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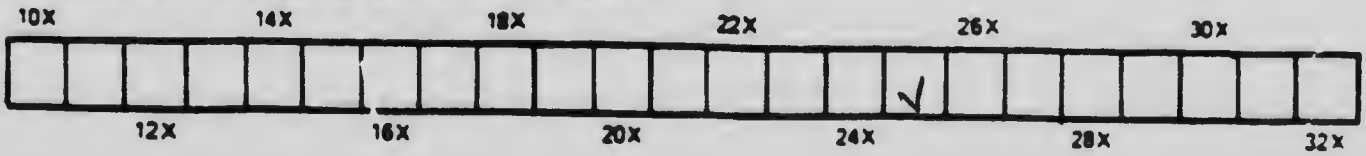

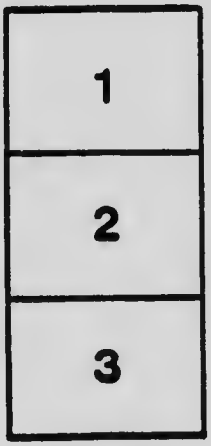

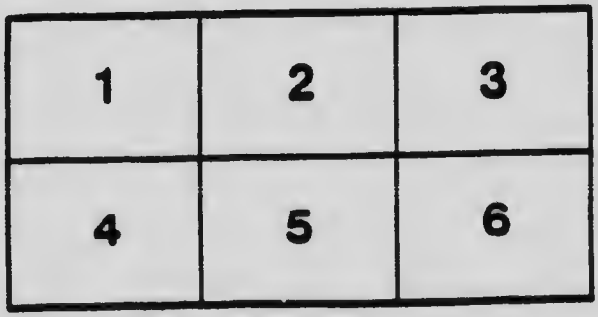

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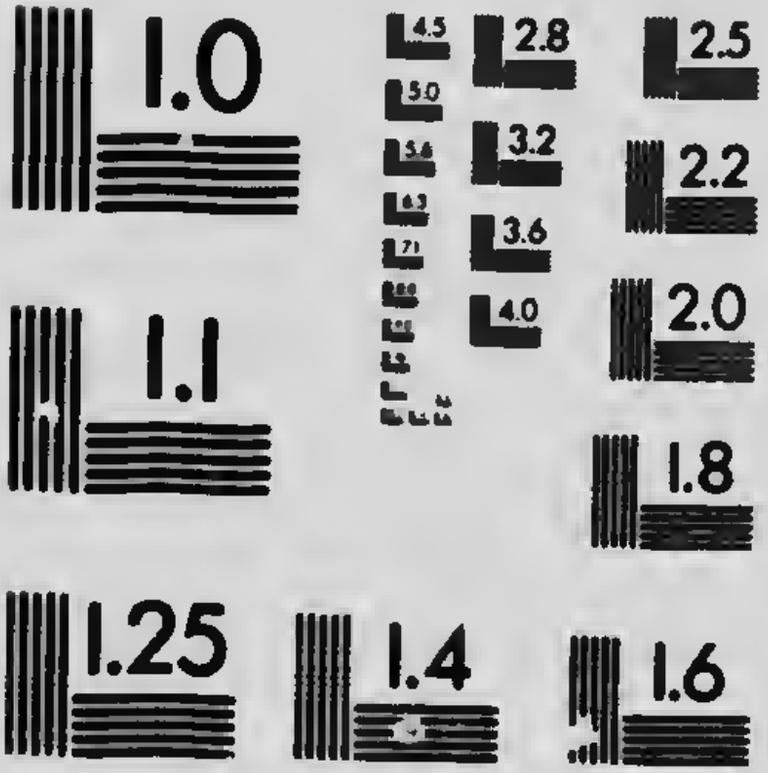

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The Moraine Systems of Southwestern Ontario

BY

FRANK B. TAYLOR.

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THE MORAINE SYSTEMS OF SOUTHWESTERN ONTARIO.*

By Frank B. Taylor.

Introductory.

At its maximum extent the front of the Wisconsin ice sheet reached nearly to Cincinnati, Ohio, and covered completely the whole province of Ontario. It is now well known that the movement of the ice sheet from its centres of growth in the North was due to the force of gravity acting upon a mass of ice so vast and piled up to so great a height that it had at all times a continuous surface slope descending from its centre to its edge. This surface slope was the fundamental condition of its movement. Its motion was a slow, semi-viscous, flowing movement in which the ice, like water, was always seeking a lower level. To a certain extent, but imperfectly, it obeyed the laws of hydrostatics. The fact that it filled the Great Lake basins, completely overflowed the highlands between them and even overtopped mountain peaks, like the Catskills, the Adirondacks and the White mountains, shows the enormous thickness which the ice must have had in Labrador in order to have had a descending surface slope that would pass over the tops of such mountains as Mt. Washington in the White mountains and Mt. Marcy in the Adirondacks. On the basis of such facts it has been estimated that at its maximum the ice at its centre in Labrador must have been at least 13,000 feet thick and may have attained a thickness of 15,000 or 20,000 feet. Fragments of Potsdam sandstone were carried from low levels near the north end of Lake Champlain to the tops of the Adirondacks. The possibility of the performance of such feats by the ice used to be strenuously denied. But knowing the nature of glacial movement and the enormous thickness of the ice, it is easy to see that detritus could be carried up hill to or over the top of any object—any hill or mountain—over which the ice mass was moving.

Since the ice was plastic and moved under the action of gravity, it was influenced largely by the topography of the land over which it moved. Thus, at its maximum the Wisconsin ice sheet reached nearly to Cincinnati, but in western New York reached only to Salamanca. But Salamanca is on the Alleghany plateau near its front and stands high above the lake basins to the north. The front of the plateau extends southwest along the south side of Lake Erie to the vicinity of Cleveland, Ohio. This great bulwark of the land guided the movement of the ice toward the southwest and caused it to overspread the lower plains of

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western Ohio and Indiana. The ice stream which flowed westward and southwestward through the basins of Lakes Ontario and Erie was one of the greatest currents of the ice sheet. The southwestern peninsula of Ontario lay between this stream and another like it which crossed Georgian Bay and moved southward through the basin of Lake Huron, turning toward the southwest to join with the Ontario-Erie stream in northwestern Ohio. The culminating point of the highlands forms the promontory or "mountain" west of Collingwood. This highland obstructed the flow of the ice and was overflowed by it for a relatively brief time, as compared with the lower lands around it. This is why ice lobes projected forward from the mean line of the ice front in the lake basins and re-entrants reached back from that line on the highlands. The larger elements of relief gave the ice front its lobate form.

THE MANNER OF THE GLACIAL RETREAT.

One of the peculiarities which characterised the retreat of the Wisconsin ice sheet was the oscillation of its front or edge. During the time of its general retreat its front did not retreat evenly nor at a uniform rate, but by alternating and recurring steps of advance and retreat, in which the backward steps were always longer than the forward steps. It was as though the retreating ice front underwent continual oscillations in which it took two steps backward and one forward over and over again, the result being that, on the whole, the front of the ice retreated in a northerly direction. These are known as the stadial oscillations of the ice front. Other oscillations subordinate to the stadial oscillations are known as minor oscillations.

The amplitude of the stadial oscillations, by which is meant the distance or space over which the ice front retreated and readvanced in each complete oscillation varied considerably under different conditions and has been determined with only approximate accuracy in a few cases. We know that in one instance at least the retreat was not less than 30 or 40 miles and may have been much more, and that even if the retreat was only 30 miles, the readvance was not less than 20 or 25 miles. This was on the "thumb" of Michigan, where the ice front had stood a little farther south than the Port Huron moraine, and its next step of retreat carried the front back northward from the "thumb" far enough to open a relatively wide passage between Saginaw Bay and the south part of Lake Huron. Just before this time the ice front rested at such an altitude on the "thumb" that the lake waters in the basin of Lake Erie were held up to an altitude about 80 feet higher, for the lake level fell this much in consequence of this step of retreat and the passage opened

around the north side of the "thumb" was wide enough to allow heavy storm waves to make strong beach ridges. Then when the ice readvanced it closed this passage and pushed up onto the "thumb" far enough to raise the lake waters about 45 feet. At the climax of this readvance the ice front rested for a relatively long time on nearly the same line and it was during this time that the Port Huron moraine was built. Not that the ice itself was stationary, for it was not. The ice was always moving slowly forward, but it was also melting. The melting of the ice always tended to drive the front back and it was only when the rate of melting exactly balanced the rate at which the ice advanced that the front became, as we say, stationary. At these times the ice front paused or halted, though the ice itself kept moving, and it was only during these times that terminal or marginal moraines were built. Whether the ice front at any given time or place retreated or advanced or stood in a stationary state depended upon the ratio between melting and the forward movement of the ice. If melting did not take place there was no loss of ice and the front advanced; if melting took place faster than the ice advanced, then more ice was lost in a given time than came forward and the front retreated.

Whenever the ice front halted a marginal deposit of some kind was made, for the ice nearly always carried in its lower layers more or less dirt or detritus gathered from the surface of the ground or of the rock over which it moved. This detritus comprised all grades of coarse and fine rocky materials, and they were mixed promiscuously together. Since a moraine of some kind was always made when the ice front halted for any length of time, we are compelled to believe that moraines were built at halts following movements of retreat as well as at those following movements of advance. But the moraines formed at climaxes of retreat were always overridden and obliterated at the next advance. From this fact it follows that the moraines which we see and study were made at successive climaxes of readvance during a general movement of retreat. This record of the glacial retreat furnishes by far the greater part of the material available for the study of the manner of glacial movements and for the study of the origin of the drift forms which make up the greater part of the surface. Southwestern Ontario is covered with a series of these terminal moraines all made at climaxes of readvance during the general recession. That some movements of retreat and advance covered more distance than others and were more important in their significance is not to be doubted, but only one or two distinctions of this kind have been made at the present time.

The outline of the ice front changed greatly with the progress of retreat. At first the whole region was covered and there were no lakes in

this part of Ontario. Then the Erie and Huron ice lobes became separated in the region northeast of London, though still united toward the southwest. Soon the two lobes parted and were sharply defined, until the ice had melted far back in each of the basins. Up to this time the ice in the basin of Lake Ontario had not become differentiated into a separate lobe, but was simply the basal part of the Erie lobe, and the same was true of the Georgian Bay-Lake Simcoe ice mass. But when it had retreated nearly to Buffalo the ice in the basin of Lake Ontario began to take shape as a sharply defined lobe. It not only ceased to occupy any part of the basin of Lake Erie, but it became sharply separated from the ice to the north of it in the basins of Lake Simcoe and the Trent valley, the line of division being along the high ridge of land—the Oak Ridges—north of Lake Ontario. By the shrinking of the Lake Huron lobe and its separation from the Lake Ontario lobe, the ice mass in the basins of Georgian Bay and Lake Simcoe and the Trent valley became a separate lobate mass. It was blunt in shape and less pronounced in its lobate form, but it took on a system of movements of its own which clearly make it a separate lobe in this stage of the retreat.

MAP SHOWING DISTRIBUTION OF MORAINES.

The accompanying map, in colours, shows the present state of knowledge concerning the terminal moraines of this part of Ontario. All the moraines represented, excepting the two small fragments shown northeast of Lake Simcoe, were studied and mapped by the writer. Parts of these beyond the border of the map were studied by the writer in 1907. The parts shown were mapped by W. A. Johnston of the Canadian Geological Survey and his assistants. Some of the moraines are shown extending across the border into Michigan and New York. These were also mapped by the writer, excepting parts of some of those east and south of Buffalo. Those in Michigan and New York are put upon the map in order to show the continuity of the individual moraines beyond the boundary, and especially in order to make more clear the symmetrical relations of the moraines to the lake basins. The area in Ontario is a large one, covering approximately 30,000 square miles, and the moraines shown are a part of the results of numerous field excursions beginning in the summer of 1893. The mapping is still far from complete; some of the moraines are known as yet only in fragments and the relations of some are not yet worked out. But enough has been done to show the system of the moraines and their relations to the several ice lobes. Some parts of the region have not yet been studied and the completion of the mapping awaits the exploration of those parts. The map-

ping done is also quite uneven in degree of detail; in some parts, especially the northwest, the work was mainly of the nature of reconnaissance and was done early in the studies. Other parts, as the moraines on the Niagara peninsula, those along the escarpment southward from Collingwood, and those north of London and north of Toronto were studied in much more detail. This was the natural result of work carried on through many years on an independent basis. Since 1908 the work has been done under the direction of the Director of the Geological Survey of Canada.

THE UNCOVERING OF "ONTARIO ISLAND".

One of the results of the influence of topography upon the movements of the ice was the formation of what may be called "Ontario Island". At its maximum the ice was probably not less than 2,000 or 3,000 feet deep over the region around Dundalk on the top of the highland south of Collingwood. But as the ice melted off, this covering grew thinner, until at last it became so thin that it ceased to move. Streams melted out tunnels and canyons in it and reached down into the dirty basal layers of the ice. From these the streams gathered gravel and sand, and where they filled the tunnels and canyons with this material they made eskers, like the magnificent ones which extend southeast from Flesherton and Mount Forest, or, where they dumped their load in an expanded cavity or recess in the ice they made kames, as in the great hills of gravel and sand northeast of Stratford and north of Barrie. But soon this thin ice covering melted off and a large area extending northeast from London was freed of ice, but was still surrounded by ice on every side.

During the warm season each year the ice sheet was affected by melting, not alone along its edge, but over a marginal belt several hundreds of miles wide. It is to be remembered also that great ice streams like those which flowed past this island are always hundreds of feet higher along the line of their central axes than at their sides. On this account, an extensive high obstruction in the path of the ice sheet, but over which the ice moved, always caused a depression in the surface of the ice sheet, and where the obstruction was so great as the highland between Lake Ontario and Lake Huron, it formed a correspondingly large depression. The surface of the ice sheet for 50 to 100 miles all around sloped toward this depression, and all the water from the melting on these slopes flowed into it. It is manifest that there was no chance for an outlet for this water anywhere north of London. But along a

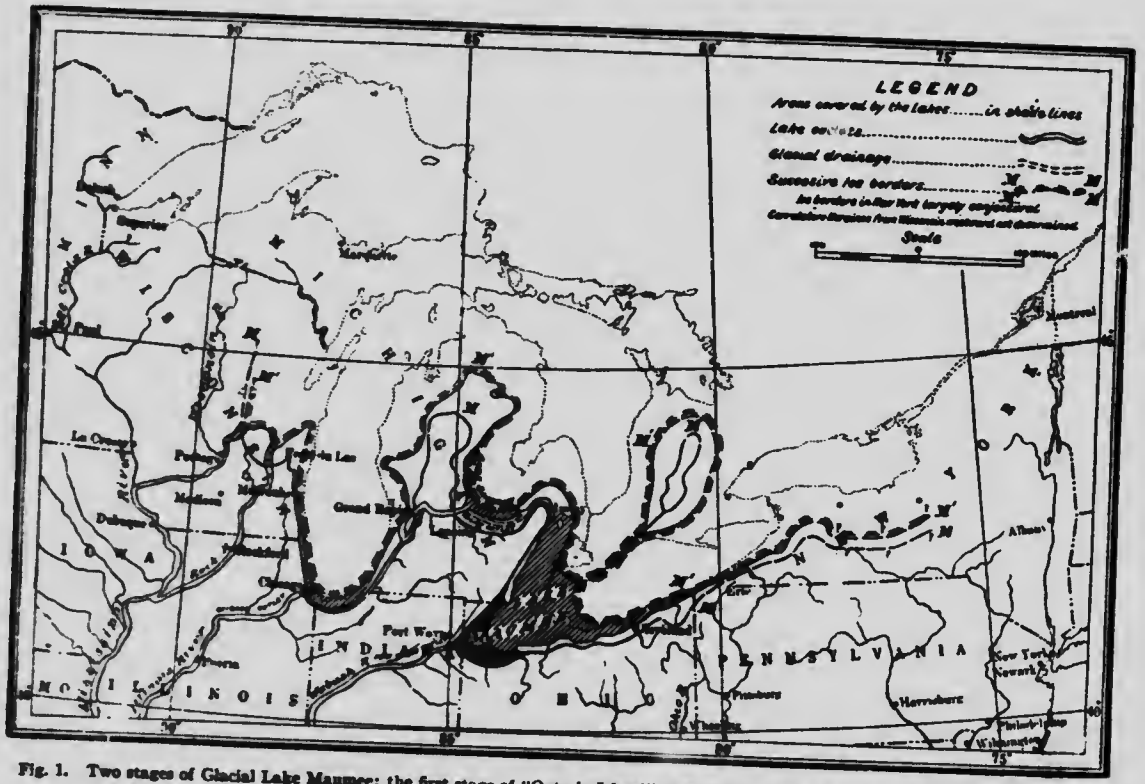


Fig. 1. Two stages of Glacial Lake Maumee: the first stage of "Ontario Island" is marked M, and a later stage M'; both stages entirely surrounded by ice.

line running southwest from London the ice of the Huron and Erie lobes met head on. This produced a dead line in the ice and a trough or crease in its surface. This crease led southwest from London to the edge of the ice sheet and was the only possible way of escape for the water that flowed into the depression of "Ontario Island". Judged by its hydrographic basin, that river, which we may call the "Crease River", should have been a river of large size. It was the glacial precursor of the modern Thames River.

There are several interesting facts bearing upon the existence of this glacial river beyond the boundaries of Ontario. The details cannot be given here, but it may be said that a great river issued from the ice sheet in central Indiana at and for some time after the maximum of the ice. This river came abruptly from the ice and carried no sediment. Remembering that the depression in the surface of the ice sheet existed over "Ontario Island" before the island itself was uncovered, it is evident that the "Crease River" at that stage encountered no dirty ice and gathered no sediment. It issued at the ice front as clear water. When the ice front had retreated to a position marked by a moraine which passes through Defiance, Ohio, a river issued from the ice which brought an immense quantity of sand, enough to cover the greater part of Fulton county, Ohio. No earlier deposit of this kind is known, and it is believed that the deposit mentioned marks that time when the Crease River first encountered dirty ice; that is, when the kames northeast of Stratford were made, which was just before the uncovering of "Ontario Island". At this time there was probably a continuous narrow trough and a gradual descent from Stratford to Fulton county, Ohio. A little later, when the island was first uncovered, its surface near London was probably covered by a shallow, temporary lake which stopped the escape of sediment, and the ice lobes soon after pulled apart so as to let the water of glacial Lake Maumee nearly up to London, and then the gravels were deposited in it, as may be seen in the great gravel beds near Komoka, a few miles west of London. Curiously enough, in the uncovering of "Ontario Island" the first part to appear above the ice was not the highest part of the highland, which is located not far from the village of Dundalk, but was a long, flat area extending from the city of London at least 60 or 70 miles toward the northeast with a width of 10 to 20 miles. This area formed a low-lying flat island in the midst of the ice field and was more than 100 miles from the nearest part of the mainland.

With continued recession of the ice, the front drew back on all sides enlarging the area of the island. But the separation of the two lobes did not increase the land surface southwest of London, because glacial

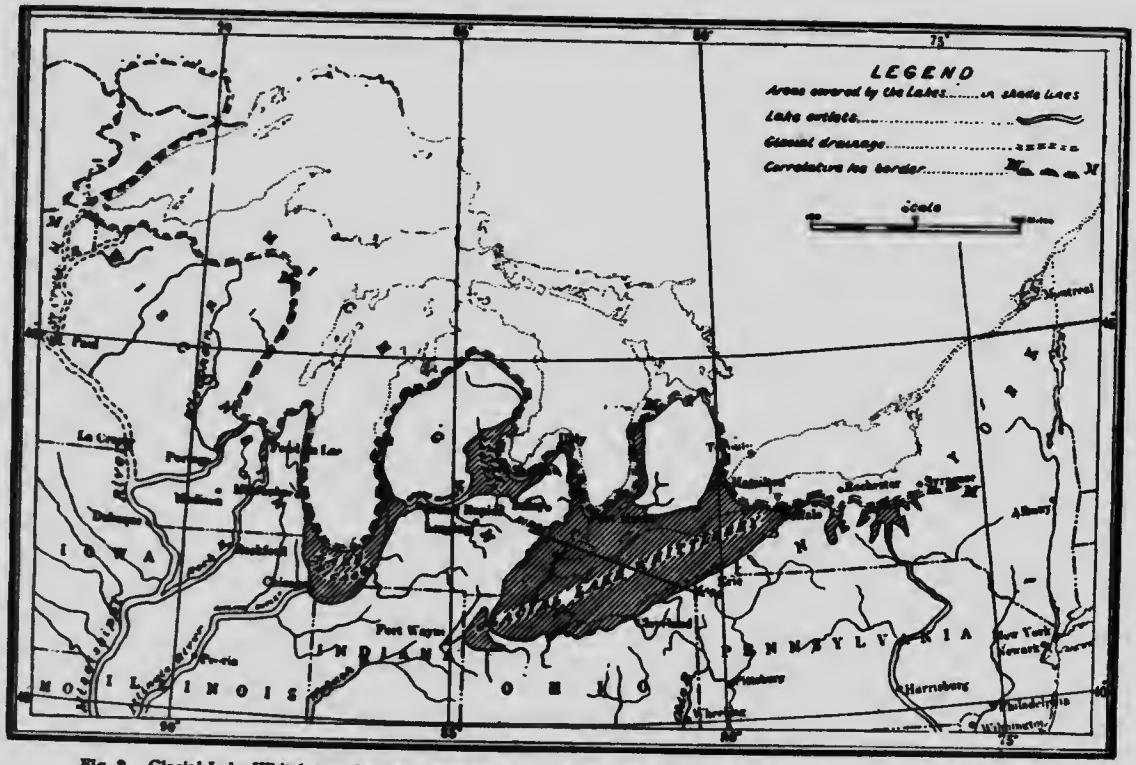


Fig. 2. Glacial Lake Whittlesey, showing a later stage of "Ontario Island" in which the ice barrier formed less than half of its boundary.

lake waters occupied the area as soon as the ice withdrew. This left the island still bounded by ice on all sides, excepting a small part at the southwest end which had a shore of lake water instead of ice.

In a general way, this condition continued for a relatively long time. The central part of the peninsula was still an island in the true sense, until late in the glacial recession. After a time, however, it came to have a longer shore of water than of ice, but it did not expand so as to be separated from the adjacent mainland only by the narrow waterways of the St. Clair, Detroit and Niagara rivers until quite late in the glacial recession. As the ice front withdrew the island expanded both by the melting back of the ice and by the falling of the lake waters to lower levels. The progress of this expansion will be noted below as the successive steps of retreat marked by the moraines are described.

On the accompanying map most of the moraines have been given names, generally the names of towns through or near which they pass. Fragments are also named, where they are of any length. The names are applied merely as a matter of convenience in description, and while those of the longer moraines may perhaps stand permanently, the names of some of the fragments will probably be only temporary, for future studies in the field will no doubt show that they are not independent moraines, but are parts of one individual. In such cases the names will have to be revised at some later time.

MORAINES OF THE LAKE HURON ICE LOBE.

The moraines formed along the east side of the Lake Huron ice lobe have not been fully investigated, especially in the flat, low region southwest of London, where they become faint, waterlaid forms, but nine or ten moraines belonging to this group have been mapped.

1. *The Essex Moraine.*—This moraine, known as the Detroit moraine in Michigan, extends from Detroit southeastward through Essex to the high knoll west of Leamington. Its relation to the ice lobes has not yet been clearly worked out. In Michigan its descent down the slope from Birmingham to Detroit transverse to the valley axis suggested an interlobate origin, but the part in Ontario seems more like a moraine of the Lake Huron ice lobe. If it was interlobate in origin it was subglacial, but if it was a simple, terminal deposit it was laid down in about 200 feet of water. This moraine is a low, broad ridge of till, very smooth and with such gentle side slopes as to be quite inconspicuous to the eye as a ridge. It has, nevertheless, a relief above the flat lake plains around it of 12 to 15 feet. At present the relation of this moraine to the others farther north and belonging to the Lake Huron lobe is not known. The intervening area has not been studied.

Fig. 8. Glacial Lake Warren, showing a later enlargement of "Ontario Island", when the ice barrier formed only a small part of its boundary.

2. *The Milverton Moraine.*—This moraine runs on an irregular course north-northeast from London and has been followed to a point five miles northeast of Mount Forest. It is a slender, lightly built moraine, rather narrow but quite well defined, its relief being generally 20 to 30 feet, sometimes 50 feet. It was deposited on land and had a temporary glacial river flowing along its front for a considerable part of its length. This moraine marked the western boundary of "Ontario Island" in the first stage of its existence. The ice front probably retreated to a position a little farther west before readvancing to this moraine.

3. *The Mitchell Moraine.*—This is another moraine of the same slender type and strength and was formed at the next halt after the Milverton. Only a fragment of it is now known.

4. *The Lucan Moraine.*—This is a third moraine of the same slender type and was formed on a line only a little back of the Mitchell moraine. A fragment of the same length was traced and two or three smaller fragments farther north are believed to belong to it. The Milverton, Mitchell and Lucan moraines all grow faint towards the northeast where they pass up onto the higher part of the plateau. Their relations there have not been determined.

5. *The Seaforth Moraine.*—This moraine is somewhat stronger and more bulky than the three preceding it. It is generally slightly wider and higher than the others and the ice at the margin when it was being built was probably thicker than at the times of the earlier three, for this one appears to have been less sensitive to topography. A longer portion has been mapped but a gap remains north of Seaforth. Beyond this it is believed to find continuation in an equally strong moraine which passes through Clifford, Holstein and five miles east of Durham. Farther on it turns sharply to the east and passes through Ceylon and turns a sharp angle toward the southeast two miles west of Singhampton. The Seaforth moraine is strongly developed, especially toward the northeast from Mount Forest. It crosses the highest part of the highland south of Georgian Bay and some of its knolls may be the highest point of this part of Ontario, attaining an altitude of over 1,700 feet above sea level. The moraine itself is generally 50 to 80 feet higher than the plain in front of it and in some places reaches considerably more than 100 feet. It had a large river flowing along its front, beginning at the extreme northeast angle. South of Ceylon this stream had become quite large, and here and west of Mount Forest it filled a wide, shallow depression in front of the moraine with an extensive deposit of gravel and sand. South of Seaforth the same strong drainage line continues and its bed leads to the gravel deposits west of Komoka, to which this stream was probably the largest contributor.

These four moraines, not including the Essex, are all landlaid forms so far as mapped, but all become waterlaid in the old lake bed southwest of London. The same set of slender moraines occurs on the "thumb" and in the Saginaw valley in Michigan.

6. *The Clinton Moraine.*—As now known, this is a small fragment of moraine lying west and northwest of Clinton. It is strongly developed and stands high above the plain. It ends abruptly at the Bayfield river and farther south was overridden by the Wyoming moraine. It probably continues some distance northward, but has not been mapped.

7. *The Wyoming Moraine.*—This is one of the strongest moraines of the series and in its relations to the other moraines one of the most important. It is the continuation in Canada of the Port Huron moraine in Michigan. As was stated above, this moraine marks a readvance of the ice front after an exceptionally long step of retreat involving not only greater distance, but probably also a much greater time than for the average of the stadial oscillations. In Michigan and Wisconsin this moraine is distinctly out of accord with the moraines that preceded it. In Ontario its continuation in the Wyoming moraine stands in the same relation. The Clinton moraine is a fragment of an earlier moraine which has been overridden south of Bayfield river by the Wyoming moraine. On the "thumb" in Michigan the Port Huron moraine overrides the Arkona beaches in the valley of Black river northwest of Port Huron, and in Ontario, on the east limb of the same ice lobe, the same or Wyoming moraine overrides some parts of the same beaches between Arkona and Bayfield river. In both localities the Whittlesey beach is contemporary with this same moraine, but the Warren (Forest) beach is later and extends along the rear slope of the moraine.* About 7 miles west of Port Huron and 4 miles west of Wyoming this moraine becomes waterlaid and is low and inconspicuous in its relief. In this form it crosses the St. Clair river just north of St. Clair, Michigan, and Courtright, Ontario. Northeast of Wyoming to the Au Sable river it is stronger, but is wide and of rather low relief. Father north it presents a bold, high front to the east along the west sides of the Au Sable and Maitland valleys. Beyond this it is strong and exercises a pronounced control over the drainage, especially on the courses of the Maitland and Rocky Saugeen rivers. Between Whitechurch and Berkely it has not yet been mapped in detail, but was seen near Walkerton and Hanover in early reconnaissances. It is narrower, but quite definite and strong north-

*A brief account of the glacial lakes, including Lakes Maumee, Arkona, Whittlesey, Warren, etc., may be found in the report of the Smithsonian Institution for 1912. More detailed descriptions will appear in a monograph of the U. S. Geological Survey, now in press.

west and northeast of Flesherton where there was a sharp lobe projecting south, and it turns sharp angles northeast and east of Gibraltar, the latter angle being located on the edge of the escarpment. A large river flowed southwest along its front and it was this stream that deposited around Flesherton the well known "Artemesia gravels" of Bell and other early writers. This stream entered an arm of glacial Lake Whittlesey west of Clinton.

8. *The Goderich Moraine.*—This moraine first appears on the top of the bluff south of Goderich and runs northeast to the brow of the promontory west of Collingwood. It is a strongly developed moraine and has much influence on the stream courses. It shows a sharper pointed lobe north of Flesherton and turns a sharp angle in two strands at Banks, on the top of the promontory.

9. *The Kincardine Moraine Strands.*—Near Kincardine five rather slender moraine ridges terminate on the bluff. They seem like deployed minor strands of a single moraine, but they have not yet been followed inland.

10. *The Port Elgin Moraine.*—This moraine begins on the bluff about 10 miles south of Port Elgin and runs northeast to Hepworth, where it turns towards the southeast around the valley of Owen Sound. It is a strong moraine and the north part is very bouldery. A small fragment probably belonging to this moraine lies three miles east of Owen Sound.

THE MORAINES OF THE LAKE ERIE ICE LOBE.

The possible relations of the Essex moraine have already been mentioned. The remainder of the moraines of the Erie lobe have not been much studied, excepting the last two in the eastern part of the basin.

1. *The Kingsville Bowlder Belt.*—A well marked boulder belt, with occasional very low, stony knolls of till, runs west through Kingsville and Harrow from the hill west of Leamington. It probably marks the course of a waterlaid moraine, but has not been fully worked out.

2. *The Blenheim Moraine.*—A well defined moraine passes just south of Taylor and Ridgetown and through Blenheim. Six miles southwest of Blenheim it is cut off abruptly at the lake shore, and from this point to Port Alma, a distance of about 10 miles, appears to have been entirely cut away by the modern lake. Running west from Port Alma and curving southwest to the knoll west of Leamington there is a low, flat ridge, hardly visible as a ridge, which seems to be its westward continuation. It is perhaps doubtful as yet whether this moraine may not be of inter-

lobate origin. Northeast of Blenheim it has a relief of 20 to 30 feet and is well defined. It passes to the north of the Michigan Central Railway a few miles east of Taylor.

3. *The St. Thomas Moraine.*—Another well defined moraine passes just south of Dutton and runs northeast through St. Thomas. To this point the moraines of the Erie lobe are all waterlaid, but a part of this moraine is probably landlaid.

4. *The Ingersoll Moraine.*—This moraine runs east from London along the south side of the Thames River and is in some parts a strong landlaid form. Small fragments of other moraines north and south of this one have been observed, but not yet traced any distance. The Ingersoll moraine is probably continued in the high ridge at Mount Elgin, six miles northwest of Tillsonburg.

5. *The Tillsonburg Moraine.*—This is a strong, high landlaid moraine, but only a small fragment of it is as yet known.

6. *The Waterloo Moraine.*—This is a finely formed moraine ridge running south from Waterloo to Ayr and west to Bamberg, but it has not been traced farther. It is higher and more bulky than the average.

7. *The Paris Moraine.*—This is one of the best known moraines in Ontario, having been traced with substantial continuity from the shore of Lake Erie southwest of Fort Rowan to the brow of the escarpment south of Collingwood, where it is found to be the same as the Seaforth moraine of the Lake Huron slope. At or near Paris this moraine becomes waterlaid toward the south and grows steadily lower and fainter toward Lake Erie. It is still a sharply defined ridge at Scotland, but is weaker at Vanessa and is quite faint east of Delhi. Farther south it is scarcely perceptible as a ridge, but exerts some control over minor drainage. North of Paris it is landlaid and is strongly developed.

Inasmuch as the Ontario and Georgian Bay-Simcoe lobes had not yet become differentiated, this moraine may as well be described as one of the Erie group through its entire extent up to the angle south of Collingwood. The Paris moraine is unusually high southwest of Galt and it continues from Galt northeastward in strong development to a point near Acton. At Paris and Galt it is 25 to 30 miles west of the Niagara escarpment, but at Galt it trends more to the east and at Acton is less than 10 miles back. From Acton to a point 6 or 7 miles north of Orangeville it holds a place a few miles back of the escarpment, but for a number of miles beyond it is on or very near the escarpment. It is in this position west of Glen Cross and Mono Centre, east of Primrose, at Whitfield, east of Honeywood and at Maple Valley. But from Maple Valley to the angle west of Singhampton it lies some distance back. While it is strong all along, this moraine is truly magnificent in its de-

Fig. 4. Front view of the Paris moraine near Guelph, looking east.

Fig. 5. A section of boulder clay or till, rather more stony than the average. The moraines are built chiefly of this material.

velopment from Orangeville to Singhampton. It is particularly fine east of Primrose and Honeywood, where it is over 100 feet in height. In both of these places it rises like a miniature mountain range, with steep, high front, and faces west over the nearly smooth plain of the highland which is a country entirely different from it in form and expression.

North of Credit Forks the course of this moraine is greatly influenced by the stream valleys that indent the escarpment. The ice barely overtopped the escarpment and gave full expression to these indentations in the sharp bends and angles of the moraine.

At this time there was, of course, a great gathering of water along the front of the ice and it formed a river of great size and increasing volume as it flowed away southward. Its headward parts have not all been worked out, but south of Orangeville its course is well marked, at first meandering among the drumlins of Erin and Eramosa. This stream flowed past the present sites of Guelph, Hespeler and Preston, and passing two or three miles west of Paris, emptied into one of the glacial lakes in the vicinity of Port Dover Junction. This Seaforth-Paris moraine furnishes the first complete ice boundary as yet established for "Ontario Island". At this stage the island had expanded to several times its original size, but was still bounded by ice along a line nearly eight times as long as the lake shore boundary across its south end. It was still nearly 100 miles to the nearest mainland.

8. *The Galt Moraine.*—This moraine is very closely linked with the Paris moraine. From Scotland, about 12 miles south of Paris, to Singhampton it is nowhere more than two or three miles back or east of the Paris moraine. This might be expected along the escarpment, where this moraine drops below its edge and vertical descent counted for as much or more than horizontal distance in retreat. But this relation continues from Credit Forks southward to Scotland where the moraines are 20 to 25 miles back of the escarpment.

The Galt moraine keeps its strength southward from Brantford to Simcoe and, indeed, is still a distinct ridge at Port Ryerse, where it is cut off at the lake shore. Between Galt and Eden Mills the two moraines are almost merged in one. From a point three miles southwest of Acton to Credit Forks the Galt moraine rests on the very edge of the escarpment and is quite fragmentary. Another moraine coming up from the south is set close behind the Galt moraine north of Credit Forks, and there are reasons for believing that this moraine overrides the Galt moraine at some point farther north. The studies of these lower moraines that skirt the escarpment is not yet complete, and w[illegible]mplete work seemed to show the Galt moraine extending to Gi[illegible]nd finding its continuation in the Wyoming-Port Huron moraine [illegible]ne Huron basin,

there are weighty reasons against this conclusion and which make it practically certain that it is not the Galt moraine but a later one that unites with the Wyoming moraine at Gibraltar. The reasons for this conclusion will be given in the discussion of the next moraine.

The moraines of the Lake Erie ice lobe described above have their correlatives on the south side of Lake Eri · a group of moraines which run along the face of the Alleghany escarpm. They have been mapped and described by Mr. Frank Leverett in U.S. Geological Survey Monograph XLI, 1902. Fragments of three moraines belonging to this series are shown on the map south of Buffalo—the Gowanda, Hamburg and Marilla moraines. These are probably correlatives of some of the moraines shown on the Canadian side, but their relations have not been fully determined.

The drainage associated with this moraine is even more remarkable than that related to the Paris moraine. Being below the escarpment most of the way from Singhampton to Credit Forks, the water was confined in a narrow valley. This valley was first aggraded or filled with gravel in several of its wider parts, only to be deeply trenched at a later stage by the same stream. The deep channel in the gravel filling east of Lavender illustrates this condition. East of Primrose and betwee Violet Hill and Mono Centre the same changes took place. One mil southeast of Granger the remains of a cataract about 75 feet high may be seen. During the first part of the time of this moraine the ice mounted too high on the salient of the escarpment east of Orangevil' to let the water past, so it kept to the old channel past Orangeville to Cataract and Credit Forks.

At Credit Forks the glacial river found a lower passage than the old channel by running close along the edge of the ice where the latter rested on the edge of the escarpment, thus flowing in a bed the east bank of which was the ice itself. In this relation the river ran to a point three miles south of Acton and the result is that the Galt moraine is almost entirely washed away in this interval and the old river bed for nine miles lies on the edge of the escarpment with no bank on its east side, but a steep descent of 200 feet or more to the Credit River. South of Eden Mills the Paris and Galt moraines are merged together forming high ground and leaving no passage for the river, which on this account cut a valley 100 feet deep westward through the Paris moraine, emerging at Eden Mills, where it re-entered the older channel. This it followed to Preston, where it found an opening back through the Paris moraine to Galt, and went thence southward in the narrow valley between the two moraines and emptied into one of the glacial lakes below Scotland.

Some of the details relating to the drainage associated with the ice front at the time of the Paris and Galt moraines are given, because they show with absolute clearness the impervious nature of the ice sheet, that it was in effect a solid geological formation which served the purpose of controlling the associated waters as effectively as would a formation of solid rock. If the waters were running rivers it controlled the rivers; if the waters were lake waters it was capable of serving as a dam to hold them up to the level of the lowest point on their rim. The same ice mass which formed the bank of the river along the escarpment from Credit Forks to Acton spanned Lake Erie 100 miles farther south and formed a solid dam which held up the lake waters in the basin of Lake Erie to the level of an outlet in Michigan which carried them to the Mississippi River and the Gulf of Mexico.

THE MORAINES OF THE ONTARIO ICE LOBE.

When the ice retreated from the Galt moraine it appears to have withdrawn to an unusual distance, just as it did in Michigan before the building of the Port Huron moraine. No certain evidence of terminal morainic deposits have been found in the relatively wide interval between the Galt moraine at Simcoe and Waterford on the west and the first of the slender moraines east of Grand River.

1. *The Crystal Beach Moraine.*—This moraine starts at the shore of Lake Erie just east of Crystal Beach and runs west through Sherks and in broken form westward a mile or two from the shore to Lot Banks. West of this it is lost, first in swamps and further on in extensive deposits of sand. But it reappears northeast of Cayuga and is fairly distinct northwestward to a morainic complex which it enters west of Ancaster. This moraine and, indeed, the whole group on the Niagara peninsula are of the faint, slender type. They are narrow and their relief is often not over 10 to 15 feet, sometimes less. It is this weakness of development that makes them so hard to follow and so easily obscured or lost in sandy or swampy regions.

This moraine finds its continuation in New York in the Alden moraine which leaves the shore near West Seneca, south of Buffalo. At Alden, 20 miles east of Buffalo, it overrides the Arkona beach ridges in precisely the same way as the Port Huron moraine overrides them on the "thumb" in Michigan and as the Wyoming moraine overrides them in the Au Sable valley, south of Clinton, Ontario. This fact leaves no room for doubt that the Alden-Crystal Beach moraine of the Ontario ice lobe is the same as the Port Huron-Wyoming moraine of the Huron ice lobe. Not only is this moraine east

of Buffalo related in the same way as the Port Huron-Wyoming moraine to the Arkona beaches, but it is also related to the Whittlesey and Warren beaches in the same way as is the moraine in the Lake Huron basin. Thus, while the Wyoming moraine clearly extends up to Gibraltar on the highland, it is not continued southward along the escarpment in the Galt moraine, but in the Crystal Beach moraine, or in a bulkier moraine made up of a union of two or three of the slender moraines on the Niagara peninsula. Such a moraine extends from Copetown northward back of the escarpment nearly to Limehouse.

2. *The Fort Erie Moraine.*—This is the next of the slender group on the Niagara peninsula. It begins at Fort Erie, where it is well defined, and extends with one or two weak intervals past Welland to Binbrook, Glanford to the complex at Ancaster. It has the same weak development and in the middle part of the peninsula is extremely faint. It continues eastward in New York as the Buffalo moraine.

3. *The Niagara Falls Moraine.*—This moraine is extremely faint east of Chippawa, but to Niagara Falls and westward is distinct and fairly strong. It keeps its strength quite well westward past St. Ann, Smithville and Elfrida to Ancaster. Niagara River has cut deep embayments into it on the west side of the river at the Falls. This moraine is continued in New York in the Tonawanda moraine.

4. *The Vinemount Moraine.*—This moraine lies on the top of the escarpment and close to its edge throughout its whole course from the Brock monument above Queenston to Hamilton, and excepting in two or three short intervals is quite sharply defined with a relief of 15 to 35 or 40 feet. It is narrow and not bulky, but is clearly defined. Between St. David's station on the Grand Trunk Railway and Camden and again from Mount Albion west it sets back one or two miles from the escarpment, but elsewhere is much closer, generally less than half-a-mile back. This moraine is continued in New York in the Barre moraine, which continues on the brow of the escarpment to Lockport.

A later moraine, called the Albion moraine in New York, has not been surely identified west of Niagara River. A few knolls were found along the face or base of the escarpment that may belong to it, the most prominent ones lying between Bartonville and Stoney Creek.

All of these moraines are substantially horizontal in their courses across the Niagara peninsula, but they rise a little toward Ancaster. West of Ancaster the first three or four appear to combine into a single more bulky ridge and this, after making a sharp turn to the north around Copetown, runs northeast and north back of the escarpment to Lime-

Fig. 6. Rolling topography on the top of a strong, landlaid moraine.

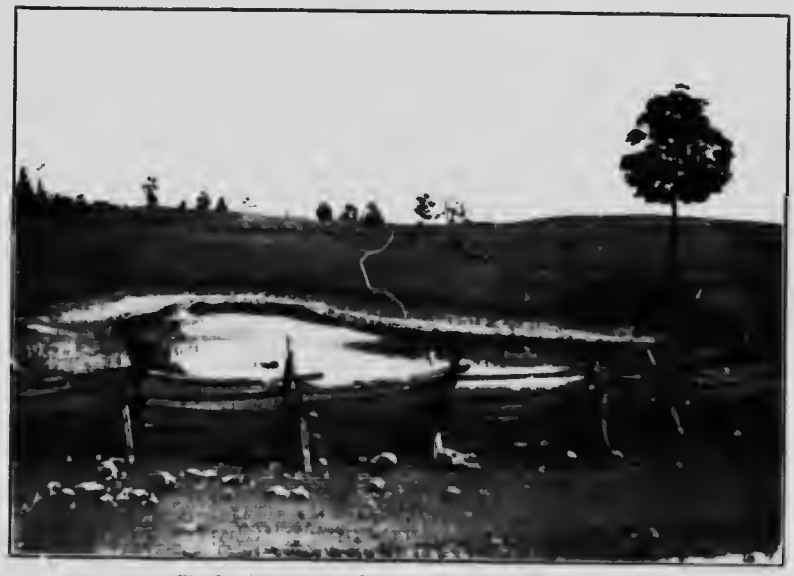


Fig. 7. A pond in the Paris moraine west of Cheltenham.

house. It seems probable that somewhere in this interval this moraine will be found to override the Arkona beaches just as at Alden, N.Y., and in the Lake Huron basin, but the critical ground has not yet been studied.

Northward from Copetown to the angle on the highland west of Collingwood the Crystal Beach moraine and whatever others are combined with it pass through a rough country, in part of which drainage along the edge of the ice prevented the building of moraines, while in the northern part the ice front rested against the steep face of the escarpment, a very unfavourable place for the deposition of terminal moraines and where such small, faint fragments as were deposited are exceedingly hard to identify. The course of the Crystal Beach moraine through this difficult region has not been fully determined.

Along the front of the ice in this position there was a large glacial river flowing south close to its edge from near Limehouse to a point 5 or 6 miles north of Copetown, where it entered lake waters and deposited a considerable quantity of gravel and sand.

On the north side of Lake Ontario the moraines are fewer in number and no certain correlation having yet been established, they are given separate names. The moraines on this side, excepting those already described, above the base of the escarpment, all turn eastward and join with moraines made by ice coming from the north out of the basin of Georgian Bay, Lake Simcoe and the Trent valley.

1. *The Palgrave Moraine.*—This is a short fragment extending south and east from Palgrave, and was made by ice moving toward the northwest. It is a strongly developed ridge with a rough, hilly surface. South of Mono Road it is overlapped by a later moraine and 6 or 7 miles east of Palgrave it unites with a moraine made by the southward moving ice of the Lake Simcoe ice lobe. It laps around the south side of Mt. Wolfe, which is a small till plain standing 150 feet or more higher than the moraine. During the building of this moraine a large river coming from the northwest flowed south along its front.

2. *The Cheltenham Moraine.*—This moraine begins about three miles north of Georgetown and extends north along the east side of Credit River, but from Mono Road it keeps a northeastward course through Castlederg and beyond this turns east and unites with the moraine of the ice from the north two or three miles west of Eversley. Its south part is smooth and low and seems clearly waterlaid, and it is less rugged throughout than the Palgrave moraine. One or two small fragments between Georgetown and Limehouse may belong to this moraine, and it probably continues southward along the escarpment. During the time of this moraine there was a large river flowing south along the front of the Palgrave and Cheltenham moraines. This stream occupied the

strongly marked old river bed between Tottenham and Georgetown a deposited the gravels upon which the latter town is built. It was outlet of a temporary lake in the valley to the north. The lake w probably narrow, but extended a considerable distance to the nor for great delta terraces were built by the streams descending from t escarpment in quiet waters standing at the level of the head of this outl northeast of Palgrave.

3. *The Bolton Moraine.*—This moraine begins at the base of t escarpment west of Milton and extends in a gradual curve past Georg town and Bolton station and thence in more irregular form to King. is waterlaid and quite faint in most parts. In all probability it follow the escarpment south to the Dundas valley, where it continues in som one of the moraines of the Niagara peninsula.

4. *The Oak Ridges Moraine.*—Southeast of King the Bolton morain appears to unite with the higher landlaid deposit which extends t Maple and thence northeast past Bond Lake to the main high ridg which lies between Lake Ontario and the Trent valley. The deposit eastward from King and Maple are quite complex and their relation are not fully made out. The large, deep depressions or basins which li along its central axis suggest that it is an interlobate deposit, the south half made by the Lake Ontario lobe partly overlapping the north half made earlier by the Simcoe lobe. South and west of Bond Lake the deposit has rather smooth slopes, but near Maple and around Bond Lake and eastward it is very rugged. Eastward from Willcocks Lake the broad, high and hilly ridge forms one of the strongest moraines in Ontario. To the vicinity of Burketon Junction it was built mainly by ice moving north out of the Lake Ontario basin. This is clearly established, for along the whole south side of the deposit from King and Maple eastward the ground moraine slopes up imperceptibly into the terminal moraine without any deposit of sandy or gravelly outwash. On the other hand there are extensive outwash deposits along much of the north side, showing clearly that in this part the ice was facing north while the moraine was being built. Detailed studies have thus far been carried only about 5 miles east of the south end of Scugog Lake. Beyond that the general course of the ridge is well known, as shown upon the map, but the details remain to be studied.

5. *The Scarboro Moraine.*—This moraine begins at the base of the escarpment southwest of Ash and runs roughly parallel with the lake shore to Toronto. At Scarboro bluffs it rests on the edge of the high cliffs and is being cut away by the lake. From Scarboro it runs northeast in a nearly direct line to Claremont and thence eastward to a point 4 miles east of Columbus, which is as far as it has been studied. It is

Fig. 8. A distant view of the Scarboro moraine two miles northeast of Malvern, looking south. The houses are on the moraine ridge, which is faint and of low relief, because it was waterlaid.

Fig. 9. A great glacial drainage channel west of Acton, about half a mile wide and 100 feet deep.

waterlaid throughout and is generally weak and faint, especially so between Streetsville and Toronto and from Claremont east. In the city of Toronto its course as indicated by the parts east and west of the city would lie along the Waldron ridge, which is the bluff extending from west to east through the northern part of the city a little south of St. Clair Avenue. But in this part no certain evidence of the moraine was found. This may be due to the heavy cutting on this part of the shore of Lake Iroquois, for the bluff of Waldron ridge was made by that cutting, which removed a considerable body of drift that once extended south from where the bluff now is. West of Toronto the ice front at this time had three sharply pointed tongues or lobes corresponding to the valleys of the Credit, Etobicoke and Humber rivers. This, with the obstructing rôle played by the high ground at Scarboro bluffs, shows the sensitiveness of the ice to topography. From its altitude and general relations there is much reason to believe that the Scarboro moraine is the correlative or continuation of the Albion moraine in New York. East of Lockport the Albion moraine lies at the front of the escarpment. Very little that might belong to it has been found farther west, but the Scarboro moraine holds the same relation to the escarpment southwest of Ash and all the moraines on the Niagara peninsula are substantially horizontal from east to west.

The space interval between the Bolton and Scarboro moraines is unusually wide for the series of the slender moraines. At several places, especially south of Milton, faint evidences of a moraine were found in this interval, but they seemed too faint and uncertain to put upon the map.

Two or three miles northeast of Port Nelson there are low till knolls which appear to be part of a terminal moraine. They are very bouldery and give the impression of having been severely washed down during submergence, which is probably the case, for they lie below the Iroquois beach. It seems probable that this fragment finds its correlative in the Carlton moraine in New York.

MORAINES OF THE GEORGIAN BAY-LAKE SIMCOE ICE LOBE.

The moraines along the escarpment have been discussed in connection with the Erie and Ontario ice lobes, and besides these there are at present very few morainic deposits to be discussed in connection with this lobe.

1. *The Owen Sound Moraine.*—Small fragments of a moraine lower than the Port Elgin moraine were found on the slopes east and west of the city of Owen Sound. They are well defined and very bouldery.

2. *The Hope Bay Moraine.*—A slender, but sharply defined mor
was found not far from the shore at Hope Bay on the Saugeen penins

3. *The Linton Moraine.*—North of Palgrave there is a strong mora
which turns away to the northwest, but has not been followed in t
direction more than 15 miles, so that its relations toward the north h
not been determined. This same moraine, however, runs east arou
the north side of Mt. Wolfe and joins the Palgrave moraine. Fart
east Linton is on its summit and commands a magnificent view bo
north and south. This moraine is stronger and stands at a higher le
than the Palgrave moraine. One mile east of Linton a low gap throu
the moraine was probably the course of a large stream issuing from t
Simcoe lobe. There is a deposit of sand along the north or rear side
this moraine from Linton to and beyond the gap north of Willcocks Lak
This deposit is not regarded as outwash, but as the work of a strea
flowing westward between the ice and the moraine just before the fin
withdrawal of the ice. The gap at Willcocks Lake suggests a large strea
coming through the moraine and flowing west past King. This may hav
been the case just before the ice readvanced to the Bolton moraine, bu
when the ice stood at the Bolton moraine, it pressed against the hig
spur west of Nobleton, and this must have cut off the escape of th
waters toward the west. Eastward from Willcocks Lake to the vicinity
of High Point the great volume of outwash along the north side of the
moraine shows, as stated above, that the bulk of this ridge was built
by ice moving towards the north from the basin of Lake Ontario. This
is the Oak Ridges moraine described above. At the same time the front
of the Simcoe ice lobe must have been close by, for there seems to have
been strong drainage westward along the north side of the moraine from
a point east of Ballantrae.

4. *The Uxbridge Moraine.*—At a time probably a little earlier than
the Oak Ridges moraine the ice of the Trent valley pressed southward
and built a set of strong, sharply defined morainic ridges running east-
southeast one to three miles south of Uxbridge. The remarkable thing
about this moraine is that it is composed almost wholly, so far as seen,
of gravel. This gravel is not in the usual forms of glacial or
glacio-fluvial origin, but is cast into the typical form of a terminal moraine.
Evidently, the material which the ice gathered near by was almost wholly
gravel, probably outwash of slightly earlier date. There are several
strands of this gravelly moraine, all in parallel arrangement.

Between these ridges and extending west to a line running sou
west from Vivian a great body of gravelly and sandy outwash cov
the surface between the gravelly moraine ridges. Its depth varies, but

Fig. 10. A small drainage channel cutting through the Paris moraine east of Guelph, looking west.

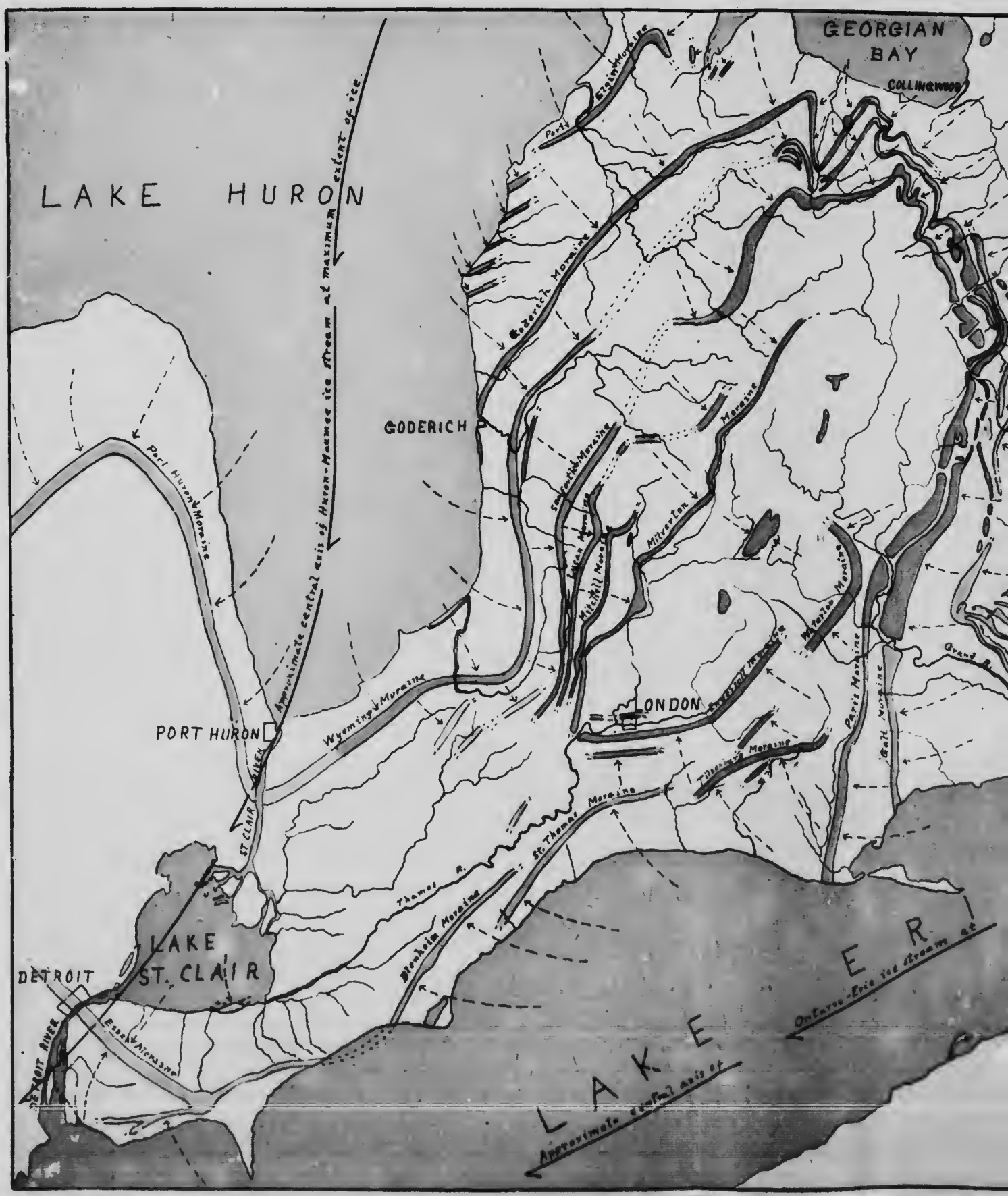
Fig. 11. Side view of a drumlin near Campbellville.

is in some places 100 feet or more. The regions farther north and northwest have not yet been studied and the relations of this moraine are not fully made out. Between Glen Major and High Point its ridges appear to be overridden obliquely by the Oak Ridges moraine.

CONCLUSION.

In this paper I have drawn attention almost exclusively to the terminal moraines of the Wisconsin ice sheet. There is older drift in large quantities in some parts of the area, notably at Toronto and north and east of the city. It also forms a deep deposit in the region west and southwest of Lake Simcoe and several exposures of it were found at and near Niagara Falls. The most famous beds, however, are here in the city of Toronto and have been studied and most interestingly described by Prof. A. P. Coleman of Toronto University. Another citizen of Toronto, Dr. J. B. Tyrrell, has also contributed much to our knowledge of the Ice Age by exploring the centres of glacial accumulation in the Far North. Many other phases of the drift deposits might have claimed part of our attention, such as drumlins, eskers, kames, old drainage lines, lake beaches, deltas, etc. But the chief object was to present some account of the system of terminal moraines, and the number to be mentioned and briefly described was so great that there has been no room for the consideration of other forms. Some of the old river channels, however, have been mentioned, because they help so greatly in the interpretation of the successive positions of the ice front, and reveal at the same time the great function of the solid ice mass, sometimes as a barrier controlling rivers and at others as a greater barrier holding up lakes of larger size than the Great Lakes of to-day.

The very fragmentary and incomplete nature of the observations and studies here presented is of course evident. But in presenting the results I have not tried to conceal the unfinished state of the investigations, but have sought rather to point out the unsolved problems in the belief that this course will do more to arouse the active interest of others, and especially of Canadian geologists, than the selection of some more complete and specialised phase of the subject. I have sought to do no more than present a general view of the moraine system of southwestern Ontario, as far as it is now known, and to give some hints on the bearing of this system upon the development of the surface features of this part of the Province.


LAKE HURON
GEORGIAN BAY
COLLINGWOOD
Port Elgin Moraine
Goderich Moraine
GODERICH
Maxinkuckee Moraine
Lucan Moraine
Mitchell Moraine
Milverton
Wentworth Moraine
Paris Moraine
Grand R.
Port Huron Moraine
Approximate central axis of Huron-Maumee ice stream at maximum extent of ice.
Wyoming Moraine
PORT HURON
LONDON
Tillsonburg Moraine
Gait Moraine
St. Clair River
St. Thomas Moraine
Thames R.
Glenhelm Moraine
LAKE ST. CLAIR
DETROIT
Detroit River
Essex Moraine
Ontario-Erie ice stream at
LAKE ERIE
Approximate central axis of

TRANS. OF CAN. INST.
VOL. X. MAP I.

This map shows the terminal moraines of southwestern Ontario, so far as they had been mapped in 1912. Those shown in the heavier color were laid down at the margin of the ice on land and are known as *landlaid* moraines; those in lighter color were laid down at the margin of the ice in water and are called *waterlaid* moraines. Sometimes the distinction is difficult to make, but waterlaid moraines are generally lower, smoother and weaker in their development than the landlaid form. The long arrows show the directions and axes of the greater ice streams when the ice was at its maximum extent; the smaller, broken-line arrows show the direction of movement of the ice towards the moraines at the margins of the lobes. The direction was generally normal to the trend of the terminal moraines or nearly so.