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, watercourses 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

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[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, 544.

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, 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.

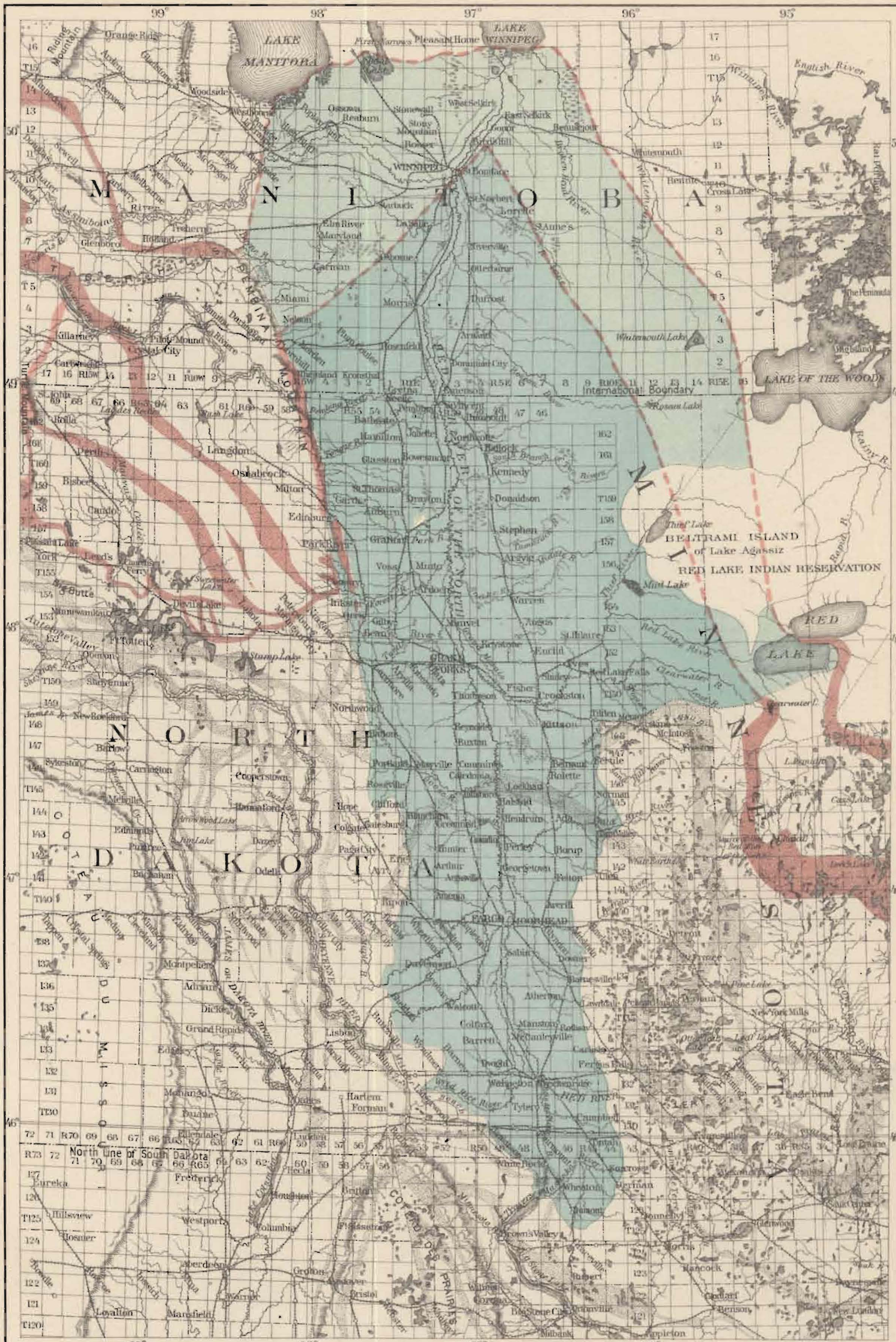
These estimates of depths, it is to be noted, are derived from the determinations of the height of the shore-lines formed during the highest Herman stage, with allowance for the known north-northeastward differential elevation of the basin since the old plane of the lake surface was marked by the waves 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.

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. I, 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

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[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

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[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 beachlines 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

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[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]

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[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

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 Mowbray 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]

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[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.