GLACIAL LAKES IN CANADA.

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(Read before the Society December 31, 1890.)

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INTRODUCTION.

Definition.—A glacial lake, according to my use of the term in this paper 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 continuing through several years, on the surface of glaciers, as in the Himalayan range, or on an ice-sheet, as observed by Nordenskiöld in Greenland.

Extent and numbers.—The abundant and extensive development of glacial lakes here to be considered attended the recession of the ice-sheet of the second or last Glacial epoch in Canada, being due to the temporary dam-

ming 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 water-shed 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. President 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."*

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 water-sheds; (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 note their special features for some of the more important Canadian glacial lakes.

Outlets.—Among the evidences of glacial lakes, the one most invariably recognizable and most definite in its testimony is the outlet showing 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's bay or the Gulf of St. Lawrence. Obviously, water-courses could only exist in these positions 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 cannot be regarded as the record of any marine submergence.

Closely associated with such channels crossing water-sheds, 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,

*Proc. A. A. A. S., vol. XXXV, for 1886, p. 208.

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 levelling, 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 Côteau des Prairies and the Minnesota river.* Others have been noted by G. M. Dawson,† McConnell,‡ and Tyrrell,§ in various parts of Alberta 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 Saskatchewan, Lake Souris, and Lake Agassiz, 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 water-sheds 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 channelled deeply into the harder rock formations. The time required for the work observed was brief.

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, with no definite beach deposit. Waves and currents at these places have been efficient to erode, by undercutting at the base of the terrace, and to carry away, rather than to accumulate. Only a small portion of the shores of Lake Agassiz examined by me consists of these steep, wave-cut slopes of till; and they nowhere form conspicuous topographic features, their range in height being from five or ten to thirty feet. This is

* Geological and Natural History Survey of Minnesota, Final Report, vol. I, 1884, pp. 508-9, 606.

† Report on the Geology and Resources of the Region in the vicinity of the Forty-ninth Parallel, 1875, pp. 263-5; Geological Survey of Canada, Report of Progress for 1882-83-84, p. 150 C.

‡ Geological Survey of Canada, Annual Report, new series, vol. I, for 1885, pp. 21 C and 74 C.

§ Ibid., Annual Report, new series, vol. II, for 1886, pp. 43 E, 45 E, and 145 E, 146 E.

indeed a very slight elevation in comparison with the cliffs of till of similar origin on some parts of the shores of Lake Michigan and others of the Laurentian lakes, where erosion has been in progress from the time of the glacial recession to the present day. Scarboro' heights on Lake Ontario, near Toronto, extending nine 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 lake 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 Tertiary 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 deposit of beach gravel and sand, forming a continuous, smoothly rounded ridge, such as is found along the shores of the ocean or of our great lakes wherever the land sinks in a gently descending slope beneath the water-level. The beach ridges of Lake Agassiz, and of the glacial representatives of the Laurentian lakes, commonly rise three to ten feet above the adjoining land on the side that was away from the glacial lake, and ten to twenty feet above the adjoining land on the side where the lake lay. In breadth, these ridges vary from ten to twenty-five or thirty rods. The beach deposit takes thus the form of a broad wave-like swell, with a smooth gracefully rounded surface. Like the shore accumulations of present lakes and of the sea coast, these glacial lake beaches vary considerably in size, having in any distance of five miles some portions five or ten 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, are found on areas of till that rise with a gentle slope of ten or fifteen 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.*

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 channelled 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, 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

* "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.

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 boulders.

Because of their relation to the receding ice-sheet, the glacial lakes might be expected to receive noticeable deposits, including boulders, 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. Boulders are absent or exceedingly rare in the beaches, deltas, and finer lacustrine sediments. In a few places, however, I have observed boulders in considerable numbers on osar ridges of gravel and sand, 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 one mile while the boulders 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 boulders exposed to view is diminished. The lake levelled the till that would otherwise have formed knobs and hills, in which process many of its boulders 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 occasional 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 CANADA.

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's 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.*

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 ten 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 north-western 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 are first found in ascending the Yukon near the Rink rapids, approximately in latitude $62^{\circ} 20'$ north and longitude $136^{\circ} 15'$ west, about 160 miles east of the line between British America and Alaska.†

No other portion of the Dominion of Canada presents a more interesting or more difficult problem in Quaternary 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 their deposition in each of the numerous basins in which they are found. But I believe that ulti-

* Reports of the Geological and Natural History Survey of Canada; Trans. Royal Society of Canada, vol. VIII, sec. iv, 1890, pp. 3-74, with five maps; American Geologist, vol. VI, Sept. 1890, pp. 163-162; Nature, vol. XLII, Oct. 30, 1890, pp. 650-653.

† Bull. Geol. Soc. Am., vol. 1, pp. 140, 146-8, 644.

mately 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 reëlevated. 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 President 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.* 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.

Alberta, Assiniboia, and Saskatchewan.—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.†

From Lake Pakowki, through which this glacial drainage for a long time flowed southward to the Milk river, the ice-front must have been withdrawn more than two hundred 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 water-shed 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

* U. S. Geol. Survey, Bulletin No. 40, p. 8.

† Compare with Mr. J. B. Tyrrell's paper in Bull. Geol. Soc. Am., vol. 1, pp. 401, 403.

probably extended from Regina sixty 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. 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. 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; 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.

A noteworthy feature of many of the old water-courses 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 is about fifty miles long from south to north and one to two 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 sixty feet above the bed of the outlet from the glacial Lake Saskatchewan. The table on page 252, compiled from Hind's Report of the Assiniboine and Saskatchewan Exploring Expedition, brings into view the remarkable topographic features of this 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.

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 Lang's 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 Brown's valley, by which Lake Agassiz outflowed where now lie lakes Traverse and 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.

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-----	0	1619	-----	140
Ponds on the River that Turns-----	7-8	1686	about 10	110
Height of land-----	12	1704	-----	110-140
Sand Hill or Eyebrow lake-----	24-28	1685	about 20	115-150
Buffalo lake-----	58-74	1635	about 20	190
Lake-----	88-84	1624	about 15	185
Fourth Fishing lake-----	135-144	1504	54	270
Third Fishing lake-----	144-149	1503	57	270
Second Fishing lake-----	150-153	1501	48	275
First Fishing lake-----	154-160	1500	66	300-350
Crooked lake-----	198-203	1389	36	300-320
Round lake-----	218-223	1364	30	310
Mouth of the Qu'Appelle-----	268	1264	-----	220

Manitoba and Keewatin.—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 the greater part of Manitoba and a considerable area of eastern Saskatchewan and southwestern Keewatin. The length of Lake Agassiz from south to north extends across nine degrees of latitude, from its mouth at Lake Traverse on the western line of Minnesota, below latitude 46°, to an undetermined northern limit on the Nelson river probably north of latitude 55°. On the east Lake Agassiz covered the present sites of Rainy lake and Lake of the Woods, and on the west it washed the bases of Pembina, Riding and Duck mountains and the Porcupine and Pasquia hills, reaching on the Assiniboine to Brandon, and on the Saskatchewan to the vicinity of Prince Albert, some forty miles west of the junction of the North Saskatchewan and South Saskatchewan rivers. Its area was about 110,000 square miles, or more than the combined areas of the five great lakes which outflow by the St. Lawrence. At the time of the formation of its highest beach, the depth of Lake Agassiz above Fargo and Moorhead was nearly 200 feet; above Grand Forks and Crookston, a little more than 300 feet; above Pembina, Saint Vincent, and Emerson, on the

international boundary, about 450 feet; above Winnipeg, about 550 feet; and above the central part of Lake Winnipeg and the north end of Lake Manitoba, respectively about 750 and 650 feet.

The highest shore of Lake Agassiz, very distinctly marked by beach ridges and rarely by low eroded cliffs, I have traced with levelling along an extent of about 600 miles in Minnesota, North Dakota, and southern Manitoba; and Mr. J. B. Tyrrell, of the Canadian Geological Survey, has extended this examination a hundred miles farther northward, along the escarpments of Riding and Duck mountains. The mouth of Lake Agassiz at its highest stage was 1,055 feet above the present sea level, and the highest observed portion of its shore line, reported by Tyrrell near latitude 52° on the northern part of Duck mountain, has an elevation of about 1,460 feet. Along the distance of 400 miles from the southern end and mouth of Lake Agassiz to the north end of Duck mountain, its highest shore thus ascends 400 feet; and the rate of ascent is somewhat uniformly about one foot per mile through the entire distance. This glacial lake has an outlet 125 to 150 feet deep and about one and a half miles wide, called Brown's valley, crossing the continental water-shed where lakes Traverse and Big Stone now out-flow respectively to the north and south; and the glacial river which discharged the overflow of Lake Agassiz along this channel and the present course of the Minnesota river has been named the River Warren, in honor of Gen. G. K. Warren, who carefully surveyed the whole extent of the valley and rightly explained its origin. The very extensive delta deposits of gravel and sand brought into Lake Agassiz by the Sheyenne, Pembina, Assiniboine, and other rivers, and the associated lacustrine sediments of fine silt spread farther over the lake bed, will be noticed in a later part of this paper, which relates to the departure of the ice-sheet and its contributions of englacial drift to these deltas.*

The glacial Lake Souris, occupying 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, outflowed in its earliest stage, as already noted, by the James river to the Missouri; and later to Lake Agassiz by successively lower outlets, first along the Sheyenne, and last of all by the way of Lang's valley and the Pembina river. North of the Souris basin, an arm of Lake Souris 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

* Detailed reports on Lake Agassiz are published by the Geological and Natural History Survey of Minnesota, Eighth and Eleventh annual reports, and Final report, vols. I and II; by the U. S. Geological Survey, Bulletin No. 39; and by the Geological and Natural History Survey of Canada, Annual report, new series, vol. IV, part E. More full descriptions and discussion of this glacial lake, now in preparation, will form a monograph of the U. S. Geol. Survey.

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 $50^{\circ} 35'$; and its maximum width, north of Turtle mountain, was nearly 70 miles.

When the ice-sheet west of Lake Agassiz had receded so far as to uncover Turtle mountain, the outflow from Lake Souris passed north of this mountain by the Pembina, perhaps after taking for a brief time the course of the Clearwater river, Lac des Roches, and the Mauvaise coulée to Devil's 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 twenty-five miles. Its average width in each of these portions is about one mile. 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 and interglacial course, where its old valley became wholly or partly filled with till in each of the glacial epochs. The topographic features of this valley will be more fully shown by the notes of approximate elevations referred to the sea level on page 255; 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.

At the Mowbray bridge the bottom land is about an eighth of a mile wide and ten feet above the river. About forty 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 one and a half miles to the east, and also well shown in many places on each side of the river for six 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 three miles to the east from the Mowbray bridge and road, with a maximum width of about one and a half 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 twenty-five miles from this bridge to the Pembina delta, especially in the vicinity of the fish trap, the

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.	Do., top of the bluffs enclosing 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 Lang's valley-----	0	1265	1475
Divide in Lang's valley, near the line between sections 31 and 32, T. 5, R. 17, Manitoba, separating Lang's creek flowing west to the Souris and Dunlop's creek flowing east to the Pembina, determined by railway survey-----	4	1364	1475
Bone lake, three miles long and a half mile wide-----	5- 8	1357	1480
Grass lake-----	10-11	1355	1485
Pelican lake, ten miles long and about a mile wide, mostly 10 to 15 feet deep, but in its deepest portions about 20 feet, rising three feet between its lowest and highest stages-----	11-21	1355	1485-1510
Junction of outlet of Pelican lake with the Pembina-----	22½	1348	1510
Lake Lorne, area about one mile square, maximum depth about 8 feet-----	23-24	1346	1510
Lake Louise, of nearly the same area and maximum depth-----	25-26	1345	1510
Mouth of Badger creek-----	27	1343	1510
Rock lake, eight miles long and one half to one mile wide, maximum depth, 10 feet*-----	30-38	1335	1510-1550
Mouth of Clearwater river-----	40	1332	1525
At the Marringhurst bridge, on the north line of section 16, T. 3, R. 12, Manitoba-----	42	1330	1480
Swan lake, five miles long and one mile wide, maximum depth probably about 10 feet-----	50-55	1310	1500
At La Rivière, determined by railway survey-----	67	1287	1550
At crossing of the Boundary Commission road†-----	75	1265	1550
At crossing of the old Missouri trail-----	80	1250	1545
At the Mowbray bridge, on the line between sections 21 and 22, T. 1, R. 8, Manitoba-----	85	1235	1540
On the international boundary-----	100	1125	1540
At the fish trap, section 30, T. 163, R. 57, North Dakota, two miles west of the Pembina mountain escarpment and seven miles west of Walhalla-----	108	1050	1400-1500

* Glenora prairie, north of Rock lake, a slightly undulating expanse of modified drift, stratified gravel and sand, extending six miles from west to east and two to three miles wide, has an elevation of 1510 to 1500 feet, descending eastward with the valley.

† Dr. Dawson notes a wide terrace here, in some places thickly strown with boulders, on the southwestern side of the river and about 200 feet above it; and he refers its origin to preglacial erosion of the valley.

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 one 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 coulee and the Sheyenne was approximately 1,600 to 1,500 feet above the present sea level, being gradually cut down about a hundred 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 Lang's 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 Lang's 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 twenty feet above the present divide in Lang's 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 Lang's valley has been raised probably ten feet by the deposits of Dunlop's creek.

Seventeen shore lines of Lake Agassiz are recognized in descending order, which were formed while this great glacial lake outflowed southward by Lakes Traverse and Big Stone; and eleven lower shore lines record later pauses in the declining lake level, while it outflowed northeastward across the south part of Keewatin. Perhaps at first this northerly outflow was turned eastward and then southward, passing along the border of the receding ice-sheet which still covered the area of Hudson's bay, and eventually flowing through lakes Superior and Michigan to the Mississippi. When the ice upon Hudson's and James's bays and the adjoining country was so far melted as to admit the ocean there, it at first covered the land west of James's bay 350 to 500 feet above the present sea level. Lake Agassiz, and the numerous glacial lakes which had existed in the basins of the Moose, Albany, and other rivers tributary to James's bay, were then drained northward into this inland sea. An early northeastward outflow

from Lake Agassiz probably crossed the water-shed between the Poplar and Severn; and later outlets were found along lower courses, including the canoe route by the Hill and Hayes rivers. Each of the 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's bay finally permitted drainage to take the course of the Nelson, the ice-dammed Lake Agassiz being thus changed to Lake Winnipeg.

Within the time after the ice-sheet had retreated beyond the valley of the lower Saskatchewan, and before its melting upon Hudson's bay permitted Lake Agassiz to gain an outlet northeastward to the sea, it seems certain that the ice must have been melted upon a large region north of the Saskatchewan basin, where drainage now passes east by the Churchill and north by the Mackenzie, but was then pent up in lakes by the ice-barrier and caused to flow to the south. Lake Agassiz thus received the waters of the upper Churchill, and of the basins of the Athabasca and Peace rivers, the great head streams of the Mackenzie; and the Churchill, and probably also the upper Mackenzie basin, continued to be tributary to this lake through all its lower stages of outflow to Hudson's bay.

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

The water-course by which the Churchill, bringing the Athabasca outflow, passed into the Saskatchewan, tributary to Lake Agassiz, extends southeastward about a hundred miles by 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

* Descriptive Sketch of the Physical Geography and Geology of the Dominion of Canada, 1884, p. 32.

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 three hundred and eighty 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 river, 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.*

Ontario.—The province of Ontario, extending from the mouth of the Ottawa westward to Lake of the Woods and from the great Laurentian lakes northward to Albany river and James's bay, presents a most admirable field for the exploration of glacial lake shores, deltas, and channels across watersheds. The recession of the ice-sheet was in general from the southwest and south toward the northeast and north. As soon as its border was withdrawn across the various parts of the water-shed 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. Portions of the Canadian 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 boundary, where they were held in by the receding ice-barrier on the northeast and north, the land shows no shore erosion nor beach deposits.

From the western part of the basin of Lake Superior a glacial lake outflowed to the Mississippi at the lowest point of the present water-shed between the Bois Brulé and Saint 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 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. Silts referable to this 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 Michigan had probably permitted Lake Superior to become confluent with Lake Michigan over

* Narrative of a Journey to the shores of the Polar Sea, in the years 1819, '20, '21 and '22, by John Franklin, Captain R. N., F. R. S.; including an appendix of Geognostical Observations by John Richardson, M. D., Surgeon to the Expedition. Also, Sir John Richardson's Arctic Expedition in Search of Sir John Franklin.

the low divide of the Au Train and Whitefish rivers, the latter of which is tributary to Little bay de Noc. The series of beaches observed north of Lake Superior at a locality near the Petits Écrits, between Nipigon bay and the Slate islands, at heights in descending order 331, 267, 259, 224, 90, 40, and 30 feet above the lake,* are apparently referable, for the highest, to a time when Lake Superior was confluent with the adjacent great lakes, with outlet by Chicago to the Illinois river, and, for the lower levels, to later stages of separate existence of Lake Superior, with discharge by a river, probably at first crossing the Au Train water-shed, but afterward, during the formation of the three beaches at and below 90 feet, outflowing by the present mouth at the Sault Ste. Marie. Like the beaches of Lake Agassiz, this series seems to indicate that the departure of the ice was followed by a northward uplift of the land.

Beaches of sand and gravel occur on Owen Sound, at the southwestern side of Georgian bay, about 200, 150, and 120 feet above Lake Huron, or about 780, 730, and 700 feet above the sea.† These probably belong to a stage of the glacial retreat when a vast confluent glacial lake, which Spencer has named Lake Warren, stretched 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 twelve or fifteen feet above the lake and approximately 595 feet above the sea, while the outflow from Lake Erie passed over the lowest point of the water-shed 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 water-shed of the Shiawassee and Grand rivers, allowing the glacial lake Erie-Huron to flow into the glacial Lake Michigan by a pass which is now 729 feet above the sea. Soon after this, and apparently previous to the dates of the Owen Sound beaches, Lake Erie-Huron was further lowered by the recession of the ice from the Strait of Mackinaw; and the fully extended Lake Warren, probably holding one level through connecting straits from lakes Ontario and Erie to Lake Superior, discharged its surplus waters by the Chicago outlet. If the correlations here indicated are true, the differential uplift of portions of the shores of Lake Warren, toward the north, northeast, and east-northeast, above its Chicago outlet, has been approximately 338 feet near the middle of the north side of Lake Superior, 185 feet on Owen Sound, and about 265 feet near the eastern end of Lake Erie, where

* Geological Survey of Canada, Report of Progress to 1863, p. 913.

† Ibid., p. 912.

Gilbert finds a beach of this glacial lake 860 feet above the sea. Doubtless a distinct series of these beaches is traceable upon the southwestern part of Ontario from near Toronto and Hamilton westward and northward to Georgian bay, marking pauses in the uplifting of the country while the ice-barrier still occupied a large part of Lake Ontario and turned the glacial drainage of this whole district into the Mississippi.

The further 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, have been ably discussed by Gilbert. On a different theory, not recognizing an ice-sheet and referring the high ancient beaches of this basin to marine submergence, the same field has also been elaborately and ably studied by Spencer. 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 Ontario, outflowing at Rome, formed a well marked beach which Gilbert has mapped, with determinations of its height by levelling, 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, who has given to the beach and lake the names "Iroquois beach" and "Lake Iroquois." The height of Lake Ontario is 247 feet; and that of the old outlet crossing the water-shed at Rome is 440 feet, above the sea level. Thence the beach in its course northward adjacent to the eastern end of Lake Ontario has a gradual ascent of about five 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, there is a vertical fall of approximately 500 feet; and from the latest in the series of several Iroquois beaches near Water-

town, where they 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 second Glacial epoch, which was the barrier of these glacial lakes; for fossiliferous marine beds overlying the till extend inland along the St. Lawrence valley to Ogdensburgh 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 the 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 50 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 130 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 Ogdensburgh. 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 Lake Iroquois, between the formation of its latest beach with outflow by Rome to the Mohawk and the complete departure of the ice 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 is probably at least 250 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 650 or 600 feet, which differs only slightly from its present height of about 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 vicinity of Owen Sound and the region north of Lake Superior were respectively about 180 feet and about 300 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.

A similar comparison of the latest beaches of Lake Agassiz with the marine submergence of the country southwest of James's bay, where the land after the withdrawal of the ice-sheet stood 350 to 500 feet below its present height, suggests that the outlet of Lake Agassiz at lakes Traverse and Big Stone was slightly lower in relation to the sea level then than it is now, perhaps by a difference of 25 or 50 feet; but probably this difference was considerably greater, amounting to 100 or 200 feet, when the earliest and highest beaches of that glacial lake were formed. In this connection it may also be remarked that the studies of Chamberlin and Salisbury on the driftless area of Wisconsin indicate a greater depression on the western than on the eastern part of that area in the closing stage of the first Glacial epoch,* just as Chicago had its present height while western Minnesota was somewhat depressed at the time of recession of the later ice-sheet.

Before leaving the Laurentian lakes, we may glance rapidly over some of the explanations of their ancient elevated shore lines 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.† 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.‡ In 1861 Professor E. J. Chapman attributed the deposition of drift in this lake region to a marine submergence exceeding 1,500 feet, but he was unable, like all subsequent observers, 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 highlands.§ During the same year Mr. Sandford Fleming published a detailed description and map of the Davenport ridge and terrace, which are portions of the Iroquois shore line near Toronto, referring them to the action of Lake

* U. S. Geol. Survey, Sixth Annual Report, pp. 277, 304.

† Proceedings Geol. Soc. London, vol. II, pp. 537-8.

‡ Travels in North America, vol. II, chapter xx.

§ Canadian Journal, new series, vol. VI, pp. 221-229 and 497-8.

Ontario when it stood "about 170 feet above its present level."* 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."† 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 is the only recent writer who has examined this region and believes the beaches to be sea shores.§

The water-shed which divides the upper St. Lawrence basin from the basin of James's bay, is covered by many channels of outflows from glacial lakes pent up between that water-shed and the departing ice-sheet on the north. Kenogami or Long lake, north of Lake Superior, having a length of about fifty-four miles from northeast to southwest and a width mostly between a half mile and two 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.|| 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 seventy 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

* Canadian Journal, new series, vol. VI, pp. 247-253.

† Ibid., vol. XV, pp. 388-413.

‡ 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. of the Geol. Soc. of Edinburgh, 1887. G. K. Gilbert, "Changes of Level of the Great Lakes," in The Forum, vol. V, June, 1888, pp. 417-428; 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.

§ J. W. Spencer, "The Iroquois Beach," in Trans. Royal Society of Canada, sec. iv, 1889, pp. 121-134, with map; and "The Deformation of Iroquois Beach and Birth of Lake Ontario," in Am. Jour. Sci., 3d ser., vol. XI, Dec., 1890, pp. 443-451.

|| Geol. Survey of Canada, Report of Progress, 1871-72, p. 336.

bulk of the accumulation of boulders and the rocky bluff on that side." The ancient water-course 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 water-shed 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 S. 48° W., is twenty-four miles long, nearly straight, and varies from a half to one and a half miles in width."* 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 eight and a half 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 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 Mat-tagaming 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's bay region became merged in one of great extent, rivalling Lake Agassiz, the outlet of this confluent lake crossed the low water-shed south of the eastern end of Lake Abittibi, passing to Lac des Quinze and 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 water-shed 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.

The Ottawa then received not only the overflow of a vast glacial lake in the basin of James's and Hudson's bays, but also, as Gilbert has shown, the discharge of Lakes Superior, Michigan and Huron, through Georgian bay and by Lake Nipissing and the Mattawan river. Lake Nipissing is only 58 feet above Lake Huron, or 639 feet above the sea; a low water-shed of gravel and sand divides it from Trout lake, tributary to the Mattawan; and the junction of this river with the Ottawa, distant only 100 miles from Georgian bay, is about 50 feet below that bay and lakes Huron and Michigan. But on account of the northeastward depression of the upper St. Lawrence and Ottawa basins when the ice disappeared, the avenue of dis-

* Geol. Survey of Canada, Report of Progress, 1875-76, p. 330.

charge from the upper lakes by way of Lake Nipissing was then considerably lower than either their earlier Chicago outlet or their present outlet by Detroit and Lake Erie.

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;* 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 water-shed 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 to Quebec and Montreal, 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.†

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's and Hudson's 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 water-shed, should be carefully looked for, as not the least important of our records of the ice age.

EXTENT AND THICKNESS OF THE ICE-SHEET.

The relation of the glacial lakes to the ice-sheet leads us to inquire what were the extent and thickness of the ice, its centers of outflow, the manner of its final departure, and the areas probably occupied by its latest remnants. In connection with these inquiries, we learn much from the delta deposits of the glacial lakes, especially Lake Agassiz, concerning the outlines of the ice in its recession and the amount of its englacial drift, which was contained in the ice-sheet and was set free during its final melting.

The extreme southern limit of the glacial drift, and the division between

* *Geology of New Hampshire*, vol. III, 1873, pp. 103-120.

† *Bull. Geol. Soc. Am.*, vol. I, p. 566.

the earlier drift, belonging to the first Glacial epoch, and the later drift, belonging to the much later second Glacial epoch, have been delineated by President Chamberlin, combining the results obtained by the explorations of many observers during the past twenty-five years.* The southern margin of the drift is shown to lie wholly within the United States, excepting that it is indented at the eastern foot of the Rocky Mountain range by an angle which barely touches the 49th parallel. Dr. Dawson's more recent map of the extent of the drift in the western part of Canada, however, places the apex of this angle south of the international boundary, along which he has had exceptional opportunity for examination.† But the limit of the ice-sheet of the second Glacial epoch, to which our glacial lakes are referred, is found north of this boundary from the 104th to the 114th meridian, that is, across southern Assiniboia and Alberta, from the Coteau du Missouri to the Rocky Mountains. The abundance of lakelets held in hollows of the drift and the small amount of change in the drift contour since the departure of the ice-sheet indicate that the latest glaciation of these provinces reached south to the Wood mountain and Cypress hills and to Lake Pakowki and the upper portion of Milk river.

Including this Canadian part of the southern limit of the second ice-sheet, its course may be briefly noted as follows: From Nantucket, Martha's Vineyard, Block island, and Long island, it runs west-northwestward across northern New Jersey and northeastern Pennsylvania, to an angle near Salamanca, N. Y., about fifty miles south of Buffalo and the eastern end of Lake Erie; thence it passes southwestward into southern Ohio; thence west-northwestward and northward in numerous loops through Indiana, northeastern Illinois, and Wisconsin, to an angle less than seventy-five miles southeast of the western end of Lake Superior; thence southward to Des Moines, Iowa; thence north-northwestward to the head of the Coteau des Prairies; again southward to the Missouri river and northeastern edge of Nebraska; thence northwestward, very irregularly lobate, through South Dakota and North Dakota, to Wood mountain in the southern edge of Assiniboia; thence westward by the Cypress hills to the Rocky Mountains on the international boundary; and thence, in lobes determined by the mountainous character of the country, across northwestern Montana, the narrow northern extremity of Idaho, and the northeastern edge and the central and western parts of Washington, to the Pacific coast in the latitude of 48°, Puget sound and the Strait of Juan de Fuca being wholly inside the glaciated area.

Along the shores of British Columbia and southern Alaska the ice-sheet pushed through gaps of the Coast range and terminated in the sea from the

* U. S. Geological Survey, Seventh Annual Report, Plate VIII.

† Trans. Royal Society of Canada, vol. VIII, sec. iv, 1890, Plate II.

Strait of Juan de Fuca and Vancouver island northwestward to the vicinity of the Copper river and Prince William's sound.* But most of Alaska and a portion of the adjacent Northwest Territory of Canada had too little snowfall or were otherwise affected by climatic conditions unfavorable for glaciation. The northwestern limit of the continental ice-sheet, as determined by Russell,† McConnell,‡ and Dawson,§ passes northeastwardly from the Coast ranges about Mount St. Elias, to cross the Yukon and Pelly near the meridian 136° 15', and thence extends nearly due north to the Arctic ocean close west of the mouth of the Mackenzie.

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

On the Atlantic coast it filled Hudson strait with an eastward outflow, as determined by Dr. Robert Bell;¶ Labrador was wholly ice-covered excepting the upper portion of the mountain range south of Cape Chidley, which seventy miles from the cape attains an elevation of about 6,000 feet above the sea;*** Newfoundland, enveloped by the farthest eastward portion of this ice-sheet, was glaciated radially outward into the ocean on the north, east, and south;†† and thence southwestward the border of the ice-sheet, passing beyond the shore-line of Nova Scotia, rested on the irregular submarine ridges and plateaus of the Fishing Banks, which consist of Tertiary strata more or less overspread with morainic drift deposits, extending from Newfoundland to Cape Cod and Nantucket.

The part of North America and outlying islands thus enclosed, amounting to more than 4,000,000 square miles, I believe to have been occupied by the ice-sheet of the second Glacial epoch at its time of maximum area. In the following discussion of the probable thickness of this ice-sheet, I shall endeavor to set forth my reasons for this belief, which differs from the opinions of Mr. J. B. Tyrrell, who thinks that a narrow driftless tract borders the

* G. M. Dawson, in *Quart. Jour. Geol. Soc., London*, vol. XXXVII, 1881, p. 278; *Trans., Roy. Soc. Can.*, vol. VIII, sec. IV, 1890, Plate II.

† *Bull. Geol. Soc. Am.*, vol. I, pp. 140, 146-8.

‡ *Ibid.*, p. 544.

§ *Geol. and Nat. Hist. Survey of Canada, Annual Report, new series*, vol. III, for 1887-88, pp. 132 B and 149 B.

|| G. M. Dawson, *Geol. and Nat. Hist. Survey of Canada, Annual Report*, vol. II, for 1886, pp. 56-58 R.

¶ *Geol. and Nat. Hist. Survey of Canada, Report of Progress*, 1882-84, p. 36 DD; *Annual Report*, vol. IV, for 1888-89, p. 111 E.

*** A. S. Packard, *Memoirs of the Boston Society of Natural History*, vol. I, 1886, p. 219, 220.

†† John Milne, *Quart. Jour. Geol. Soc., London*, vol. XXX, 1874, p. 725-8.

eastern base of the Rocky Mountain range in Canada,* and of Dr. G. M. Dawson, who doubts that an ice-sheet has ever existed on a much wider area stretching from the Rocky mountains far eastward across the Peace and Saskatchewan plain country nearly to Lake Athabasca and the lakes of Manitoba.† Without entering into a discussion of the methods of formation of the various drift deposits, it may make my views more readily understood to add that I agree perfectly with Mr. Tyrrell in referring all deposits of boulder-clay or till directly to the agency of land-ice, without modification or aid by water; while Dr. Dawson, on the other hand, refers all these deposits of till to a glacio-natant origin, that is, to deposition from floating ice supplied from glaciers and borne over the till-covered areas during their submergence by lakes or the sea.

In a paper published last year,‡ I presented somewhat in detail the evidence that the ice-sheet of the second Glacial epoch covered the highest summits of the White mountains, the Green mountains, and the Adirondacks, flowing over them from the north and northwest. The thickness of this ice-sheet at the culmination of the latest glaciation of the northeastern part of our continent was about one mile over northern New England and northern New York; and Dana has shown, from the directions of striation and transportation of the drift, that over the Laurentide highlands between Montreal and Hudson's bay it had probably a thickness of fully two miles. On the east we are indebted to Professor C. H. Hitchcock for the proof that the ice-sheet overtopped Mt. Washington, 6,293 feet above the sea; and in British Columbia Dr. Dawson finds that it covered mountains 5,000 to 7,640 feet high, and he estimates that its highest central part upon that province "had an elevation of at least 7,000 feet above the mean elevation of the interior plateau, which would be equivalent to an elevation of about 10,000 feet above the present sea-level, or probably 11,000 feet above the sea-level of the time."§ Between these eastern and western areas of great known thickness of the ice, as determined by the height of glacial drift and striæ on mountains, probably this ice-sheet across the the interior of Canada at one time attained a thickness of a mile or more on a central belt several hundreds of miles wide, reaching from the Rocky Mountains and the upper Mackenzie to Reindeer lake and Lake Winnipeg, the southwestern part of Hudson's bay, James's bay, the Laurentide highlands, southern Labrador, and the Gulf of St Lawrence. This proposition differs so widely from the views of the authors before cited, for the country adjoining the eastern base of the Rocky Mountains, that the evidences of its truth for that district must be definitely and particularly stated.

* Bull. Geol. Soc. Am., vol. 1, pp. 396, 400, 401.

† Trans. Roy. Soc. Canada, vol. VIII, sec. IV, pp. 54-74.

‡ Appalachia, vol. V, pp. 291-312; also in American Geologist, vol IV, 1889, pp. 165-174 and 205-216.

§ Trans. Roy. Soc. Canada, vol. VIII, sec. IV, p. 28.

The prevailing courses of glaciation and dispersal of the drift lead me to recognize, with Dr. Dawson, the existence of two central areas upon which the ice was accumulated in greater depth than elsewhere and from which consequently it flowed outward on all sides. One of these areas embraced the Laurentide highlands, James's bay, a portion of Hudson's bay, and the western part of the Archean region from lakes Superior and Winnipeg to Great Slave and Great Bear lakes. From this large northeastern or Laurentide center of outflow, the ice-sheet crept southward, eastward, and northward, to the limits of glaciation before noted. Westward the ice from this area outflowed, as I believe, to the limit of Archean boulders on or near the base of the Rocky Mountains, where I find, from Dr. Dawson's observations of the drift in Alberta and on the Peace river, that it abutted against and was confluent with ice outflowing eastward and southeastward from the Rocky Mountains. The other area whence currents of the ice-sheet flowed radially in every direction was the northern-central part of British Columbia; and the portions of the ice-sheet pouring outward respectively from these two centers have been named by Dawson the Laurentide and Cordilleran glaciers. Toward the south, west, and northwest, the Cordilleran outflow extended to the boundaries of our glaciated area; but eastward, pouring through passes of the Rocky Mountains, and in the Peace river region probably overtopping the highest summits, which there are only about 6,000 feet above the sea, the Cordilleran ice pushed across a narrow belt adjoining the mountains, to a maximum distance of nearly 100 miles, and there (on land about 2,500 feet above the sea) became confluent with the Laurentide ice, the two united currents thence passing in part to the southward and in part to the northward from the interior tract where the confluent ice was thickest.

Taking up the particular description of localities where the junction of the Laurentide and Cordilleran drift has been observed, we may begin at the international boundary and proceed northward. Laurentian erratics and drift are stated by Dawson to extend quite to the foot of the Rocky Mountains near the 49th parallel and to occur between the 49th and 50th parallels "stranded on the surface of moraines produced by the large local glaciers of the Rocky Mountains."*

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

*Trans. Roy. Soc. Canada, vol. VIII, sec. IV, p. 57. American Geologist, vol. VI, Sept., 1890, p. 162.

direction * * * about thirteen miles east of the mountains, in a region of wide valleys and low foot-hills." *

On the Peace river in its course close east of the Rocky Mountains, and on its tributary, Pine river, Dawson reports drift containing a large proportion of "hard quartzite pebbles like the more resistant materials of the axial range of the Rocky Mountains. These are mingled with a preponderating number of fragments of the softer sandstones of the country, and imbedded in a whitish or cream-colored silty clay, not unlike the material representing the boulder-clay over wide districts west of the Rocky Mountains. No Laurentian or other fragments of eastern origin were observed in this region." Continuing eastward, these drift deposits become more conspicuous, attaining in places a thickness of 150 feet. On reaching the D'Echafaud river, about 100 miles from the mountains, though "no change in the character of the drift deposits was noted, * * * Laurentian pebbles and boulders were for the first time seen in considerable abundance * * *. East of this point * * * the surface is thickly covered with drift deposits, so much so that exposures of the underlying rocks are, as a rule, only found in the larger river valleys." † No better evidence could be desired by a glacialist, accounting for the formation of the boulder-clay by the agency of land-ice, to demonstrate the confluence here of two currents of the ice, one flowing eastward from the Cordilleran area, and the other flowing westward from the Archean area, whose nearest portion is on Lake Athabasca, about 400 miles distant.

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

Farther northward, the Laurentide or eastern portion of the ice-sheet pushed northwestward to the extreme limit of the drift. "The till near the lower ramparts of the Mackenzie," according to Mr. R. G. McConnell, "is in approximately the same latitude as the northern boundary of the Archean area on the east, and the gneissic boulders which it contains must have travelled either directly west or northwest in order to reach their present situation." He therefore infers that "the ice from the Archean gathering grounds to the east poured westward through the gaps and passes in the eastern flanking ranges of the Rocky Mountains until it reached the barrier

* Geol. and Nat. Hist. Survey of Canada, Report of Progress, 1882-84, pp. 146 C, 151 C; Annual Report, new series, vol. I, for 1885, p. 167 B.

† Geol. and Nat. Hist. Survey of Canada, Report of Progress, 1879-80, pp. 139, 140 B.

‡ Geol. and Nat. Hist. Survey of Canada, Annual Report, vol. III, 1887-88, p. 119 B.

formed by the main axial range, when, being unable to pass this, it was deflected northwestward in a stream from 1,500 to 2,000 feet deep down the valley of the Mackenzie and thence out to sea.”*

A partial measure of the thickness of the ice-sheet on British Columbia is furnished by the elevation on the sides of mountains to which it has spread its deposits of till. These accumulations of glacial drift are noted in many places by Dr. Dawson, who however refers them to lacustrine or marine action. They reach upward to an approximately horizontal limit or terrace 1,000 to 2,500 feet or more above the general level of the country, and to heights from 3,500 feet to more than 5,000 feet above the sea. In some places their upper margin may form a true terminal moraine, marking the boundary of the ice at its maximum thickness or at some stage of pause or readvance during its final melting. Elsewhere it is probably determined by the general upper limit to which englacial drift was carried in the ice in sufficient amount to produce by its deposition a well defined sheet of subglacial till or ground moraine. The material of the higher terraces, according to Dawson, is “identical in character with that of the general covering of boulder-clay, or so closely alike as to be indistinguishable from it.”†

During the departure of the ice-sheet, its melting was due to the influence of sunshine and rains, the latter being doubtless brought then as now by great storms sweeping across the continent in an eastward and northeastward course. In consequence the borders of the ice-sheet appear to have been pushed back generally in the same northeastward direction. Along the valley of the St. Lawrence, the glacial current, which had before passed southeastward transversely across it to the coast of New England, was during this recession of the border of the ice-sheet deflected toward the southwest, conforming to the law that the glacial motion near the edge of the ice turned perpendicularly toward its boundary.

In the latest stages of the waning ice-sheet it probably became divided into three remnants, one covering northern British Columbia and contiguous portions of the Northwest Territory and Alaska; another occupying the region west, northwest and north of Hudson's bay, stretching northward to the large islands of the Arctic ocean; and a third covering Labrador and the country north of the St. Lawrence. From the second of these areas, glacial currents moved south-southwestwardly across the Churchill river and Reindeer and Athabasca lakes, partly obliterating the earlier westward striæ, and southeastwardly across Marble island in the northwestern part of Hudson's bay. Possibly the recession and final melting of the continental ice-sheet caused it to extend over lands within the Arctic circle which had not been covered by the ice when it reached farthest south. From the melting of

* Bull. Geol. Soc. Am., vol. 1, p. 543.

† Geol. and Nat. Hist. Survey of Canada, Annual Report, vol. III, 1887-88, pp. 89, 91, 96, 119, 172 B; Trans. Roy. Soc. Canada, vol. VIII, sec. IV, p. 36.

its last remnants, moisture-laden winds doubtless carried portions of it across Baffin's bay and Davis strait to be deposited again in the ice-sheet that still covers the interior of Greenland.

PROPORTION OF ENGLACIAL DRIFT SUPPLIED TO THE DELTAS OF GLACIAL LAKES.

Osars, kames, and terminal moraines, the comparatively loose upper part of the till, and the beds of gravel, sand and clay which form valley terraces and plains in drift-covered regions, appear to be derived from the englacial drift that had been gathered up into the ice-sheet from the surface over which it moved, especially from the sides of hills and mountains, being thence borne forward in the lower portion of the ice. My observations of the Côteau des Prairies at lakes Benton, Shaokatan, and Hendricks in south-western Minnesota,* and of the osar at Bird's Hill, Manitoba,† indicate that the amount of englacial drift contained in certain favored portions of the ice-sheet, as near its border where conspicuous moraines were being formed, or on tracts to which glacial currents converged, was equal to a general drift sheet 30 to 40 feet thick. During the departure of the ice, its englacial drift became superficial by the melting of its upper part, until, when only a thickness of a few hundred feet or less of the ice remained, its surface was covered by the drift which it had held; and such a condition probably extended many miles back from the margin of the ice-sheet during its entire retreat from the glaciated area. The latest glacial melting and the attendant rains therefore caused much of the englacial and finally superficial drift to be washed away by streams and deposited as stratified or modified drift, some of the coarsest portions being laid down in ice-walled channels as osars and kames, but far the greater part being borne beyond the ice-margin to form flood-plains of rivers and deltas of lakes or of the sea.

The "White silts" of British Columbia were doubtless in large part derived directly from the englacial drift of the Cordilleran portion of the ice-sheet; and the relationship of the topography to the recession of the ice determined for the various districts where these silts are developed whether their deposition was fluvial or lacustrine. And the direction of glacial drainage across water-sheds affords reliable information of the course of retreat of the ice-border on the same areas. For example, the old river-bed described by Dawson as descending to the southward and westward between Dease lake, tributary by the Liard and Mackenzie to the Arctic ocean, and the Tanzilla river, tributary by the Stikine to the Pacific, proves that the ice-border there retreated northeastward.‡

* *Geology of Minnesota*, vol. I, 1884, pp. 603-4.

† *Geol. and Nat. Hist. Survey of Canada, Annual Report*, vol. IV, 1888-89, pp. 38-40 E.

‡ *Geol. and Nat. Hist. Survey of Canada, Annual Report*, vol. III, 1887-88, p. 69 B.

The deltas of Lake Agassiz show that extensive contributions of silt were received in that lake from the englacial drift of the retreating ice both on the east and west; and these deposits agree with the terminal moraines of that region in indicating that against this great glacial lake the ice was melted back faster than on the adjoining land areas. On the eastern side of Lake Agassiz only the Buffalo and Sand Hill rivers brought in noteworthy deltas, but several other tributaries from the east are at the present time larger than these. No topographic or other now existing causes for this difference are discoverable; and we are left to the inference that, during the vicissitudes of the glacial recession, exceptionally large rivers poured down from the ice-surface, laden with its drift, to these deltas. Similar conditions seem also to have been largely efficient to produce the three great deltas which I have examined on the western side of Lake Agassiz, namely, the Sheyenne and Pembina deltas in North Dakota and that of the Assiniboine in Manitoba. Each of these demonstrably contains much tribute of modified drift, that is, of drift brought directly from the ice by the rivulets, brooks, and rivers formed in its melting. But this could not have taken place, if a considerable embayment in the ice-front had not been made by its more rapid melting where it was washed by the glacial lake. In like manner, the portions of the ice-border washed by the sea in the Gulf of St. Lawrence and in Hudson strait and Hudson's bay were undoubtedly melted back exceptionally fast during the departure of the ice-sheet. At the last, indeed, the ice probably became divided into Arctic and Labrador areas on opposite sides of Hudson's bay.

In closing this essay, we may profitably notice the Assiniboine delta of Lake Agassiz and attempt to estimate its proportion of modified drift as distinguished from the alluvium of ordinary river erosion. This remarkable delta of gravel and sand covers an area of about 2,000 square miles and has an estimated average depth of at least fifty feet. Its volume therefore is about twenty cubic miles, which exceeds the combined capacity of the Qu'Appelle valley, which was the outlet of the glacial Lake Saskatchewan, and the Assiniboine valley from the mouth of the Qu'Appelle to this delta. Each of these valleys has an average width of about one mile, and their depth probably averages 250 feet along their extent of about 350 miles, being eroded in drift and the underlying soft Fort Pierre shales. This was doubtless a preglacial and interglacial water-course, which became partly filled with drift in each of the principal epochs of glaciation. Much of the erosion of the upper Qu'Appelle valley during the departure of the last ice-sheet was effected by its glacial river while it emptied into the Lake Souris; and probably the lower valley and that of the Assiniboine were only filled on the average to the extent of a third or half of their depth by the drift of

the last glacial epoch. The erosion of the valley therefore must have fallen far short of supplying the material of the Assiniboine delta, not to mention the fine silt and clay which were carried into the lake beyond the gravel and sand delta and may be of equal volume. Probably at least half of these lacustrine deposits were modified drift brought down by streams from the melting ice-sheet on the upper Assiniboine basin north of the mouth of the Qu'Appelle and swept forward by the strong current of the river until they could be deposited in Lake Agassiz.

DISCUSSION.

Dr. GEORGE M. DAWSON: It is unfortunate that the time at Mr. Upham's disposal has been so short that he has been able to present to the Society only the outlines of his paper, but even these are sufficient to show that he has been as diligent and untiring in this as in his former publications in the collection and collation of facts. Since many of the observations quoted by him are those made by myself, it is particularly interesting to me to note how these may be reërranged under hypotheses which differ in part from those which I have suggested; and I may be permitted, even at this late period of the meeting, to refer to one or two of the points upon which he has touched.

I infer from Mr. Upham's remarks that he now believes the southern and western limit of the area of the Great Plains affected by the second maximum of glaciation to have been coëxtensive, or nearly so, with that of the first maximum. This, I am pleased to find, nearly agrees with the view which I have been led to favor and have lately advanced, viz., that the area affected by the second glaciation was even greater than that of the first in the region in question. As Mr. Upham further adopts my definition of the Laurentide and Cordilleran centers of glaciation, the most important outstanding difference in our views, in so far as the western half of the continent is concerned, is that connected with the mode of glaciation of the Canadian Great Plains. If the bowlder-clay is to be explained as the bottom-moraine of a great ice-sheet, he must be right in carrying this ice-sheet as far as the bowlder-clay extends, or, in other words, practically to the western and southern limits of the drift-covered region. My own view, based on extended opportunities of observation in the actual region, is that the bowlder-clay, like the other drift deposits of at least the greater part of the plains, is of glacio-natant origin. There is also, I think, much to show that even if the Laurentide glacier did extend across the plains to the western limit of the drift, it did not there become confluent with the Cordilleran glacier, but reached that limit at a time when the latter was comparatively reduced, and overlapped the deposits of an earlier and wider Cordilleran glaciation.

Those valleys of southern Alberta which are adopted by Mr. Upham as former channels of glacial lakes have been examined and in some cases surveyed by me, and I have elsewhere discussed their origin, mentioning the explanation advocated by the author as a possible one. It is doubtful whether our present stock of information is sufficient to enable perfectly definite or final conclusions to be reached respecting them, as they are susceptible of various explanations. Referring to Mr. Upham's allusion to the

opinions expressed by Mr. Tyrrell, I believe I am right in stating that that gentleman has not advocated the existence of a driftless area along the base of the Rocky Mountains in Alberta, but rather that such eastern drift as occurs along a belt of country near the base of the mountains is to be explained as the deposit made in a lake or lakes held in there by the margin of a continental glacier.*

On the question of the meaning of the White silt formations of the British Columbian region, I need not, I think, say anything at the present time, as the general result of my examination of these deposits, with reference to the observations made over all parts of the area in which they are found, have lately been published. Nothing has since occurred to affect the general conclusions at that time provisionally arrived at, and I can scarcely accept Mr. Upham's strictly academic statement of his belief on the subject as weakening the force of such arguments as have grown up around the facts.

* Bull. Geol. Soc. Am., vol. 1, p. 401.