, from Port Arthur, Lake Superior, to the Rocky Mountains, extending northeast to Hudson Bay and Lake Mistassini.

Panicum capillare L., common along streams, and in sandy cultivated fields.

Panicum virgatum L., frequent, often abundant, on somewhat moist portions of the prairie, especially in southwestern Minnesota and South Dakota.

Andropogon furcatus Muhl., abundant on rather dry tracts in South and North Dakota, where it is usually called "blue joint," and is highly esteemed for hay; less common in Manitoba; whitish and glaucous, not abundant, among the sand dunes of the Sheyenne delta of Lake Agassiz.

Andropogon scoparius Michx., abundant, occupying drier land than the last.

Chrysopogon nutans Benth., common or frequent in the Dakotas; less so farther north; much cut for hay, with *Andropogon furcatus* and *Panicum virgatum*.

Phalaris arundinacea L., abundant in marshes.

Hierochloe borealis R. & S., very common on moist ground and along rivers and lakes throughout this northern prairie region.

Stipa spartea Trin., deservedly named "porcupine grass," but more commonly called "wild oats" in Minnesota and the Dakotas; abundant on the dry prairie, especially in South Dakota.

Stipa viridula Trin., extending east, on sandy alluvial soil of bottom-lands, to the Red River; also common westward on the general prairie.

Muhlenbergia glomerata Trin. (chiefly the var. *ramosa* Vasey), plentiful on moist land; frequently persisting as a weed in wheat fields and other cultivated ground.

Sporobolus cuspidatus Torr., common on dry portions of the prairie in the Dakotas, Manitoba, and Assiniboia.

Sporobolus heterolepis Gray, also plentiful from Nebraska to northwestern Manitoba.

Agrostis alba L., var. *vulgaris* Thurber, indigenous and common on moist land, especially northward.

Agrostis scabra Willd., abundant along rivers, so that in late summer the wheel ruts of roads are often filled with its dead panicles, broken off and blown thither by the wind.

Deyeuxia canadensis Hook. f. (*Calamagrostis canadensis* Beauv.), abundant on wet meadows bordering streams, especially in the forest region.

Deyeuxia neglecta Kunth (*Calamagrostis stricta* Trin.), plentiful on similar ground throughout the prairie region west of Winnipeg.

Ammophila longifolia Benth. (*Calamagrostis longifolia* Hook.), which binds the sand dunes along the south shore of Lake Michigan, is generally abundant on sandy ridges through all the prairie region from the Red River west to the Rocky Mountains.

Avena pratensis L., var. *americana* Scribner, common from Portage la Prairie westward.

Danthonia intermedia Vasey, common from the Red River to the sources of the Qu'Appelle; also found at the east in Anticosti and Gaspé, extending west to Vancouver Island.

Bouteloua oligostachya Torr., the most valuable and widely spread of the "buffalo grasses," observed as the main species of grass on large tracts of the prairie between Devils Lake and the Souris River; described by Vasey and Havard as the commonest species on the great plains, surpassing all others in its importance as pasturage for stock of all kinds, even in winter, when its dried tufts or bunches still retain their nutritive quality.

Phragmites communis Trin., abundant, often 10 to 15 feet high, in the edges of lakes. A prostrate stem 20 feet long, rooting at the joints, was observed at Red Lake, Minnesota.

Kœleria cristata Pers., very abundant on the drier portions of the country, affording good pasturage; estimated by Lieberg as constituting fully half of the entire growth of grass along the Northern Pacific Railroad between the James and Yellowstone rivers.

Distichlis maritima Raf., var. *stricta* Thurber, very abundant on the borders of saline and alkaline marshes.

Poa tenuifolia Nutt., one of the much-prized "bunch grasses," common from Brandon westward to the Rocky Mountains, and the most important pasture grass of British Columbia, Vancouver Island, and southward.

Poa nemoralis L., forming much of the pasture northward.

Poa serotina Ehrh., plentiful in swampy places on lakes and rivers.

Poa pratensis L., the famous "blue grass" of Kentucky, indigenous and abundant, rapidly taking the place of other species westward, and destined, according to Macoun, to be the chief pasture grass of this region.

Glyceria distans Wahl., var. *airoides* Vasey, abundant in saline marshes from Winnipeg westward.

Festuca scabrella Torr., a valuable "bunch grass," abundant at Brandon and westward to the mountains.

Bromus kalmii Gray, abundant northward.

Agropyrum glaucum R. & S., var. *occidentale* V. & S., common on moist land, especially where the soil is somewhat saline and alkaline; in Montana, according to Scribner, the most highly valued of the native grasses for hay.

Agropyrum tenerum Vasey, abundant, with the preceding, from Winnipeg to Edmonton and southward; one of the best grasses for hay. Dr. Vasey remarks that in southwestern Minnesota and South Dakota, wherever the ground has been broken and not cultivated, *Agropyrum glaucum* and *A. tenerum* have commonly taken possession.

Agropyrum caninum R. & S., plentiful in the northern prairie region, from Winnipeg to Edmonton.

Hordeum jubatum L., a worthless species, well named "squirrel-tail grass" and "tickle grass;" very abundant by roadsides and on slightly saline, moist land.

Elymus canadensis L., a conspicuous species, common on the banks and bluffs of rivers.

Besides the grasses, the prairies bear multitudes of native flowers of showy red, purple, blue, yellow, and orange hues, and pure white, which bloom from early spring till the severe frosts of autumn. Earliest of all is the pasque flower, named for its blooming at Easter, common over all the prairie region. With this, or later in the spring, are other species of windflowers, the wild columbine, indigenous buttercups, violets, and many more.

During the summer the prairies are decked with species of larkspur, Psoralea, Amorpha, Petalostemon, Astragalus, Oxytropis, Vicia, Lathyrus, Geum, rose, evening primrose, many Compositæ, nearly all conspicuous by their flowers, the harebell, gentian, phlox, Pentstemon, Gerardia, Orthocarpus, Pycnanthemum, Monarda, Spiranthes, Sisyrinchium, Uvularia, Smilacina, lily, wild onion, spiderwort, etc. Often I have seen large tracts of the natural prairie yellow with sunflowers or golden-rod; other areas purple with Petalostemon, Liatris, or Gerardia, or blue with asters; and still others white with the profusely flowering *Galium boreale* L. Several yellow-flowered species of the Compositæ, blooming in the middle and later portions of summer, resemble each other by growing frequently in clumps or bunches, as the Grindelia, Aplopappus, Chrysopsis, and Gutierrezia in the list of western plants, here noted in the declining order of their height.

Numerous species of plants prefer the sandy beaches of Lake Agassiz and grow there in greater abundance and luxuriance than elsewhere, among these being the pasque flower, *Psoralea argophylla* Pursh, and *P. esculenta* Pursh, two varieties of *Potentilla pennsylvanica* L., *Rosa arkansana* Porter, *Liatris punctata* Hook., *Chrysopsis villosa* Nutt., *Lepachys columnaris* Torr. and Gray, *Gaillardia aristata* Pursh, *Lilium philadelphicum* L., and *Ammophila longifolia* Benth. Near Arden, Manitoba, one of the beaches of Lake Agassiz has been named by the settlers Orange Ridge, from its orange-red lilies, and another is called the Rose Ridge.

DEVELOPMENT OF AGRICULTURE.

The aboriginal tribes of Ojibways and Dakotas, living on the southern portion of the area of Lake Agassiz, had made little progress toward a system of agriculture which would provide their principal food during the whole year. Like the other tribes of hunting Indians who inhabited all the area of the United States, excepting its southwestern borders, their dependence was chiefly on the chase and entrapping of game and on fishing. But even their rude and very limited efforts in agriculture yielded an important and valued portion of their sustenance. In pre-Columbian times and onward to the present day the Indians have cultivated small patches of land, carefully tending their crops and storing up the harvest for gradual use during the rigors of winter and until the next harvest, supplementing thereby their principal diet of game and fish. Such aboriginal agriculture, untaught by white men, yet far from being despicable, I saw in September, 1885, at the Ojibway village a mile southeast of the Narrows of Red Lake. This largest village of the Ojibways in Minnesota consists of thirty or forty permanent bark lodges, scattered on an area which reaches a half mile from northwest to southeast, and is 40 to 60 rods wide. Adjoining the village were fields of ripening maize or Indian corn, amounting to about 50 acres, besides about 5 acres of potatoes and probably an acre or more of squashes. These crops showed a luxuriant growth and abundant yield, and the weeds among them had been held in check by hoeing. During the spring, summer, and autumn, most of the one hundred and fifty or two hundred inhabitants of this village are usually absent in expeditions for hunting, and in successive portions of the season to make maple sugar, to gather Seneca snakeroot for sale, to pick cranberries, and to reap the natural harvest of wild rice (*Zizania aquatica* L.) which grows plentifully in the streams and shallow lakes and forms the most substantial part of the provisions laid up for the winter.[1] In the prairie country the place of the wild rice is partially supplied by the very nutritive, turnip-like root of the pomme de terre (*Psoralea esculenta* Pursh), which is dried, pulverized, and used as flour by the Dakotas.[2]

At an earlier time, of which no distinct tradition is preserved by the hunting tribes of Indians inhabiting this region, other tribes, who built the mounds and probably lived more by agriculture and less by the chase, overspread all the prairie district of Lake Agassiz, extending also east in the wooded country to Rainy Lake. The enduring earthworks erected by this people testify of their formerly wide extension throughout the Mississippi and Red River basins, and show that the sites of their villages were chosen usually on the banks and bluffs which overlook the food-giving rivers and lakes, often commanding an extensive and beautiful prospect. Most of the mounds within the area of Lake Agassiz are round and have the form of a dome, their height ranging from 3 to 10 feet or rarely more

[1]The Flora of Minnesota, in the Twelfth Annual Report, Geol. and Nat. Hist. Survey of Minnesota, for 1883, p. 159.

[2]Ibid., p. 42.

above the general surface, with a diameter of 30 to 100 feet or more at their base. Nearly all of them were made by the people for the burial of their dead, and the relics found with their bones prove that they surpassed the present Indians of this region in having skill to make rude pottery; but the superiority was very slight, and there are no evidences of the development of handicrafts to a degree at all comparable with the aboriginal arts of Mexico and Peru. There was some commercial interchange from great distances, but it was probably limited to a few articles which were highly valued for beauty or regarded as mysterious and sacred. Thus in the mounds on the bluffs of the Souris River and Antler creeks, in southwestern Manitoba, Prof. George Bryce found ornaments made of sea shells, others of copper from Lake Superior, and pipes from the sacred red pipestone quarry at Pipestone, Minn., which Longfellow has described in "The Song of Hiawatha."

Further notes of the mounds of the area of Lake Agassiz and the adjoining country on the west are given in Appendix B.

The first immigration of white men to colonize the fertile basin of the Red River of the North, bringing the civilized arts and agriculture of Europe, was in the years 1812 to 1816, when, under Lord Selkirk's far-sighted and patriotic supervision, the early pioneers of the Selkirk settlements, coming by the way of Hudson Bay and York Factory, reached Manitoba and established their homes along the river from the vicinity of Winnipeg to Pembina. In its beginning this colony experienced many hardships, but, in the words of one of these immigrants, whose narrative was written down in his old age, in 1881, "by and by our troubles ended, war and famine and flood and poverty all passed away, and now we think there is no such place to be found as the valley of the Red River."[1]

Fifty to sixty years after the founding of the Selkirk colony the margin of the advancing wave of immigration in the United States reached the Red River Valley. In a few places on the Red, Wild Rice (of North Dakota), and Sheyenne rivers small bands of immigrant farmers had begun the settlement of this rich agricultural area a few years before the building

[1]Manitoba: Its Infancy, Growth, and Present Condition, by Prof. George Bryce, London, 1882, p. 166.

of railroads across it; but the main tide of immigration came after the railroads had provided means of sending the staple product of the country, wheat, to the markets of St. Paul, Minneapolis, and Duluth. The Northern Pacific Railroad was built from Duluth to Moorhead and Fargo during the years 1870 to 1872, and the next year it was extended to Bismarck. Within the next three years a line of the Great Northern Railway (then the St. Paul and Pacific) was built to Breckenridge, and another line to Crookston and St. Vincent. From 1875 to 1885 the settlement of the Red River Valley and of a large contiguous area of North and South Dakota went forward very rapidly, nearly all the land in this valley being taken up during these ten years by homestead and preemption claims from the Government and by purchase from the railroad corporations which had received land grants.

The wise policy of the United States Government was to parcel out its land in small farms to actual settlers, selling none to non-residents, and allowing to no one rights to secure more than three-quarters of a section, or a total of 480 acres. This large amount was possible to be obtained from the Government only by use of three separate rights, each securing a quarter section, according to the respective laws for homesteads, preemption, and tree culture. Most of the farms received from the Government comprise only 160 acres; and these were deeded, upon payment of small fees at the land offices, to any citizen, including naturalized foreigners, those affirming their intention to become naturalized legal voters, and widows and unmarried women, all of whom were required to take the land to be their permanent homes. For these free gifts of the fertile prairie of the Red River Valley, surpassed by no other area of the world in its natural value for agriculture, multitudes came, bringing housekeeping equipments in their emigrant wagons ("prairie schooners"), which passed in long processions through St. Cloud and Alexandria, Minn., on their way from the older portions of that State and from other States farther east and south. Many also came directly from the Old World, especially from Sweden and Norway, being carried from the eastern seaports by railroads to the Red River and James River valleys and other parts of North and South Dakota, there being welcomed and soon established on their own freeholds in near neighborhood with others of their countrymen who had come to the United States many years earlier.

A considerable number of very large farms were acquired, however, by discerning capitalists, who saw the capabilities of this district for the convenient employment of large companies of laborers, marshaled with almost military order, in the various operations of farming, as in plowing, seeding, harvesting, and thrashing, and who, at an early stage in the rapid progress of settlement, foresaw the profits of wheat raising on a grand scale. These "bonanza farms," as they were afterward called, were made up in great part by purchasing from the railroad corporations the odd-numbered alternate sections which had been given as Government subsidies to foster the early railroad enterprises that opened the region to settlement. But the railroad lands formed no compact tract, being in square miles touching each other only at the corners, like the spots of a single color on a checkerboard. To remedy the difficulty and fill out continuous tracts, many of the intervening portions were obtained by purchase from settlers who had received the land from the Government in good faith, with the full intention of continuing to live on it; but in some instances claims also were obtained from the Government by fraudulent agents, who professed their intention to comply with this legal requirement in taking land by preemption.

Among the most famous and successful of these extensive farms are the Lockhart and Keystone farms, in Minnesota; that of the Messrs. Dalrymple, comprising some 30,000 acres, in the vicinity of the station of this name on the Northern Pacific Railroad, 18 miles west of Fargo; the lands of the Grandin Farming Company, about 40,000 acres, in eastern Traill County; and the Elk Valley Farm, near Larimore. Nine establishments of farm buildings have been erected by the Grandin Farming Company, and these are connected with the headquarters (Hague post-office) by 25 miles of telephone lines, the farthest set of buildings being at a distance of 12 miles. About 280 horses and mules are used by this company, and 200 to 300 men are employed during the summer, distributed somewhat equally in the nine divisions; but in winter, when comparatively few men are retained, the horses are stabled at only two or three places. One stable at the headquarters has 180 stalls. In some fields of this great farm the teams plow 3 or 4 miles straight forward, being interrupted only by roads on the section lines, where the plow is thrown out of the ground for a few rods. The first breaking on both the Dalrymple and Grandin farms was in 1875, the same year in which the land was mostly purchased, and their first crop of wheat was harvested in 1876. During every year since that time the harvests on these lands and in general throughout the Red River Valley have been good, with no failure on account of drought, which for several years (from 1885 to 1889) was very severe upon many portions of the Dakotas west and southwest of this valley.

WHEAT AND OTHER CEREALS.

One man, if very industrious, with two pairs of horses and ample "farm machinery"—that is, plows, harrows (here often called drags), seeders, a self-binding harvester, etc.—can cultivate 100 to 150 acres in wheat. An intelligent and energetic farmer in Traverse County, Minn., with whom I conversed in June, 1886, informed me that during the preceding autumn, beginning after the harvest and working daily until the ground froze, he plowed 130 acres, walking behind the plow. In the spring of 1886 the seeding of his crop of 210 acres was done entirely by his wife, not an especially strong woman, who rode on the seeder, driving a pair of horses, while he with another pair was dragging (harrowing) the plowed lands to prepare them for seeding. He expected to harvest the whole with one harvester, estimating that this would occupy fifteen days, working from the time when the dew would be mostly gone in the morning until it would gather heavily in the evening. The amount of work accomplished, however, by most farmers with their hired men is no more than to cultivate 50 or 75 acres in wheat for each man laboring through the season.

The seedtime for wheat, oats, and barley is shortly after the ground is thawed in the spring, usually occupying the second half of April and the first week or two of May. The harvest comes during August, northward extending somewhat into September, after which follow stacking, thrashing, and plowing, until winter arrives. Harvesting is the busiest part of the farmer's work, since the crop ought to be secured as soon as it is ripe. Delay permits much of the wheat to be shelled out of the heads and scattered on the ground. There is also much liability to loss at this time from the occurrence of rainy weather, and hail may destroy or greatly damage the crop at any time after it has attained a considerable height until it is cut.

Usually, if the season is favorable, the first crop from newly broken prairie land is somewhat more bountiful than any to be obtained in the following years, which range from 10 to 20 bushels of wheat on an average per acre. The same fields have in many instances been successfully cultivated in wheat ten to fifteen years or more in the Red River Valley south of the international boundary, and twice as long in other parts of Minnesota and in the Selkirk settlements of Manitoba, without the use of any manure, and yet without exhibiting any noticeable impoverishment of the soil. The time must come, however, after a few decades of such unrequited cropping, when fertilizers will be needed to restore and sustain the original productiveness.

A rotation of crops and diversity of farming, with stock raising and butter making, will doubtless be found more advantageous than the production of the cereals only, when a long series of years is considered. The growth of villages and towns in this district, affording near markets for miscellaneous farm produce, and the tendency, with the increase of population, toward subdivision of the large farms, and even of the ordinary homesteads, into two or four farms in each quarter section, indicate for the future an increasing diversification of agriculture. Wheat and other cereals will probably continue to be the chief crops for exportation, but many other crops will attain more importance than now, and there will be a greater average expenditure of labor for each acre cultivated, with proportionally enhanced profits.

Comparatively few Indians were able to derive their subsistence by hunting and fishing upon the area of Lake Agassiz or in any other region. Probably their numbers living at any time upon the portion of this lake area within the United States did not exceed 5,000. But now that the land is occupied by white immigrants and is sown with wheat, the present yearly product is about 285 bushels apiece for each man, woman, and child of the

161,049 enumerated by the census of 1890 in the twelve counties which lie mainly within the Red River Valley.

Six of these counties are in Minnesota and six are in North Dakota. Tabulations of their population in 1880 and in 1890, and of their production of wheat during the same years in Minnesota and during 1879 and 1891 in North Dakota, are here presented, for the purpose of exhibiting the rapid progress in the agricultural development of the district. The ratio of the wheat yield to the population in 1880 was 69 bushels for each person, or less than one-fourth as much as in 1890 and 1891. The latter high ratio of 285 bushels for each person is probably near the maximum which this ratio can attain, from which it will decrease relatively to the increasing population, the place of wheat cultivation being destined to be partially taken by other crops, by stock raising, and by other industries.

An equally prosperous development of the agricultural resources of Manitoba has been going forward during the same time, as is also exhibited by the similar statements of the population and wheat production of that province.

Population of counties in Minnesota lying mainly within the Red River Valley.

Counties.	1880.	1890.
Wilkin	1,906	4,346
Clay	5,887	11,517
Norman[1]	....	10,618
Polk	11,433	30,192
Marshall	992	9,130
Kittson	905	5,387
Total	21,123	71,190

[1] Organized in 1881 from part of Polk County.

Population of counties in North Dakota lying mainly within the Red River Valley.

Counties.	1880.	1890.
Richland	3,597	10,751
Cass	8,998	19,613
Traill	4,123	10,217
Grand Forks	6,248	18,357
Walsh[1]	....	16,587
Pembina	4,862	14,334
Total	27,828	89,859

[1] Organized in 1881 from parts of Grand Forks and Pembina counties.

The population of Manitoba, according to the census of 1881, was 69,954; and in 1891 it was estimated to be 150,000. About a third part of these and a small fraction of the population noted in the Minnesota and North Dakota counties are outside the boundaries of Lake Agassiz; but the total inhabitants within the lake area are nearly a quarter of a million people. Approximately three-fourths of this population are engaged in farming, the other fourth being resident in the villages and large towns and engaged in commercial and manufacturing pursuits.

Wheat production of counties in Minnesota lying mainly within the Red River Valley.

Counties.	1880.			1890.		
	Acres.	Bushels.	Bushels per acre.	Acres.	Bushels.	Bushels per acre.
Wilkin	9,871	144,424	14.60	42,212	474,050	11.20
Clay	28,444	479,833	16.87	93,568	1,284,551	13.70
Norman				84,188	1,293,429	15.30
Polk	63,135	1,035,428	16.40	222,223	3,002,754	13.50
Marshall	1,121	17,367	15.49	88,819	1,056,425	11.80
Kittson[1]						
Total	103,363	1,692,183	16.37	(531,010) [2]600,000	(7,111,209) [2]8,000,000	13.33

[1] Not reported. [2] Including estimated addition for Kittson County.

Wheat production of counties in North Dakota lying mainly within the Red River Valley.

Counties.	1879.			1891.		
	Acres.	Bushels.	Bushels per acre.	Acres.	Bushels.	Bushels per acre.
Richland	9,086	184,753	20.33	156,631	3,195,680	20.40
Cass	51,727	1,012,565	19.57	527,070	9,939,034	18.86
Traill	13,707	333,409	24.32	269,426	6,441,546	23.88
Grand Forks	4,978	98,352	19.76	262,992	6,881,624	26.17
Walsh				241,673	6,202,940	25.67
Pembina	2,398	63,676	26.55	218,066	5,202,332	23.86
Total	81,896	1,692,755	20.67	1,675,858	37,863,156	22.59

Wheat production of Manitoba.

	1883.			1891.		
	Acres.	Bushels.	Bushels per acre.	Acres.	Bushels.	Bushels per acre.
Whole province	208,674	4,549,093	21.80	916,664	23,191,599	25.30

Summing these figures, and deducting the estimated portion belonging outside the boundaries of the glacial lake, we find the present annual wheat crop upon the prairie area of Lake Agassiz to be approximately 50,000,000 bushels. This is about 200 bushels apiece for each inhabitant, when the populations in the United States and in Manitoba are considered together; and if the wheat were distributed among all the people of the United States, it would supply nearly a bushel for each individual. But no more than a quarter part of the arable prairie land of this lacustrine area is now under cultivation in all crops, the proportion being greater in the United States and less in Manitoba. When all this area shall be brought into agriculture, the wheat product will probably be almost or quite 200,000,000 bushels yearly, but the ratio to the population of the Red River Valley will be smaller than now.

All the wheat raised in this district is sown in the spring, none being "winter wheat," sown in the fall. The kernel is plump and hard, yielding in the "roller mills," with the present perfected processes of manufacture, the finest, whitest, and most salable flour of the world. Nearly every city and large village in Minnesota, North Dakota, and Manitoba, has one or more flouring mills; but far the greater part of the wheat crop is shipped eastward, by way of Duluth, Superior, and Port Arthur, to milling cities on the Great Lakes, excepting the large fraction which is marketed in Minneapolis, whose flouring mills have a daily capacity of about 30,000 barrels.

Production of oats in the year 1890 in counties of Minnesota lying mainly within the Red River Valley.

Counties.	Acres.	Bushels.	Bushels per acre.
Wilkin	10,004	238,285	23.80
Clay	23,609	659,738	27.90
Norman	18,694	585,785	31.30
Polk	38,839	1,044,406	26.80
Marshall	11,438	256,569	22.40
Kittson[1]	....	....	....
Total	102,584	2,784,773	27.15

[1] Not reported.

Production of oats in the year 1891 in counties of North Dakota lying mainly within the Red River Valley.

Counties.	Acres.	Bushels.	Bushels per acre.
Richland	24,355	901,135	37
Cass	70,695	2,777,303	39.29
Traill	33,689	1,494,949	44.37
Grand Forks	38,334	1,854,940	48.40
Walsh	33,341	1,476,215	44.28
Pembina	34,546	1,579,246	45.71
Total	234,960	10,083,788	42.90

Production of oats in the year 1891 in Manitoba.

	Acres.	Bushels.	Bushels per acre.
Whole province	305, 644	14, 762, 605	48. 30

Production of barley in the year 1890 in counties of Minnesota lying mainly within the Red River Valley.

Counties.	Acres.	Bushels.	Bushels per acre.
Wilkin	1, 961	45, 784	23. 30
Clay	3, 842	104, 955	27. 30
Norman	2, 925	80, 145	27. 40
Polk	14, 120	298, 017	21. 10
Marshall	13, 043	145, 950	11. 10
Kittson[1]			
Total	35, 891	674, 851	18. 80

[1] Not reported.

Production of barley in the year 1891 in counties of North Dakota lying mainly within the Red River Valley.

Counties.	Acres.	Bushels.	Bushels per acre.
Richland	4, 900	158, 136	32. 27
Cass	12, 915	416, 508	32. 25
Traill	11, 091	402, 157	36. 25
Grand Forks	18, 359	682, 343	37. 17
Walsh	14, 397	559, 883	38. 89
Pembina	22, 950	826, 200	36
Total	84, 615	3, 045, 227	35. 99

Production of barley in the year 1891 in Manitoba.

	Acres.	Bushels.	Bushels per acre.
Whole province	89, 828	3, 197, 876	35. 60

Rye is only sparingly cultivated in this district. The total area of this grain in the six Minnesota counties in 1890 was 423 acres, yielding 6,541 bushels, an average of 15.46 bushels per acre. In the six counties of North Dakota 774 acres of rye were reported in 1891, with a yield of about 19,139 bushels, or an average of nearly 25 bushels per acre.

The season between the last severe frost of spring and the earliest in autumn is often too short for the maturing of maize, or Indian corn, which, therefore, will never be raised extensively in the Red River Valley. In the same counties of Minnesota 2,026 acres were planted with maize in 1890, the yield being 44,125 bushels, averaging 21.78 bushels per acre; and in the North Dakota counties there were 5,685 acres of maize in 1891, yielding 148,217 bushels, or 26.07 bushels per acre.

HAY, POTATOES, FLAX, AND OTHER CROPS.

The principal grasses cultivated for hay in the prairie region of Lake Agassiz are the Italian millet, or Hungarian grass (*Setaria italica* Kunth), and timothy (*Phleum pratense* L.). In Minnesota these are not kept separate by the report of the commissioner of statistics, but in North Dakota the returns to the State department of agriculture show that the millet crop far exceeds that of all other cultivated grasses (here known as "tame grasses"). The Minnesota reports state the quantity of wild hay made on the unbroken prairie, which in the Red River Valley often yields a ton of very good hay per acre on the somewhat dry general surface and 2 to 3 tons of an inferior quality on marshy ground. The wild hay gathered in the North Dakota counties is not reported, but doubtless surpasses the figures of Minnesota, which has only about one-third, while North Dakota has about two-thirds of the width of the Red River Valley. With the prospective increase of attention to stock raising and dairying, the cultivation of hay will become more prominent. Timothy, redtop, and other choice perennial species will probably then come more into favor, displacing in part the present coarse fodder supplied by the annually sown fields of millet.

Production of hay in the year 1890 in counties of Minnesota lying mainly within the Red River Valley.

Counties.	Cultivated hay.			Wild hay.
	Acres.	Tons.	Per acre.	Tons.
Wilkin	990	1,616	1.63	11,757
Clay	2,840	4,642	1.64	40,114
Norman	5,113	11,286	2.21	32,395
Polk	5,082	6,840	1.35	72,733
Marshall	1,883	2,798	1.49	26,104
Kittson[1]	....	....	....	....
Total	15,908	27,182	1.71	183,103

[1] Not reported.

Production of hay in the year 1891 in counties of North Dakota lying mainly within the Red River Valley.

Counties.	Millet (Hungarian grass).			Other cultivated hay.		
	Acres.	Tons.	Per acre.	Acres.	Tons.	Per acre.
Richland	3,942	8,672	2.20	936	1,248	1.33
Cass	12,870	31,102	2.42	3,965	7,731	1.95
Traill	8,235	19,215	2.67	3,959	5,938	1.50
Grand Forks	15,901	37,632	2.37	3,147	5,114	1.62
Walsh	10,827	24,360	2.25	2,782	4,868	1.75
Pembina	8,313	19,397	2.33	690	1,044	1.60
Total	60,088	140,378	2.34	15,479	25,943	1.68

The crops of oats, hay, and potatoes raised in the Red River Valley are almost all consumed by the farmers themselves, excepting the part sold for use in the villages and cities of the district. It seems probable, however, that the cultivation of potatoes for exportation to Minneapolis and St. Paul, to Duluth and West Superior, and to the mining towns of Montana, would be on the average as remunerative as wheat raising.

Production of potatoes in the year 1890 in counties of Minnesota lying mainly within the Red River Valley.

Counties.	Acres.	Bushels.	Per acre.
Wilkin	202	17,527	86.77
Clay	1,174	119,934	102.16
Norman	579	84,401	145.77
Polk	3,081	174,657	56.69
Marshall	476	30,894	64.90
Kittson[1]			
Total	5,512	427,413	77.54

[1] Not reported.

Production of potatoes in the year 1891 in counties of North Dakota lying mainly within the Red River Valley.

Counties.	Acres.	Bushels.	Per acre.
Richland	1,972	247,305	126
Cass	1,645	251,685	153
Traill	654	103,550	158
Grand Forks	1,157	243,697	211
Walsh	1,545	346,767	224
Pembina	1,146	319,243	279
Total	8,119	1,512,247	186

In Manitoba 12,705 acres were planted with potatoes in 1891, yielding 2,291,982 bushels, or an average of 180.4 bushels per acre.

Flax is considerably cultivated in the Red River Valley, chiefly south of the international boundary, the seed being sold for the extraction of linseed oil. None of the flax of this country is used for the manufacture of linen, although it seems wholly suitable for that industry.

Production of flaxseed in the year 1890 in counties of Minnesota lying mainly within the Red River Valley.

Counties.	Acres.	Bushels.	Per acre.
Wilkin	1,005	7,761	7.70
Clay	515	4,987	9.60
Norman	475	3,594	7.50
Polk	289	2,749	9.50
Marshall	210	1,161	5.50
Kittson[1]			
Total	2,494	20,252	8.12

[1]Not reported.

Production of flaxseed in the year 1891 in counties of North Dakota lying mainly within the Red River Valley.

Counties.	Acres.	Bushels.	Per acre.
Richland	2,079	24,717	11.89
Cass	1,745	19,195	11
Traill	1,703	20,436	12
Grand Forks	1,559	22,818	14.64
Walsh	4,927	77,994	15.83
Pembina	38	494	13
Total	12,051	165,654	13.76

The light, sandy soil best adapted for buckwheat is found within the prairie area of Lake Agassiz only on its deltas, and this crop has been very scantily raised.

Sorghum, which is much cultivated for the manufacture of sirup in southern Minnesota, requires a longer season than is free from frosts in the Red River Valley.

Most of the common garden produce, as peas, beans, tomatoes, beets, carrots, turnips, cabbages, squashes, melons, etc., can be successfully grown in this district; but in the heavy labor given to the staple crops, as wheat and oats, these valuable additions to the farmer's household fare have been too generally forgotten or neglected. There is, however, an evident increase of attention to these crops, both for home use and for sale in the cities.

The winter climate is too severe for apples, pears, peaches, plums, and grapes; but many hardy small fruits, as currants, gooseberries, raspberries, blackberries, and strawberries, thrive and yield bountifully wherever they receive proper care.

STOCK RAISING AND DAIRYING.

During the early years of rapid development of wheat raising, little labor or thought was given to stock and the dairy. Most of the farmers bought for their work imported horses which had been raised in Iowa or adjoining States. Butter also was imported from the same States, and the majority were willing to live without fresh meat or milk. Nowhere, however, can more favorable climate and natural conditions be found for the successful raising of all the stock needed by the farmer in diversified agriculture and for the dairy than in the Red River Valley. Recently, therefore, many enterprising farmers have secured the best blooded stock of horses, cattle, sheep, and hogs; and this portion of the farming interests of the district bids fair to assume its due importance. In the near future probably the sale of butter and cheese will form one of the principal sources of income in many townships. Poultry and eggs are also coming to be considered a needful part of every provident farmer's resources.

The following tables give the numbers of live stock in the counties of the Red River Valley in Minnesota and North Dakota. By the kindness of H. T. Helgesen, commissioner of agriculture and labor for North Dakota, the assessed valuations of the horses and cattle in the counties of that State are also noted.

Live stock in 1891 in counties of Minnesota lying mainly within the Red River Valley.

Counties.	Horses, mules, and asses.	Cattle.	Sheep.	Swine.
	Number.	*Number.*	*Number.*	*Number.*
Wilkin	3, 373	5, 485	1, 387	1, 143
Clay	6, 405	13, 201	6, 601	2, 326
Norman	5, 682	13, 595	4, 656	2, 009
Polk	13, 108	30, 214	9, 136	5, 720
Marshall	4, 425	10, 433	2, 180	2, 007
Kittson	3, 917	7, 666	2, 042	1, 268
Total	36, 910	80, 594	26, 002	14, 473

Live stock in 1891 in counties of North Dakota lying mainly within the Red River Valley.

Counties.	Horses.		Cattle.		Mules and asses.	Sheep.	Swine.
	Number.	Valuation.	Number.	Valuation.	*Number.*	*Number.*	*Number.*
Richland	7,522	$369,640	12,055	$136,439	585	3,172	2,945
Cass	15,193	758,629	14,630	148,662	1,469	5,621	4,991
Traill	9,335	571,996	9,834	107,043	952	3,011	3,285
Grand Forks	12,160	629,454	13,251	152,548	712	10,479	3,594
Walsh	10,405	535,211	11,533	133,201	267	6,716	4,114
Pembina	10,280	501,550	10,147	118,243	244	5,697	4,034
Total	64,895	3,366,480	71,450	796,136	4,229	34,696	22,967

GEOLOGIC RESOURCES.

The grand agricultural capabilities of the soil having been stated, as in the preceding pages, there remains little to be added relative to the more strictly geologic resources of the Red River Valley. All its outcrops of building stone, which are magnesian limestone, used also for the manufacture of lime, are situated in Manitoba. Bricks of the best quality are made from the clayey alluvium which borders the Red River along nearly its entire course after it turns northward at Breckenridge and Wahpeton. These constitute the complete though brief list of the commercially important products of the prairie portion of Lake Agassiz which belong to economic geology.

GOLD.

Within the wooded portion of this lacustrine area gold occurs and can perhaps be profitably mined in the Archean rocks adjoining the Lake of the Woods and Rainy Lake, which also in some places include granite and gneiss valuable for building purposes. These resources have been described by the Canadian and Minnesota Geological Surveys,[1] and need not be further noticed here.

[1] Geol. and Nat. Hist. Survey of Canada, Report of Progress, 1882–83–84, pp. 1–22 K (Report on the Gold Mines of the Lake of the Woods, by Eugene Coste); Annual Report, new series, Vol. I, for 1885, pp. 140–151 CC (Notes on Economic Resources of the Lake of the Woods Region, by Andrew C. Lawson). Geol. and Nat. Hist. Survey of Minnesota, Twenty-third Annual Report, for 1894, pp. 36–105, with map (Preliminary Report on the Rainy Lake Gold Region, by H. V. Winchell and U. S. Grant).

BUILDING STONE.

Quarries of magnesian limestone have been extensively worked at East Selkirk, Stonewall, Stony Mountain, and Little Stony Mountain, partly for lime-burning, but also in large amount for foundations, bridges, and buildings. The East Selkirk stone is beautifully mottled and banded, and is easy to cut when first quarried, but hardens much when its moisture dries out. It contains so much water that newly quarried blocks in winter are damaged by freezing; but after drying no such frost fracture is observed where this rock has been used in masonry. By exposure many years the streaked contrast in color is mostly weathered out, the brown portions losing their darker color. The Volunteers' Monument in Winnipeg is a fine example of the adaptation of this stone for ornamental purposes. The quarry at Stonewall, situated close east of the village, has been opened to an average depth of 6 or 8 feet on an area about 15 rods square. Inexhaustible supplies of stone of the most durable quality, in many portions capable of being quarried in blocks of large dimensions, outcrop there and at Stony Mountain, and have been much used for building in Winnipeg. Similar stone has been slightly quarried on the northeast quarter of section 4, township 15, range 2 east, on land of Allen Bristow, 9 miles north-northeast of Stonewall. The outcrop of Cretaceous limestone on the Assiniboine, in section 36, township 8, range 11, has also been quarried in small amount.

The abundant Archean bowlders of granite, gneiss, and schists in the till or glacial drift are readily collected wherever the till forms the surface, and on these tracts they commonly serve the immigrant for the construction of foundations of farm buildings and for the walls of cellars and wells.

LIME.

The quarry of Little Stony Mountain was actively operated several years ago for burning lime, a spur track about a mile long being laid to it from the Canadian Pacific Railway; but work had been suspended at the time of my survey of the beaches of Lake Agassiz in Manitoba, in 1887.

Besides the outcrops of the bed-rock which thus supply lime, it is conveniently obtained by collecting and burning limestone bowlders that occur in the glacial drift throughout all the prairie district of Lake Agassiz and the adjoining country, having been originally derived from these rock formations and distributed by the currents of the ice-sheet. But bowlders are absent from the lacustrine and alluvial deposits along the Red River, and from the Lake Agassiz deltas.

BRICKS.

Four brickyards in St. Boniface, on the east side of the Red River, opposite to Winnipeg, produced in total in 1887 about 4,000,000 bricks. This business began to be extensively developed there in 1880. The soil is stripped off to a depth of 2 feet, beneath which the next 2 or 3 feet of yellowish, horizontally laminated, somewhat sandy clay is used for brickmaking. It requires no further admixture of sand for tempering. The bricks, which are cream-colored and very durable, are sold at $11 to $12 per thousand, loaded on the cars or delivered in the city of Winnipeg. Another brickyard in St. James, close southwest of Winnipeg, makes about 1,500,000 bricks yearly. The light cream color of these bricks, like those of Milwaukee and of most brickyards in Wisconsin, Minnesota, and North Dakota, is due, as shown by Professor Chamberlin, to the calcareous and magnesian ingredients of these glacial clays, derived in part from magnesian limestone formations, which unite with the iron ingredient to form a light-colored silicate, instead of the ferric oxide which in other regions destitute of magnesian limestone gives to bricks their usual red color.

In the Red River Valley south of the international boundary the most important localities of brickmaking are Moorhead, Crookston, and Grand Forks; but bricks have been made in small amount at numerous other places, as Breckenridge, St. Hilaire, and Warren, in Minnesota, and Grafton, Cavalier, and Pembina, in North Dakota.

A large business in brickmaking is done at Moorhead by Lamb Bros., who began in 1874; Kruegel & Truitt, who began in 1878; and John Early and John G. Bergquist, who began in 1881. Their product in 1887 was as follows: Lamb Bros., about 2,000,000; Kruegel & Truitt, also about 2,000,000; Mr. Early, 700,000; and Mr. Bergquist 125,000. The black soil is removed to the depth of 1 foot or 1½ feet; the next 1 to 2 feet of the alluvial clay is used for brickmaking, its color being dark above and yellowish beneath; the lower continuation of this deposit is unsuited for this use because of limy concretions. No sand is required for tempering. Sand needed for mortar is brought from Muskoda at the cost of about $3 per cubic yard. The bricks are cream-colored and of very good quality, selling at about $10 per thousand. Oak wood, used for fuel, costs $5 per cord.

The brickyards of Crookston, owned by Norris & McDonald, W. A. Norcross, and G. Q. Erskine, supply 2,000,000 to 3,000,000 bricks yearly, which bring an average price of $10 per thousand at wholesale, loaded on the cars. At Mr. Erskine's yard, on the south side of the Red Lake River, a thickness of 13 feet of clay is used, lying next below the superficial 2 or 3 feet of black soil, which is removed. The more sandy lower part of the clay is mixed with the upper part, by which the whole is rightly tempered.

In Grand Forks brickmaking has been carried on by J. S. Bartholomew since 1880, his product in 1887 being 1,200,000. The upper foot of soil is stripped off and the next 7 feet of clay are used, requiring no intermixture of sand.

SALT.

The description of the artesian wells of this district given in the preceding chapter has included nearly all that needs to be stated concerning its saline well water and springs. In the early times, when the Hudson Bay Company's trading posts and the Selkirk colonists comprised all the white inhabitants of the region, the expense of importation of salt was much greater than now, and considerable quantities of it were yearly made by evaporation of the water of salt springs. One of these springs from which much salt was made for the Hudson Bay Company is situated in the channel of the South Branch of Two Rivers, about 1½ miles above its junction with the North Branch and some 6 miles west of Hallock. It is exposed only when the river runs low, and in such portions of the summers the work of salt-making was done.

The principal product of salt then used in this district, however, was from brine springs and wells on the low, flat land bordering the west side of the south end of the southeast arm of Lake Winnipegosis. This brine is so strong, according to Hind, that 30 gallons yield a bushel of salt. The product in 1874, as reported by Spencer, was about 500 bushels, sodium chloride forming 95 per cent of the manufactured salt.[1]

Brine about a third as strong as that of the salt wells of the Saginaw district in Michigan was found by the artesian wells of Humboldt, Minn., and Rosenfeld, Manitoba (pages 537 and 538). Though very pure brine, it can not be utilized in competition with the salt manufacture in Michigan, especially when the cost of fuel at the salt works there, using refuse from sawmills, is almost nothing, while on this prairie tract its cost would be about $5 per cord. A sample of salt made from the Humboldt well was exhibited at the New Orleans Exposition in 1884–85.[2]

LIGNITE.

Thin layers of lignite coal, seldom exceeding a foot in thickness, are contained in the Cretaceous shales, probably belonging mostly to the Fort Benton formation, which are scantily preserved beneath the thick drift sheet, and are occasionally exposed in outcrops, throughout the western two-thirds of Minnesota. Here and there fragments of lignite derived from these beds are found quite plentifully in the till, and also sometimes in gravel and sand deposits of the modified drift, so that hundreds of little pieces, up to 3 or 4 inches in length, and very rarely a larger mass, are obtained in digging a well or cellar, or may be found in the ravines of streams or on lake shores. But more commonly a well dug 30 or 40 feet deep in the till encounters none or no more than two or three of these fragments. Where they abound in the drift, Cretaceous shales bearing lignite had been doubtless eroded by the ice-sheet within a moderate distance to the north, and remnants of them may still exist.

[1] H. Y. Hind, Narrative of the Canadian Exploring Expeditions, London, 1860, Vol. II, pp. 43–45. J. W. Spencer, Geol. and Nat. Hist. Survey of Canada, Report of Progress for 1874–75, p. 69.

[2] N. H. Winchell, Geol. and Nat. Hist. Survey of Minnesota, Thirteenth Annual Report, for 1884, pp. 41–46.

Within the area of Lake Agassiz lignite fragments have been thus found plentifully in many localities, among which the following may be specially noted: In digging a cellar close south of the Mustinka River, in section 32, township 127, range 47, near its entrance into the north end of Lake Traverse; in wells near Tintah and at Campbell, Minn.; in a ravine which intersects the Herman and Norcross beaches, in sections 32 and 31, Keene, 8 miles north of Muskoda, Clay County; in the sand of the artesian wells on the Lockhart Farm, Norman County, at the depth of 141 to 157 feet; similarly in sand between 161 and 165 feet below the surface in artesian wells at Carman, Polk County; along the channel of the South Branch of Two Rivers, in the southwest part of township 160, range 44, at a distance of a half mile to 2 miles east of its crossing by the Roseau Lake trail, as reported by Mr. Charles Hallock and Maj. S. Holcomb, the largest piece found being about $1\frac{1}{2}$ feet square and 4 inches thick; and on the Roseau River, in Manitoba, about 20 miles east of Dominion City. Pieces of lignite are somewhat frequent on portions of the shores of Red Lake, Lake Winnebagoshish, and Namekan Lake, the last lying on the international boundary, next southeast of Rainy Lake. They also occur in gravel beds of the Pembina delta of Lake Agassiz, having been especially noticed at the springs in the south bluff of the Pembina River, 2 miles south of Walhalla.

It is not advisable, however, that any search should be made for discovery of lignite beds in remnants of the Cretaceous strata still existing within this lacustrine area; for, while the lignite is of poor quality for fuel, all its numerous known deposits thus occurring in several counties in Minnesota, and on the Sheyenne and in the Turtle Mountain, North Dakota, are too thin to be worked. On the upper portion of the Souris River, in Manitoba and North Dakota, from the vicinity of Minot northward, and on the Northern Pacific Railroad, 40 miles west of Bismarck, beds of similar lignite, but belonging, as in Turtle Mountain, to the Laramie series, the highest of the Cretaceous, ranging up to 8 feet in thickness, have been successfully mined, their product being used for fuel by many settlers in this vast prairie region.

NATURAL GAS.

A few years ago, after the wonderful discoveries of natural gas in Pennsylvania and Ohio, many people held the delusive hope and belief that it could be obtained in valuable amount by boring deeply in almost any locality or geologic formation. In the Red River Valley this hope was fostered by the occurrence of combustible gas issuing from wells in the drift in Arthur Township, Traverse County, at Argyle, and in section 10, Wanger, Marshall County, Minn., and near Argusville and Gardner, at Hillsboro, near Cummings, and near Mayville, in North Dakota. These flows of gas, though readily ignited and burning for a time with considerable flame, are of small amount, and are probably derived from fragmentary lignite and other vegetal matter very scantily contained in the drift.

To test the questions whether either artesian water or gas could be obtained from the rock formations underlying the drift at Moorhead, a well was bored there in 1889 to the depth of 1,750 feet (page 556). Below the depth of 365 feet this boring, which was done at public cost by order of the city government, was in Archean granitoid and gneissic rocks, in which a large expenditure was wasted after the State geologist, Prof. N. H. Winchell, had informed the mayor that the samples of the drillings forbade "any hope of obtaining artesian water or other product of value."[1] It is well-nigh certain that nowhere in this lacustrine area can either lignite or natural gas be found in such quantity as to be practically utilized.

WATER POWER AND MANUFACTURES.

Very valuable water powers, some of which are now used, while many others have not been improved nor surveyed, exist on the head stream of the Red River above Breckenridge, on its tributary, the Pelican River, on the Red Lake River and its tributary, the Clearwater, on the Rainy and Winnipeg rivers, at the Grand Rapids of the Saskatchewan, and on the Nelson. There are also small and less constant water powers, several of which are utilized, on the Buffalo and Wild Rice rivers, in Minnesota, on the Sheyenne, Goose, Turtle, Forest, Park, and Pembina rivers, in North Dakota, and on the Souris and Assiniboine rivers, in Manitoba.

[1] Geol. and Nat. Hist. Survey of Minnesota, Bulletin No. 5, 1889: Natural Gas in Minnesota, p. 39.

The Red River (pages 54–56) has four improved powers, varying in head from 10 to 15 feet, in the city of Fergus Falls. Moderate expense in the construction of dams to make Ottertail, Rush, and Pine lakes reservoirs, filled in spring several feet above their present level and drawn down in time of drought, would much increase the available water power of this river at Fergus Falls and along all its extent from Ottertail Lake to Breckenridge. In this distance the river falls nearly 375 feet, averaging 5 feet per mile. Its bed is the hard, stony clay of the glacial drift, affording a good foundation for dams, and along most of this distance the sloping river banks permit the water to be carried in canals so as to furnish any amount of head desired for milling purposes. On the west the wheat of the Red River Valley, and on the east oak, maple, ash, and pine timber, invite the further utilization of this magnificent water power.[1]

A series of lakes that are the sources of the Pelican River, tending to equalize its flow in wet and dry seasons, and the descent of this stream about 200 feet from Lake Lizzie to its mouth, with a channel and banks of glacial drift, make its water power almost equally valuable with that of the Red River.

Large lakes which serve as reservoirs also give a high degree of constancy to the water power of the Clearwater and Red Lake rivers (pages 52–54), already partially utilized at Red Lake Falls and Crookston, and especially to the power of the falls of the Rainy River at Koochiching and Fort Frances (page 50), and to the many rapids and waterfalls of the Winnipeg River (pages 51, 52). These streams will doubtless some day become the sites of large manufacturing cities, where the wheat of the prairies will be made into flour and the timber of the adjoining forests will be manufactured into lumber, paper, furniture, and various wooden wares. While agriculture will be the leading occupation in the prairie region of Lake Agassiz, more diverse industries will grow up in the wooded country of its eastern and northern portions.

[1] For details of the water power of the Red River and its tributaries, see "The water power of the Northwest" (pp. 204), by James L. Greenleaf, in Tenth Census of the United States, 1880, Vol. XVII.

APPENDIX A.

COURSES OF GLACIAL STRIÆ.

The following table of glacial striæ in the region of Hudson Bay and Lake Superior and westward shows the directions of the currents of the ice-sheet within the basin of Lake Agassiz and upon the country where it lay as the barrier or dam of this lake. The notes are derived chiefly from the reports of the geological and natural history surveys of Canada and of Minnesota, and are all reduced to refer to the true or astronomic meridians. Unless they are otherwise credited, the observations in British America are by Dr. Robert Bell, and in Minnesota and North Dakota by the present writer.

The lobation of the ice-sheet in this basin, its diverse and prolonged courses of transportation of drift, which depended on the glacial currents producing the striæ, and the intersection, in some localities, of two or more sets of striation, have been considered on pages 129–131. Besides the citations on these subjects there given, reference may be made to my recent papers on remarkably deflected striation in Somerville, Mass.,[1] and in the vicinity of Two Harbors, Duluth, and Carlton, Minn.[2]

Hudson Strait and Bay.

Hudson Strait:

Port Burwell, 10 miles southwest from Cape Chudleigh .... S. 85° E.

Ashes Inlet, on the north side of the strait, about.. S. 65° E.

Cape Prince of Wales, on the south side, opposite to the last .... E. to N. 70° E.

South part of Nottingham Island... S. 80° E.

Digges Island, off Cape Wolstenholme .... N. 55°–75° E.

Ottawa Islands, in the northeast part of Hudson Bay........... N. 75° E., N. 40°–20° E., and N. 5° W.

East coast of Hudson Bay:

Northern part, successively, proceeding southward.............................. NE., N., and NW.

From Cape Dufferin southward to Hopewell Head and the most northern of the Nastapoka Islands, in latitude 58° to 57° N., near the middle of the east side of Hudson Bay, numerous localities .... S. 70°, 60°, and 35° W.

[It is probable that the first two of these courses record the direction of the ice-flow during the time of maximum depth and area of the ice-sheet, or during a somewhat later stage; and that the last belongs to the time of final melting of the ice.]

Thence southward to the entrance of Richmond Gulf, numerous localities, mostly between.. S. 65°–75° W. and N. 75° W.

But in two localities, probably a later glaciation.................................. S. 35°–45° W.

Cairn Mountain Island, Richmond Gulf, several localities, mostly................ N. 60°–70° W.

But in one place varying from this to .... S. 45° W.

[1] Proc. Boston Soc. Nat. Hist., Vol. XXVI, pp. 33–42, March 15, 1893.

[2] Geol. and Nat. Hist. Survey of Minnesota, Twenty-second Annual Report, for 1893, pp. 31–43, with map of the glacial geology (striæ, retreatal moraines, etc.) of northern Minnesota.

East coast of Hudson Bay—Continued.

From Richmond Gulf and Little Whale River southward to Esquimaux Harbor, many localities .... N. 80° W. to W.

Thence to Red Head, 57 miles northeast of Cape Jones, eight localities........ W. to S. 75° W.

And one locality........ S. 55° W.

Red Head Island........ N. 70° W.

Thence southward to 40 miles south of Big River, many localities........ S. 40°–60° and 70 W.

But on the southwest extremity of Long Island, near Cape Jones, striæ bear in every direction from .... S. 70° W., around by SW. and S., to S. 40° E.

The two prevailing directions are about .... S. 45° W. and S. 15° E.

The former seems probably the older, but perhaps deflected to the south from the direction of the glacial current when the ice-sheet was thickest; and the latter, with further deflection southeastward, may belong to the closing stages of the Glacial period. An island off the southwest point of Long Island has three sets of glacial striæ .... S. 60° W., S. 40° W., and S. 20° E.

From 40 miles south of Big River southward along the east coast of the south half of James Bay, many localities........ S. 30°–55° W.

But in one locality, about 3 miles northwest of the Paint Hills, three sets of glacial striæ occur, bearing........ N. 75° W., S. 55° W., and S. 30° W.

The first probably records approximately the course of glaciation here when the ice attained its greatest area, belonging thus to a striation which was chiefly effaced by a later glacial movement to the southwest during the departure of the ice-sheet.

Again, at the Paint Hills two sets of glacial striæ are found, bearing.. S. 75° W. and S. 35° W.

And on Governors Island, at the mouth of Eastmain River, the course is........ S. 75° W.

In the country east of Hudson Bay, extending from Richmond Gulf southward and drained by the Clearwater, Great Whale, and Big rivers, forty-nine localities (A. P. Low)........ S. 50° W. to N. 60. W.

Excepting two places which have intersecting striæ, namely—

For the first .... N. 80° W. and N. 35° W.

For the second .... N. 68° W. and N. 50° W.

But in a majority (thirty-six) of the localities in Mr. Low's list the bearings range between .... S. 60° W. and W.

Marble Island, northwest part of Hudson Bay........ S. 15°–25° E.

West coast of Hudson Bay:

East side of the mouth of Churchill River........ S. 5° E.

Two and a half miles east from the last........ S. 20° W.

Five miles east from the mouth of Churchill River........ S. 15° E.

Region of the Churchill and Nelson rivers, Lake Winnipeg, and southwest to the Assiniboine.

Churchill River:

At Fort Churchill........ S. 30°–40° W.

Four miles below the mouth of the Little Churchill River........ S. 20° W. and S. 80° W.

Six and 11 miles above the mouth of the Little Churchill River........ S. 10°–15° W.

Little Churchill River:

Three localities, 4, 13, and 18 miles below Waskaiowaka Lake, respectively........ S. 40° W., S. 80° W., and N. 85° W.

Outlet of Lower Recluse Lake, various directions from........ S. 15° W. to S. 50° W.

Also........ W.

Eagle Rapid, 2 miles in a straight line below the last, two sets, both distinct... S. 20° W. and W.

[The courses to the west, or nearly so, probably mark the motion of this part of the ice-sheet during the time of its greatest depth and extent, while the southerly courses show its deflected motion during the final melting.]

Along the Nelson River:

Third Limestone Rapid, 100 miles by the course of the river above its mouth........ S. 30°–50° E.

Broad Rapid, 5 miles long, 11 to 16 miles above the last, mostly........ S. 50° W.

Also........ S. 15° W. and S. 55°–75° W.

Thence to Middle Gull Rapid, numerous localities........ S. 55°–80° W.

Along the Nelson River—Continued.

Upper Gull Rapid, and thence to the middle portion of Split Lake, numerous localities ... N. 85°–75° W.

Southwestern part of Split Lake, two localities ... S. 85° W.

Chain of Rocks Rapid, 3 miles above Split Lake, one set, probably the older ... S. 85° W.

The other ... S. 10° E.

On Grass River, tributary to the Nelson River from the west, a few miles above Split Lake, numerous localities ... S. 85° W. to W.

But in one place, at the outlet of Witchai (Stinking) Lake ... N. 75° W.

Between Split Lake and Sipi-wesk Lake, numerous localities, mainly ... S. 55°–75° W.

And occasionally ... W.

Sipi-wesk Lake, outlet and northeastern part, mostly ... S. 70°–75° W.

Also, in numerous localities ... S. 45°–65° W.

Sipi-wesk Lake, average course throughout the southwestern half of the lake ... S. 55°–60° W.

But in some places ... N. 85° W.

Southwest extremity of Sipi-wesk Lake ... S. 65° W.

From Sipi-wesk Lake to the outlet of Pipestone Lake, six localities ... S. 55°–65° W.

Pipestone and Big Reed Lakes and vicinity, five localities ... S. 40°–55° W.

Along the usual boat route from Hudson Bay, by Hayes and Hill rivers, to Lake Winnipeg:

Six miles below The Rock, Hill River ... S. 12° E.

The Rock, Hill River ... S. 10° E.

Dr. Bell reports also at this locality another and older set of striæ ... N. 79° W.

Borwick's Fall, and 1 mile above White Mud Fall, Hill River, both within a few miles southwest from The Rock, respectively ... S. 18° W. and S. 28° W.

Knee Lake, numerous localities ... S. 35°–60° W.

From Knee Lake to Pine Lake, seven localities ... S. 45°–60° W.

From Pine Lake and Molsons Lake to Great Playgreen Lake, many localities ... S. 35°–60° W.

Around Gods Lake, southeast of the foregoing route, 140 to 180 miles east-northeast from the north end of Lake Winnipeg, many localities (Cochrane) .. S. to S. 52° W., mostly S. 15°–40° W.

But in two localities ... S. 80° W.

Between Jackson Bay, on Oxford Lake, and the southern part of Gods Lake, seven localities (Cochrane) ... S. 28°–40° W.

Around Island Lake, about 40 miles south of Gods Lake, many localities (Cochrane) ... S. 10°–36° W.

Between Hudson Bay and Lake Winnipeg, along the Severn, Fawn, Poplar, and Berens rivers, on almost all exposed surfaces (A. P. Low), generally ... SW.

[The variations are only a few degrees from this on either side.]

Mouth of Lake Winnipeg and its vicinity, several localities ... S. 40°–45° W.

East shore of Lake Winnipeg:

Spider Islands, on the adjacent mainland, and at the Shoal Islands, about 30 and 45 miles south from the north end of the lake ... S. 30°–40° W.

Poplar Point, 4 miles southeast of Poplar Point, and opposite to Georges Island, a few miles farther southeast ... S. 30°–35° W.

Four localities near the mouth of Berens River, halfway from the north to the south end of the lake ... S. 57°–60° W.

Near the mouth of Berens River (Panton) ... SW. and SSW.

East side of Berens or Swampy Island (Panton) ... SW.

Of this island Mr. J. B. Tyrrell writes: "The general direction of striation is ... S. 52° W.

"While another set of striæ was found to occur under a mass of pebbles and bowlders, bearing ... S. 13° E."

Rabbit Point, near the Narrows ... S. 48° W.

Black Bear Island, also near the Narrows (Panton) ... SSW.

Intersected by other glacial striæ, bearing ... SSE.

[The latter, agreeing nearly in direction with striæ observed on Swampy Island, on the Winnipeg River above Lac du Bonnet, around the south end of Lake Winnipegosis, on lakes Manitoba and St. Martin, at Stonewall, Stony Mountain, and Little Stony Mountain, near Winnipeg, and on the Assiniboine River, appear to belong to the basal portion of the divergent glacial current which continued south and southeast in the Minnesota and Dakota lobes of the ice-sheet.]

East shore of Lake Winnipeg—Continued.
  Between The Narrows and the mouth of Winnipeg River, numerous localities...... S. 40°–45° W.
Winnipeg River, above Lac du Bonnet to the Whitemouth River (Tyrrell), approximately...... SSE. and SW.

The following, to Lake St. Martin, inclusive, are from a paper by Mr. J. B. Tyrrell, of the Geological and Natural History Survey of Canada, entitled "Pleistocene of the Winnipeg basin," Am. Geologist, Vol. VIII, pp. 19–28, July, 1891:

Lake Winnipeg:
  Northwest shore, "from William River to the mouth of the Saskatchewan," average.... S. 2° W.
  West shore, at mouths of St. Martin and Fisher rivers, probably about...... S.
Cedar Lake:
  East side...... S. 18° W.
  West side, near mouth of the Saskatchewan...... S. 39° W.
Lake Winnipegosis:
  Northeastern angle...... S. 23° W.
  A little farther down the east shore...... S. 9° W.
  Around its south end...... S. 2°–13° E.
  Dawson Bay...... S. 42°–58° W.
Red Deer River...... S. 68°–78° W.
Swan Lake...... S. 48°–53° W.
Lake Manitoba:
  Northwest arm...... Southward.
  East shore, near Steep Rock Point...... S. 8°–13° E.
Lake St. Martin, granite islands...... S. 33° E.
Stonewall, in many places (Panton, Upham)...... S. 20°–25° E.
Stony Mountain (Panton, Upham)...... S. 20°–25° E.
Little Stony Mountain (Upham)...... S. 25° E.
Assiniboine River:
  Section 36, township 8, range 11, in three places (Upham)...... S. 4°–8° W.
  And in one place...... S. 10° E.
  Section 23, township 9, range 10 (Tyrrell)...... S. 38° E.

Athabasca River and Lake, Wollaston and Reindeer lakes, and southward to Cumberland House.

Mountain Portage, Athabasca River, 7 miles above the mouth of Clearwater River...... S. 54° E.
  Or more probably...... N. 54° W.
Fort Chipewyan, near the mouth of Lake Athabasca, also 1 mile west and 8 miles southwest of Fort Chipewyan...... S. 78°–83° W.

The following observations, to Cumberland House, are by Mr. A. S. Cochrane, and are communicated by Dr. Robert Bell:

North shore of Lake Athabasca:
  Ten miles north from the Burntwood Islands...... S. 81° W.
  Twenty miles west of Black Bay...... S. 61° W.
  Halfway from the west to the east end of the lake...... S. 43° W.
  Twenty miles west of the Hudson Bay Company's post at Fond du Lac ... S. 21°, 27°, and 31° W.
  Hudson Bay Company's post, Fond du Lac, 50 miles west from the east end of the lake. S. 53° W.
On the western outlet of Wollaston (Hatchet) Lake, 15 miles east from its mouth at the east end of Athabasca Lake...... S. 85° W.
Junction of Porcupine River with the western outlet of Wollaston Lake, 50 miles east of Athabasca Lake...... S. 75° W.
North shore of Wollaston Lake, halfway between its western and eastern outlets...... S. 27° W.
Jackfish Lake, about halfway between Wollaston and Reindeer lakes, by way of Hatchet Lake River...... S. 17° W.

North end of Reindeer Lake:	
Average of numerous observations	S. 31° W.
Mouth of Hatchet Lake River	S. 17° W.
East shore of Reindeer Lake:	
Porcupine Point	S. 24° W.
Halfway from the north to the south end of the lake	S. 18° W.
South end of Reindeer Lake, and on its outlet	S. 18° W.
Churchill River:	
Near Frog Portage, 110 miles north-northwest of Cumberland House	S. 40° W.
At a small lake 10 miles east from the mouth of Isle à la Crosse Lake	S. 18° W.
On the canoe route:	
Seventy miles north of Cumberland House	S. 16° and 26° W.
Fifty-five miles north of Cumberland House	S. 26° W.

[As on the lower part of Churchill River, before noted, the more westerly courses of this list are believed to indicate the glacial motion when the ice had its maximum depth, or nearly that, continuing probably through the greater part of the period of glaciation; and the southward currents seem referable to deflection during the recession of the boundary of the ice-sheet, most of the earlier westward striæ being thereby effaced.]

From Hudson Bay to Lake Superior and the Lake of the Woods.

On the route of Dr. Bell from James Bay to Lake Huron, commonly	S. 5° E. to S. 5° W.
Rarely varying to	S. 25° E.
Between James Bay and the east end of Lake Superior:	
From Long Portage of the Missinaibi River to Mattagami Lake, both belonging to the Moose River system, mostly	SSW.
Wasquagami Portage, Missinaibi River, two sets	S. 15° W. and S. 60° E.
[The last is doubtless a local deflection, belonging to the time when the ice-sheet was being melted away.]	
Missinaibi River, east of Brunswick Lake	S. 15° E.
Around Mattagami Lake	S. 30°–65° W.
Lake Manitowick, on Michipicoten River	S. 30° W.
Long Portage of the Michipicoten River, 6 miles east of its mouth	S. 40° W.
North shore of Lake Superior:	
Falls of St. Mary, and thence 20 miles north (Agassiz)	SSE.
Twenty-five miles north of the Falls of St. Mary, and thence to the northeast angle of the lake, 75 miles east of St. Ignace Island, many localities (Agassiz)	S.
Fifty miles east of St. Ignace Island (Agassiz)	SSW.
St. Ignace Island, and the same 25 miles east (Agassiz)	S.
Southwest side of Nipigon Bay (Agassiz)	SSW.
Islands in Thunder Bay (Agassiz)	SW.
Between Thunder Bay and Pigeon River (Agassiz)	S.
Isle Royale, Lake Superior, numerous localities (Desor)	S. 20°–75° W.
Along the Pic River, tributary to Lake Superior	S. 20°–30° W.
Kenogami or Long Lake, at the head of the Kenogami River, tributary to Albany River, many localities	S. to S. 25° W.
["The grooving is as well marked on the tops of the highest hills as in the lake valleys."]	
In the country northwest of Kenogami or Long Lake, several localities	S. 30°–40° W.
Along the Kenogami River, mostly	S. 30°–50° W.
But varying to	S. and S. 60° W.
Lake St. Joseph, mostly	S. 30°–45° W.
Also in two localities	S. 15° W. and S. 60° W.
Albany River, between Lake St. Joseph and Maminiska Lake, three localities	S. 20°, 25°, and 40° W.
Maminiska Lake	S. 65° W.

Patawonga Lake ... S. 75° W.
Eabamet Lake, two localities ... S. 75° and 80° W.
Inlet of Sturgeon Lake, Bowlder River ... S. 70° W.
Attawapishkat River:
  Respectively 3, 13, 22, and 23 miles below the junction of the two channels from the lake of the same name ... S. 60°, 42°, 22°, and 15° W.
  Lowest exposure of Archean rocks ... S. to S. 10° E.
  On limestone about 75 miles from the southern mouth of the river ... S. 18° W.
  On limestone 9 miles below the last, two sets of striæ, the older ... S. 8°–12° W.
    And the newer ... S. 60°–70° E.
  On limestone at the head of Lowasky Island, about 44 miles from the southern mouth of the river ... S. 2° W.
  Southern channel, or Lowasky River, 4 miles below the last, the older striæ ... S. 35° W.
    And newer striæ varying in course from the foregoing to ... S. 80° W.
Around Lake Nipigon two sets of glacial striæ are common, and are often found crossing each other on the same rock surface. The southward set, which is the older, varies from ... S. 18° E. to S. 25° W.
    And the westward and newer set varies from ... S. 50° W. to due W.
Along and near Kaministiquia River ... S. to SW., averaging SSW.
Dog Lake, mean of several localities (Hector) ... S. 10° W.
Lac des Milles Lacs, mean of several localities (Hector) ... S. 5° E.
Sturgeon Lake, 50 miles southeast of Lonely Lake, commonly ... S. 20°–30° W.
    But in one locality ... S. 50° W.
Minnietakie Lake and vicinity, west of Sturgeon Lake, several localities ... S. 20°–55° W.
Abrams Chute ... S. 10° W.
Islands in the middle of Abrams Chute ... S. 40° W.
Lonely Lake (Lac Seul):
  Three localities ... S. 70° W., S. 85° W., and N. 80° W.
  Three other localities, respectively 10, 13, and 16 miles east of the Hudson Bay Company's post ... S. 60° W., S. 25° W., and S. 55° W.
  East extremity of the lake ... S. 45° W.
Root River, tributary to the east end of Lonely Lake, two localities ... S. 50° and 45° W.
English River, below Lonely Lake, five localities ... S. 30°–60° W.
    And one locality ... S. 80° W.
Winnipeg River, several localities (Bell) ... S. 20°–55° W.

Dr. A. C. Lawson reports the following many observations of glacial striæ in the region about Rainy Lake, on canoe routes north of this lake, on the shores and islands of the lake itself, and on Rainy River:

Kishkutena route, from Sabaskong Bay of the Lake of the Woods to the Northwest Bay of Rainy Lake, seven localities ... S. 33°–58° W.
Pipestone Lake route, extending north from the Northwest Bay of Rainy Lake, nineteen localities ... S. 20°–49° W.
Kiarskons route, several miles east of the last, six localities ... S. 28°–53° W.
Manitou route, extending north from Manitou Sound, the most northern portion of Rainy Lake, twelve localities, also ... S. 28°–53° W.
Little Canoe River route, a few miles east of the last, five localities ... S. 26°–40° W.
Big Canoe route, a few miles farther east, five localities ... S. 23°–43° W.
Redgut Bay of Rainy Lake, and the Turtle River route, extending thence northeastward, twenty localities ... S. 23°–63° W.
Seine River route and Bad Vermilion Lake, fifteen localities ... S. 36°–63° W.
Rainy Lake:
  East Arm, from its east-southeast extremity to Brûlé Narrows, twenty-four localities ... S. 28°–73° W.
  East Arm, from Brûlé Narrows and the Seine River to the mouth of the lake, forty localities ... S. 28°–61° W.

Rainy Lake—Continued.
North Arm, thirty-seven localities .... S. 18°–53° W.
Northwest Bay, eleven localities .... S. 37°–50° W.

Rainy River:
Island 4 miles above the Manitou Rapids .... S. 38° W.
One mile below the Long Sault, and at the first and second rapids of Pine River, three localities, alike .... S. 21° W.
One mile above the mouth of Rapid River .... S. 38° W.

Around the Lake of the Woods, observations in about 180 localities by Dr. A. C. Lawson and assistants, and in about 60 localities reported by Dr. G. M. Dawson, "the great majority," i. e. 82 per cent, are .... S. 35°–55° W.
But 13 per cent are .... S. 10°–34° W.
And 5 per cent are .... S. 56°–83° W.

Only four localities showed courses more westerly than S. 65° W.; one of these is on the southeast side of Big Island, where striæ bearing .... S. 75° W.
Intersect others bearing .... S. 37° W.

On the west side of Bigsby Island, which, like the preceding, lies near the middle of Sand Hill Lake (the southern and largest part of the Lake of the Woods), double sets of striæ were observed in two places, respectively .... N. 80° W. and S. 20° W.
And .... N. 83° W. and S. 33° W.

And on a joint projecting from the south shore in the southwestern part of this Sand Hill Lake, striæ bear .... S. 70° and 65° W.
With others .... S. 35° and 33° W.; also, S. 10° E.

[Probably the bearings S. 10° E. to S. 20° or 30° W. belong to the time of the maximum depth and area of the ice-sheet; the prevailing southwestern courses, to later glaciation; and the more westerly deflections, to the time of final melting of the ice.]

Minnesota.

North shore of Lake Superior southwesterly from Pigeon Point, numerous localities (Norwood and Whittlesey) .... S. 25°–45° W.
Duluth (N. H. Winchell) .... WSW.
Otter Track, Sucker (or Carp), and Long lakes, in northeastern Minnesota, south of Hunters Island (Winchell) .... SW.
Vermilion Lake, two places (Winchell), about .... S. 20° W.
And in another place (Winchell) .... S. 40° W.
Vermilion Lake (Whittlesey) .... S. 15° W.
Pike River, tributary to Vermilion Lake, two places (Winchell) .... S. 10° and 20° W.
In township 59, range 14, about 20 miles south-southeast of Vermilion Lake (Winchell), estimated .... S. 30° W.

The following, to Knife Lake, inclusive, are observations by Prof. N. H. Winchell, noted in his Fifteenth Annual Report, Minnesota, for 1886, pp. 385, 386:

Vermilion Lake:
Twenty localities .... S. 17°–24° W.
Three other localities .... S. 28° W., S. 10° W., and S.
Birch Lake .... S. 12° W. and S. 22° W.
Section 30, township 63, range 8 .... S. 8° E.
Section 35, township 63, range 9 .... S. 12° W.
Section 27, township 63, range 10 .... S. 15° W.
Basswood Lake, Northeast Cape .... S. 15° W.
Ima Lake, north shore .... S. 36° W. and S. 23° W.
Island in Thomas Lake .... S. 25° W.
Section 11, township 64, range 7 .... S. 30° W.
Knife Lake .... S. 18° W.

The two following are from Prof. N. H. Winchell, in his Sixteenth Annual Report, for 1887, p. 114:

East end of Delta Lake, west of Ogishke Muncie Lake .... S. 25° W.
Island in Pseudo-Messer Lake .... S. 10° W.

Mr. Horace V. Winchell, in the report last cited, pp. 395–478, notes the following glacial striæ, to Trout Lake, inclusive, corrected by him for magnetic variation:

Little Fork of Rainy River, five localities .... S. 10°–42° W.
Rainy River, 3½ miles below Fort Frances .... S 32° W.
Rainy Lake, nine localities .... S. 32°–64° W.
North fall on outlet from Namekan Lake to Rainy Lake .... S. 30° W.
Bowstring River (Big Fork of Rainy River):
Probably in township 63, range 26, intersecting striæ, mainly .... S. 10° W. and S. 30° E.
A short distance above the last, very distinct glaciation .... S. 60° E.
Deer River, at dam about a half mile above its junction with the Big Fork, probably in township 62, range 25 .... S. 80° E. to due E.
Big Fork:
About 3 miles above the mouth of Deer River .... Due E.
In or near section 35, township 150, range 25 .... S. 52° E.
[The southeastward and eastward striation on the Bowstring River or Big Fork belongs to the east part of the glacial current that moved to the south and southeast from the region of Lakes Winnipeg and Manitoba, carrying plentiful bowlders and gravel of limestone from those lakes and the lower part of the Red River Valley southeast to this stream and to the mouth of Rainy Lake.]
Lower Falls of Prairie River, section 34, township 56, range 25 .... S.
Elbow Lake, township 64, range 18, two localities .... S. 26° W. and S. 28° W.
Pelican Lake, mostly in townships 64 and 65, range 20, four localities .... S. 24°–36° W.
Net Lake, in the Bois Fort Indian Reservation .... S. 20°–24° W.
Trout Lake, north of Vermilion Lake, two localities .... S. 16° W. and S. 36° W.

In the Seventeenth Annual Report, Minnesota, for 1888, pp. 86–118, Mr. H. V. Winchell gives additional notes of glaciation as follows, to Disappointment Lake, inclusive:

Section 32, township 60, range 13, about .... SSW.
Summit of the Giant's Range at Hinsdale .... S. 22° W.
Section 35, township 61, range 12, south of Birch Lake, about .... S. 12°–30° W.
Section 36, township 62, range 8, south of Lake Isabelle .... S. 24° W.
Section 15, township 59, range 6, southwest of Crooked Lake .... S. 6° W.
Section 10, township 64, range 8, north of Ensign Lake .... S. 24° W.
Section 27, township 64, range 8, northeast end of Disappointment Lake .... S. 34° W.
Sand Point Lake and Sturgeon or Namekan Lake (Whittlesey) .... SW. to S. 55° W.
Rainy Lake (Whittlesey) .... S. 40°–60° W., and WSW.
Big Fork of Rainy River, about 82 miles from its mouth (Whittlesey) .... S. 80° E.
[This seems to be near the locality noted by H. V. Winchell about 3 miles above the mouth of Deer River.]

The Twenty-second Annual Report, Minnesota, for 1893, on pages 35–40, makes extensive additions to the foregoing lists of glacial striæ in the northeastern part of that State, including very abundant and exceptionally deflected courses at Duluth and elsewhere about the west end of Lake Superior. In this report (page 42) it is suggested that some of the courses noted on the Bowstring River or Big Fork may really have been westward, rather than eastward, due to deflection during the late stage of the glacial recession when the expanding Lake Agassiz caused the ice in northwestern Minnesota to be melted away earlier than on the land area about the sources of the Big Fork and easterly, so that the previous glacial currents of that area might become reversed from eastward to westward courses.

The following striæ are in central and southern Minnesota:

Hinckley, Pine County	S. and S. 5° W.
Watab, Benton County	S. 15° W.
Sauk Rapids, Benton County, numerous places	S. 45°–55° W.
But in one place	S. 15° W.
Sauk Center, Stearns County, 40 miles west of the last	S. 40° E.
Minneapolis, several places	S. 5°–28° E.
One to 7 miles southeast from Big Stone Lake, numerous places	SE.
Granite Falls, several places	S. 45°–50° E.
Beaver Falls	S. 60° E.
In the valley of the Minnesota River, 2 miles below Birch Cooley	S. 60° E.
One and a half miles west of Fort Ridgely	S. 60° E.
Redstone, near New Ulm	S. 25° E.
Jordan, at mill of Foss, Wells & Co.	SE.
Posen, Yellow Medicine County	S. 50° E.
Echo, Yellow Medicine County	S. 50°–55° E.
Township 111, range 38, Redwood County	S. 50°–60° E.
Stately, Brown County	S. 50°–55° E.
Germantown, Cottonwood County	S. 30° E., S. 50° E., and 70° E.
Amboy, Cottonwood County, mostly	S. 35°–50° E.
But also rarely deflected to	S. 70° E.
[In one place all these courses intersect on the same surface.]	
Delton, Cottonwood County, numerous localities, mostly	S. 15°–40° E.
Also, in one place, all courses from	S. to S. 80° E.
[These intersect on the same surface.]	
Selma, Cottonwood County	S. 18°–22° E.
Amo, Cottonwood County	S. 30°–32° E.
Dale, Cottonwood County	S. 20°–34° E.
Adrian, Watonwan County	S. 20°–30° E.

The only glacial striæ recorded in North Dakota are on outcrops of a bluish-gray sandstone, occupying the place of the Fox Hills sandstone, on the Willow River, in the southwest quarter of section 35, township 161, range 73, about 6 miles south from Dunseith and the southern base of Turtle Mountain. Distinct glacial furrows and striæ, here observed in eight or ten places, bear mostly due west, but in two places S. 85° W. and S. 75° W. These striæ belong to the closing stage of glaciation here, being directed normally toward the Fergus Falls and Leaf Hills moraines and the glacial Lake Souris, whose eastern shore coincided nearly with this part of the course of Willow River. During the maximum extension of the ice-sheet its current at this locality doubtless passed nearly due south.

Almost universally throughout North Dakota, eastern Montana, and a large area stretching thence northwestward to the Athabasca and Peace rivers, the bed-rocks are shales of the Fort Pierre and Laramie formations, so soft and easily eroded wherever exposed to weathering that glacial marks are not preserved. The sandstone of Willow River, however, outcrops also in the same district on Turkey and Ox creeks, but does not there retain striated surfaces. Farther west, apparently this stratum of sandstone occurs in the bluffs of the Souris River, near its most southern bend, and in hills within the area of the loop formed by this river, where other glacial striæ may probably be found.

APPENDIX B.

NOTES OF ABORIGINAL EARTHWORKS WITHIN AND NEAR THE AREA OF LAKE AGASSIZ.

Archeologists will be interested in the following brief notes of the localities of mounds in this district, to which reference has been made in Chapter XI, page 612.

Many mounds, probably not less than fifty in all, varying from 2 to 15 feet in height, are situated on the bluffs of both sides of Lake Traverse, Browns Valley, and Big Stone Lake.

Three isolated mounds, each about 5 feet high, were noted on the right bank of the Red River, in Wilkin County, Minn., one being about 12 miles east of Breckenridge, another about 4 miles north of that town, and a third in McCauleyville.

Close south of the Red River, near the mouth of Ottertail Lake, is a group of sixteen mounds, varying from 1 to 10 feet in height; and others, single or in groups, are found at many places in Ottertail County.

In Clay County, Minn., a small mound was noted near Muskoda, and another near the South Branch of the Wild Rice River.

(More detailed statements concerning these and the foregoing localities are given in the Geology of Minnesota, Vol. I, p. 631, and Vol. II, pp. 533, 558–561, and 671.)

Mounds and artificial embankments are situated on and near the beaches of Lake Agassiz in many places. In the greater part of these instances the earthworks have been already described, or at least mentioned, in this volume (pp. 284, 313, 347, 349, 354, 390, 412, 413, 431). Among all these localities the most notable is close north of the Forest River, about 6 miles northwest of Inkster (p. 349). According to a survey of this group of mounds by Mr. T. H. Lewis, they number about forty, ranging from 1½ feet to 13 feet in height, some of them being connected by low embankments.

In the south part of Crookston an aboriginal mound about 6 feet high and 100 feet in diameter lies on the south bluff of the Red Lake River, close east of Mr. Erskine's brickyard.

On the prairie, close west of the mouth of Red Lake and north of the Red Lake River, is a large mound about 15 feet high.

Beside the Roseau Lake trail, between 2 and 4 miles eastward from its crossing of the South Branch of Two Rivers, five oblong mounds or embankments, each about 3 feet high, are reported by Mr. Charles Hallock. These are on the crest of a beach ridge, probably the Tintah beach.

Two mounds, respectively 5 and 3 feet high, are situated about half way between Fort Pembina and the town of Pembina, being some three-fourths of a mile north of the fort and an eighth of a mile west of the Red River.

In the vicinity of Devils Lake, Sweetwater Lake, and Stump Lake are many mounds, mostly 3 to 6 feet high, very rarely rising to 10 feet, occurring singly, as on the tops of the hills near Fort Totten, and in groups of several, or sometimes forty or more, as at the southeast end of Devils Lake. Other lone mounds and series of mounds are seen here and there along the bluffs of the Sheyenne and James rivers.

The largest mound known in Minnesota is 45 feet high, being the central one of a group of three (the two others only 8 or 10 feet high) on the south side of the Rainy River, close east of the mouth of the Bowstring River or Big Fork. This mound, partially excavated under the direction of Prof. George Bryce, was found to contain many skeletons, and also skulls without other parts of the skeleton, as if they had been collected on a battlefield. There were also found very interesting stone and copper implements, ornaments made from seashells and others of fresh-water shells, broken pottery, and a complete pottery cup having a diameter of 3 inches. Professor Bryce states that twenty-one mounds are discovered along the whole course of the Rainy River, one (peculiar in containing a structure of charred logs some 10 feet square and 6 to 8 feet high) being at the mouth of Rainy Lake and several at the Long Sault. On the Red River, in Manitoba, he reports one mound as formerly existing at Winnipeg, and several still to be seen near the rapids about 16 miles below that city. (Historical and Scientific Society of Manitoba, Transaction 18, 1885.)

On the Souris River and its tributaries, the North and South Antler creeks, Professor Bryce surveyed twenty-one mounds within an area of 4 miles square, ranging from 4 to 7 feet in height. One of these mounds, containing a single skeleton, had with it nearly all the types of stone implements, copper and seashell ornaments, and pottery, which had been found in the large mound on the Rainy River, about 325 miles distant to the east, besides two pipes of red pipestone; but in each case no evidence of any intercourse with Europeans was found. (Historical and Scientific Society of Manitoba, Transaction 24, 1886.)

During my survey of the shore-lines of Lake Agassiz in Manitoba and examination of the adjoining country on the southwest, I observed mounds in many localities, of which the following are the most noteworthy:

In the northwestern edge of the village of Arden the crest of the Campbell beach bears a round mound 4 feet high and 75 feet in diameter, with an embankment 2 feet high and 30 feet wide extending from it 50 feet northward. A mile south of Arden, on this broad beach, a few rods east of its crest and about 1 foot lower, is an embankment 20 to 25 feet wide, about 200 feet long from north to south, parallel with the beach crest, and 1½ to 2 feet high. Along its northern two-thirds this earthwork is straight, but its southern third curves somewhat eastward and this end sinks gradually to the general surface.

The formerly famous Calf Mountain, which was visited by Palliser's expedition and appeared prominent on most of the early maps of Manitoba, is an aboriginal mound, probably built over a slight natural mound of the glacial drift. This earthwork, rising only about 15 feet above the adjoining surface, is near the north line of the northeast quarter of section 32, township 2, range 7 west. Its top is about 40 feet above Darlingford railway station and 1,600 feet above the sea. From it the land descends fast eastward to Thornhill and Morden, overlooking farther east the vast valley plain of the Red River. The earthwork consists of till, inclosing frequent bowlders up to 1 foot in diameter, with a considerable admixture of gravel, which was probably brought from the shores of a beautiful lakelet a few hundred feet distant to the north. The diameter of the principal mound, which is dome-shaped, is 95 feet, with a height of 15 feet. Thence an embankment about 2 feet high extends 10 rods southwest, and its farther portion, turning with a right angle, continues about 4 rods to the southeast. Excavation in the mound has brought to light human bones and many buffalo skulls, often much decayed and fragmentary. The name Calf Mountain, probably a translation from an aboriginal name, refers to this united sepulture of the remains of man and the buffalo.

Several round mounds, 2 to 4 feet high, are situated on the bluffs of Mowbray and Snowflake creeks. Two of these, near the southeast corner of section 9, township 1, range 9 west, were found to contain in each four or five skeletons.

On the top of Star Mound (p. 99) an artificial mound, built of till, with bowlders up to a foot in diameter, has a height of about 4 feet and diameter of 50 feet, with slight embankments extending beyond its circumference about 20 feet to the north and south. Similarly, the top of Pilot Mound (p. 99) has an earthwork about 2 feet high and 50 feet in diameter. The crests of a few of the Tiger Hills are also crowned with small mounds, some of which have been excavated and are found to have been built for purposes of burial.

On the southeast bluff of the Cypress River, close east of the mouth of Tiger Creek, are three mounds, of which the most northeastern and largest is 6 feet high. These are on land about 25 feet above the general level of the surrounding country and 1,260 feet above the sea.

Besides the foregoing, which I have examined, my assistant, Mr. Robert H. Young, noted a mound about 4 feet high and 60 feet in diameter on the crest of the southeastern end of a beach-like esker in the southeast quarter of section 30, township 12, range 1 east, near the Grosse Isle (p. 187).

A very large mound, said to be about 10 feet high, is reported on land of Mr. William Rhind beside the White Mud River, about a mile west from Westbourne. On its surface, or not far below it, stone pipes, pottery, and human skulls and other bones have been found; but at the time of this information no deep excavation had been made.

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