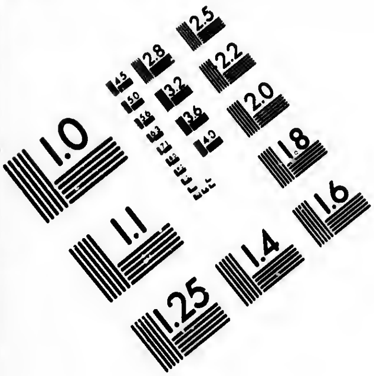


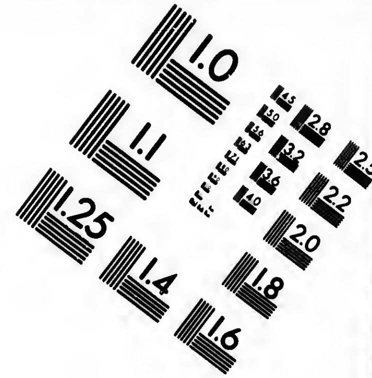
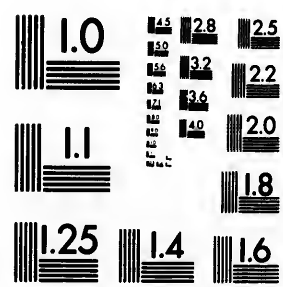
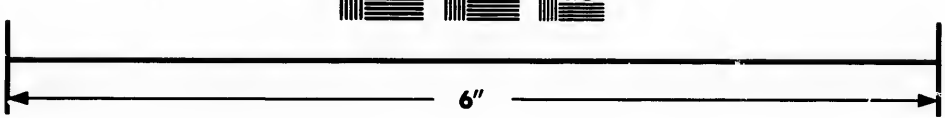
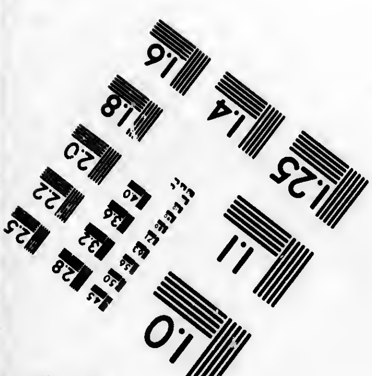
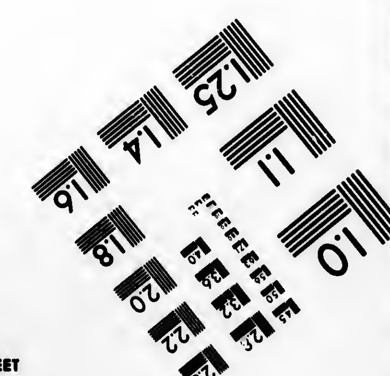


IMAGE EVALUATION
TEST TARGET (MT-3)









Technical and Bibliographic Notes/Notes techniques et bibliographiques

The Institute has attempted to obtain the best original copy available for filming. Features of this copy which may be bibliographically unique, which may alter any of the images in the reproduction, or which may significantly change the usual method of filming, are checked below.

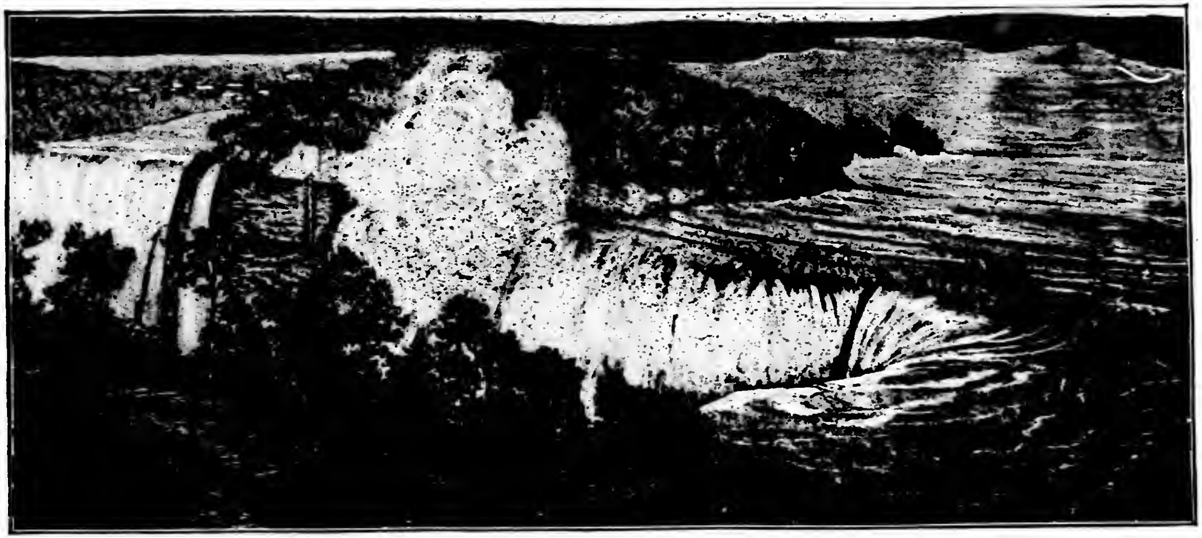
L'Institut a microfilmé le meilleur exemplaire qu'il lui a été possible de se procurer. Les détails de cet exemplaire qui sont peut-être uniques du point de vue bibliographique, qui peuvent modifier une image reproduite, ou qui peuvent exiger une modification dans la méthode normale de filmage sont indiqués ci-dessous.

- [ ] Coloured covers/ Couverture de couleur
- [ ] Covers damaged/ Couverture endommagée
- [ ] Covers restored and/or laminated/ Couverture restaurée et/ou pelliculée
- [ ] Cover title missing/ Le titre de couverture manque
- [ ] Coloured maps/ Cartes géographiques en couleur
- [ ] Coloured ink (i.e. other than blue or black)/ Encre de couleur (i.e. autre que bleue ou noire)
- [ ] Coloured plates and/or illustrations/ Planches et/ou illustrations en couleur
- [x] Bound with other material/ Relié avec d'autres documents
- [ ] Tight binding may cause shadows or distortion along interior margin/ La reliure serrée peut causer de l'ombre ou de la distortion le long de la marge intérieure
- [ ] Blank leaves added during restoration may appear within the text. Whenever possible, these have been omitted from filming/ Il se peut que certaines pages blanches ajoutées lors d'une restauration apparaissent dans le texte, mais, lorsque cela était possible, ces pages n'ont pas été filmées.
- [ ] Additional comments:/ Commentaires supplémentaires:

- [ ] Coloured pages/ Pages de couleur
- [ ] Pages damaged/ Pages endommagées
- [ ] Pages restored and/or laminated/ Pages restaurées et/ou pelliculées
- [x] Pages discoloured, stained or foxed/ Pages décolorées, tachetées ou piquées
- [ ] Pages detached/ Pages détachées
- [x] Showthrough/ Transparence
- [ ] Quality of print varies/ Qualité inégale de l'impression
- [ ] Includes supplementary material/ Comprend du matériel supplémentaire
- [ ] Only edition available/ Seule édition disponible
- [ ] Pages wholly or partially obscured by errata slips, tissues, etc., have been refilmed to ensure the best possible image/ Les pages totalement ou partiellement obscurcies par un feuillet d'errata, une pelure, etc., ont été filmées à nouveau de façon à obtenir la meilleure image possible.

This item is filmed at the reduction ratio checked below/
Ce document est filmé au taux de réduction indiqué ci-dessous.

10X 12X 14X 16X 18X 20X 22X ✓ 24X 26X 28X 30X 32X



FRONTISPIECE.

FROM A CAMERA OBSCURA DRAWING BY HENRY RANSFORD ESQ., OF ENGLAND, IN 1832. (THIS IS THE OLDEST ACCURATE PICTURE OF THE FALLS KNOWN TO THE AUTHOR.)

THE DURATION OF NIAGARA FALLS

AND THE

HISTORY OF THE GREAT LAKES.

1881-1894.

By J. W. SPENCER, A. M., Ph. D., F. G. S.

SECOND EDITION.

PUBLISHED BY

The Commissioners of the N. Y. State Reservation, at Niagara.

Albany, 1895.

PREFACE.

To the encouragement of Prof. J. P. Lesley, State Geologist of Pennsylvania, is largely due the author's interest in the investigations into the history of Niagara Falls and the Great Lakes, chapters of which have appeared from time to time in the leading scientific journals, the first of which was printed in the proceedings of the American Philosophical Society of Philadelphia, in 1881. Since that time more complete chapters have appeared. These have been compiled into their natural (although not appearing in their chronolgical) sequence owing to the profound interest taken in research by Andrew H. Green, Esq., the president of the Commissioners of the State Reservation at Niagara, and are here published in order to give a scientific history of the great cataract of the world, so that the information may extend beyond the limit of a few specialists. The full history of the lakes has not yet been told, but enough is known to write a somewhat complete story of the Falls. To Mr. F. B. Taylor is due a special acknowledgment, among other contributions, for having recently given us details of the drainage of the Huron basin by way of the Nipissing Straits and the Ottawa valley before the waters of the upper lakes changed their drainage to the Niagara river, and thus accelerated the recession of the Falls.

THE AUTHOR.

WASHINGTON, D. C., *December* 1, 1894.

PR

CH

CONTENTS.

ILLUSTRATIONS.

CHAPTER I.

The Evidence of Continental Elevation during the Formation of the Valleys of the Great Lakes.*

If, in the growth of the American continent, the moulding of the land features had not largely depended upon its projection above the sea, favoring or retarding the action of rains and rivers in sculpturing its surface, there would be little interest as to what was its relative height, before the commencement of the Pleistocene period. But we find valleys vastly greater than the meteoric agents could have produced under existing conditions Thus, there are not only deep cañons, but also vast depressions, descending to levels far below the sea, which are now filled with the earlier drift accumulations, or form channels submerged beneath ocean waves, or constitute basins occupied by lakes. Hence, in the study of the drift itself, in the investigation of the lake history, or in the research upon the growth of modern rivers, we necessarily inquire what was the altitude of the continent that would permit of the mouldings and channelings of the original rock surfaces.

Following the period of high continental elevation, the geologist sees in the valleys and old channels, still below the level of the sea, and in the high level beaches, extensive submergence, succeeded by a re-elevation, but not to the original height, when the continent was being chiseled out by the ancient rivers. That this re-elevation is still going on is shown by the northward tilting of the comparatively recent marine accumulations along the St. Lawrence valley and Gulf coast, and the raised beaches in the lake region, as well as by the shoaling of the waters of Hudson's Bay during the present period of observation.

As general statements do not satisfy investigation, it becomes necessary to search for definite measurements of the former height of the continent among the archives of the geological past. Let us first seek for the testimony recorded by the Mississippi river.

---

*Reprinted from Bull. Geol. Soc. Am vol. I, pp. 65-70, 1889, where the text appears under title of "The High Continental Elevation Preceding the Pleistocene Period."

For a distance of 1,100 miles, measured in a direct line, above the mouth of the "Father of Waters," the modern valley is merely maintaining its own size, or more generally is being slowly filled by the deposition of river alluvium upon its floor. There are only two exceptions, of a few miles each, where the river is scouring out the rocky floor, and these are over barriers recently exposed there during the changes of the Pleistocene period. To such an extent has the ancient valley or cañon been filled, first with drift, and this covered with river alluvium, that its original rocky floor is now buried to a depth of 170 feet, even at La Crosse, a thousand miles from the Gulf of Mexico.* Farther south the depth of these loose deposits increases, until at New Orleans a boring of 630† feet below sea level does not penetrate the southern drift, nor even reach to its lowest members. The lower 500 miles of the ancient Mississippi were excavated out of Eocene or Cretaceous deposits, while the valley above the mouth of the Ohio has the form of a cañon, excavated out of Paleozoic rocks, varying in width from ten to two or three miles, and having a depth (exclusive of the portion now filled) of from 150 to 550 feet, according to the late General G. K. Warren.

From this inspection of the river, it is easily seen that no natural rainfall could so increase the volume of the discharge as to remove all the deposits which now fill the old valley, much less excavate the original and immense cañon. A vastly greater elevation of the continent was necessary. Even were the whole continent uniformly elevated 630 feet, together with the remainder of the unknown depth of the ancient Mississippi river, at New Orleans, the cañon of the upper part of the river would require a still greater relative elevation of the northern country in order to give sufficient channeling power to the flowing waters; but the slope of the floor of the partially buried valley is much less than that of the modern, as was formerly shown by the author.‡ Here, again, is the proof that the country drained by the upper waters of the Mississippi once stood, relatively to that in the region of its mouth, much higher than at present. Of the amount, which was at least many hundreds of feet, we have no absolute measurement; nor can we ascertain it by calculation, for there is no register of the excess of the amount of rainfall during the epoch of the greatest sculpturing over that of the present day.

---

*Geol. Wis., Vol. I, 1883, p. 253.

†E. W. Hilgard, Am. Jour. Sc., 2nd Ser., Vol. XLVIII, 1869, p. 333

‡Am. Nat. Vol. XXI, 1887, pp. 168-71.

While these records of the Mississippi, which have been only partially deciphered, do not furnish all of the desired information, yet as far as they go they are invaluable.

Passing from the buried channel of the Mississippi to its continuation, now submerged beneath the waves of the Gulf of Mexico, we find evidence indicating such a stupendous continental elevation as to be almost incredible, were it not supported by collateral evidence, upon both the Pacific and Atlantic coasts. The soundings off the coast of the delta of the Mississippi indicate the outer margin of the continental plateau as submerged to a depth of 3,600 feet, indented by an embayment of another hundred fathoms in depth, at the head of which there is a valley a few miles wide, bounded by a plateau from 900 to 1,200 feet above its floor. This valley is now submerged to a depth of 3,000 feet, and is the representative of the channel of the ancient Mississippi river, towards which it heads.*

On the Pacific coast, in the region of Cape Mendocino, Prof. George Davidson has identified three valleys now submerged to from 2,400 to 3,120 feet, and several of inferior depth. These measurements are those of the valleys where they break through the marginal plateaus of the continent, at about six miles from the present shore, where it is submerged to the depth of 100 fathoms.†

The soundings along the Atlantic coast reveal similar deep fjords. The long-since known extension of the Hudson river, beneath the Atlantic waters, is traceable to the margin of the continental plateau, acquiring a depth of 2,844 feet, in front of which the soundings show a bar, covered with mud, which, however, is now submerged to the depth of only 1,230 feet. The unpublished soundings off the mouth of the Delaware river bring to light another valley, the floor of which is now covered by ocean waves to nearly 1,200 feet — its continuation seaward not having been ascertained. (Lindenkohl.)‡

Were the continent elevated only 600 feet, the Gulf of Maine would be replaced by a terrestrial plain, in some places 200 miles wide, but traversed by rivers, one of which, towards its mouth, would be 2,064 feet deep — that is to say, the bottom of the fjord is now submerged 2,664 feet. Even this great depth may not be its maximum, for along the line between the opposite banks, at the mouth, now beneath 100 fathoms of water (which is approximately the depth to which the real margin of the continent is submerged), we find that the sea is nearly

* J. W. Spencer, "The Mississippi River During the Great River Age," New Haven, 1884, p. 2.
† Geo. Davidson, Bull. Cal. Acad. Sc, vol. II, 1887, p. 265.
‡ Appendix 13, Rep. U. S. Coast and Geodetic Survey for 1887 (1889), pp. 270-73.

5,000 feet deep. Whether this represents an embayment of the ocean setting towards the valley or a continuation of the fjord is not determined.

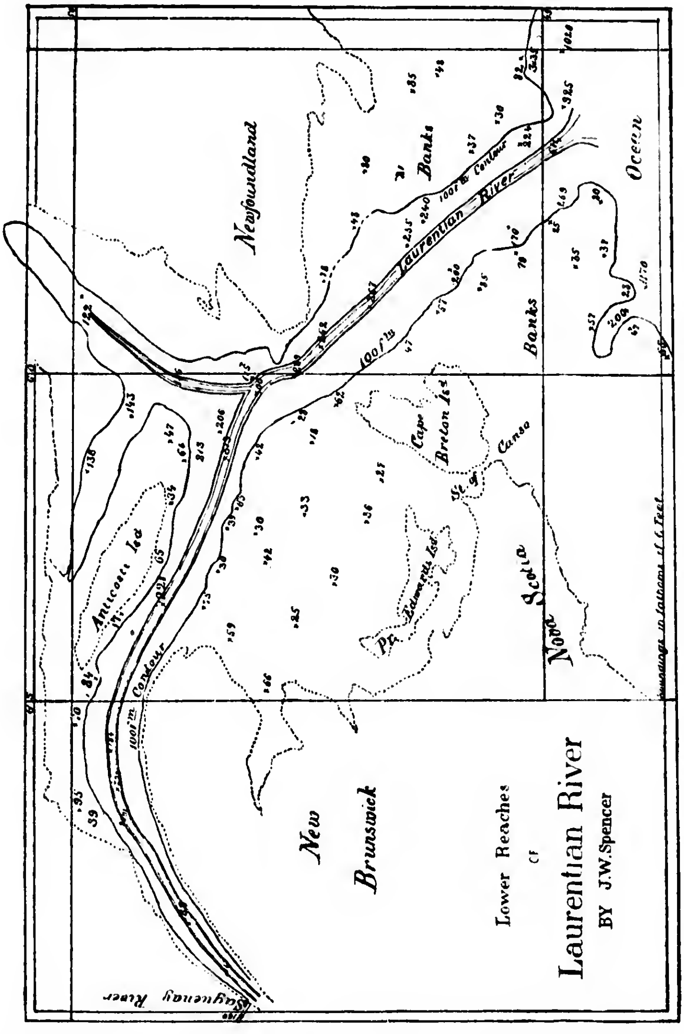


FIG. 1.—Map of the Gulf of St. Lawrence, Showing the course of an ancient river.

The St. Lawrence river and gulf bear the same testimony of the existence of deep fjords extending from the rivers through the now submerged plateau forming the margin of the continent; and the lower part of Saguenay river flows between stupendous walls and constitutes a fjord whose waters reach a depth of 840 feet. In the St. Lawrence river, a little below the mouth of the Saguenay, there is a channel 1,134 feet below the surface. This increases in depth in passing seaward. In the region of the centre of the modern gulf, the floor of the old channel is now submerged 1,878 feet, and the adjacent valley 1,230 feet; thus showing the cañon as being over 600 feet deeper. As at the mouth of the channel through the Gulf of Maine, so at the mouth of that of the St. Lawrence, there is a deep chasm; for inclosed between the banks, 100 fathoms below the surface, there is now the depth of 3,666 feet, with water 2,000 feet deeper just seaward of it. Although this ancient valley is over 60 miles wide at its mouth and was a narrow channel, yet it is not as broad as some portions of the modern so-called river. The breadth of the submerged valley throughout its windings for a length of 800 miles or more, is remarkably regular, only gradually increasing its magnitude in passing seaward. Other and smaller channels are visible in the soundings: thus, south of the Straits of Canso, between Nova Scotia and Cape Breton island, there is one 1,200 feet deep, according to the British admiralty charts, while adjacent soundings show less than 600 feet of water.

Hudson's Bay rarely exceeds a depth of 600 feet, yet at the outlet the channel is 1,200 feet deep. This depth increases in passing down the straits, where the scanty soundings show 2,040 feet before reaching the mouth. Here, in Hudson's Straits, the old valley is a chasm across a mountain system, whose peaks, upon the southern side rise to 6,000 feet above tide. The cañon of the St. Lawrence also crosses the trend of two mountain systems, but these are of no great height. The same is true for any of the other submarine valleys described.

The record of a former high continental elevation is again inscribed in the depths of the Great Lakes — Ontario reaching to 491 feet below ocean level, Superior to nearly as much, Michigan to 300, and Huron to 150 feet. The lake basins are merely closed up portions of the ancient St. Lawrence valley and its tributaries. Their distance from the sea would necessitate not merely a general elevation of the continent, but also a greater amount of elevation towards the head-waters of the system, as has been shown with regard to the excavation of the upper portion of the ancient Mississippi cañon. The lake basins are all excavated out of Paleozoic rocks, except a part of that of Lake Superior.

The soundings do not afford all the information that we desire, yet they demonstrate the presence of submarine valleys reaching upon all our coasts to depths of 3,000 feet or more. Again, the soundings show that within comparatively short distances from their mouths the depth of the valleys, below the surface of the seas, sometimes did not exceed from 1,200 to 1,800 feet, but that beyond, there was a greater increase in depth, within the last few leagues.

While depressions in the earth's surface are made and modified by terrestrial crust movements, yet the leaving open of great, yawning chasms is not of sufficiently well known occurrence to attribute all of the submerged valleys upon the American coast to such an origin, especially when we consider the great length of the submerged channel of the St. Lawrence river (800 miles), its various windings and its uniformly increasing size, until it passes into the great chasm, just before it reaches the margin of the continent. The idea of the excavation of these submerged valleys by glaciers — some of which are outside of glacial regions even of the past — is too untenable for a moment of serious consideration. Irrespective of the causes which have determined the location of the channels here described, it appears that they have been made, one and all, by the excavating power of rivers and lateral streams pouring down the hillsides. These, together with the other meteoric agents, have also, to a greater or less extent, removed the Paleozoic, and also the Triassic rocks, from the depressions now occupied by the Gulfs of St. Lawrence and Maine, which have, however, been more or less affected by terrestrial movements.

The length of time required to excavate the channels of these great rivers commenced as far back as the Paleozoic days. However, the culmination of that of the Mississippi was not until the later Tertiary, or even the Pleistocene period. As the St. Lawrence valley, now submerged to a depth of over 1,200 feet for a distance of 800 miles, is mostly cut out of rocks of the Paleozoic group, except a belt of the Triassic (across the lower portion, more or less involved in mountain uplifts), its antiquity must be very great. The culmination was also probably in the later Tertiary era, like that of the Mississippi and the channels on the California coast, for there are submerged Tertiary rocks off the coast of Massachusetts and Newfoundland, at elevations much higher than the beds of the old channel.

Although the excavating forces took so many periods to form the valleys, and required a high continental elevation, yet the extreme altitude of over 2,000 feet appears to have been of comparatively short duration, for otherwise the deep chasms in which the submerged channels terminate would have extended farther inland than we find them, and would have been headed by more gentle slopes, in place of precipitous cliffs, over which the waters of the former rivers were pecipitated in great cascades. In the fjords of Norway, merging into rapidly contracting valleys, or headed by great vertical walls, hundreds of feet in height, having the structure named *cirques*, may be seen to-day the counterpart of the coast of the American continent, when its marginal plateaus stood 3,000 feet higher than at present; yet Norway stood once much higher than now, but was afterwards submerged, from which depression it has only recently been re-elevated so that its plateaus, close upon the sea, rise to a height of three or four thousand feet, and its mountains still higher. The old hydrography is more or less distorted by warpings of the earth's crust, which, however, do not obscure the valleys, although rendering the features somewhat more complex. The amount of distortion has yet to be determined.

CHAPTER II.

Origin of the Basin of the Great Lakes of America.*

Introduction.

Even as recent as a decade ago very little was known as to the origin of the Great Lakes of America. While we find such generalized statements as "most lakes are due to terrestrial crust-movements," yet such crust-movement had not been tested in the American lake-region. Again, from the time of early geological investigations in America, statements are found that the basins were the result of erosion; but the methods of erosion were not explained, and this was the more necessary as most of the basins have rock-bound outlets. Later, in some geological literature, the method of excavation was hypothetically attributed to glaciers. Such was the unsatisfactory condition of our knowledge of the problem when the writer first commenced the study, in attempting to solve the origin of Dundas Valley, at the western end of Lake Ontario, more than a dozen years ago. This investigation has developed results bearing not only upon the origin of the lake-basins, but also upon the physical history of the lakes, and broader questions of the building and sculpturing of the continent.

The methods of investigation have been the studying—(1) of the hydrography of the modern lake-basins and submerged channels upon the coast of America; (2) of the deep wells bored into, or through, the drift deposits, by which buried channels, and their relation to or contrast with the modern valleys, have been discovered; (3) of the elevation of the continent; (4) of the direction of the glaciation in the lake-region; and (5) of the now high-level beaches, in which are recorded continental uplifts, together with the deformation of the old surfaces, owing to unequal terrestrial movements or warpings of the earth's crust.† The lakes which have been the basin of the more careful investigation are Ontario, Erie, Huron, and Michigan, with the respective altitudes of 247, 573, and, of the last two, 582 feet above the sea (see the Map, p. 15).

* From the Quarterly Journal of the Geological Society of London for November, 1890, Vol. XLVI, pp. 523-533.

† In the field-work I here acknowledge the assistance of Professors D. F. H. Wilkins, W. W. Clendenin, and W. J. Spillman.

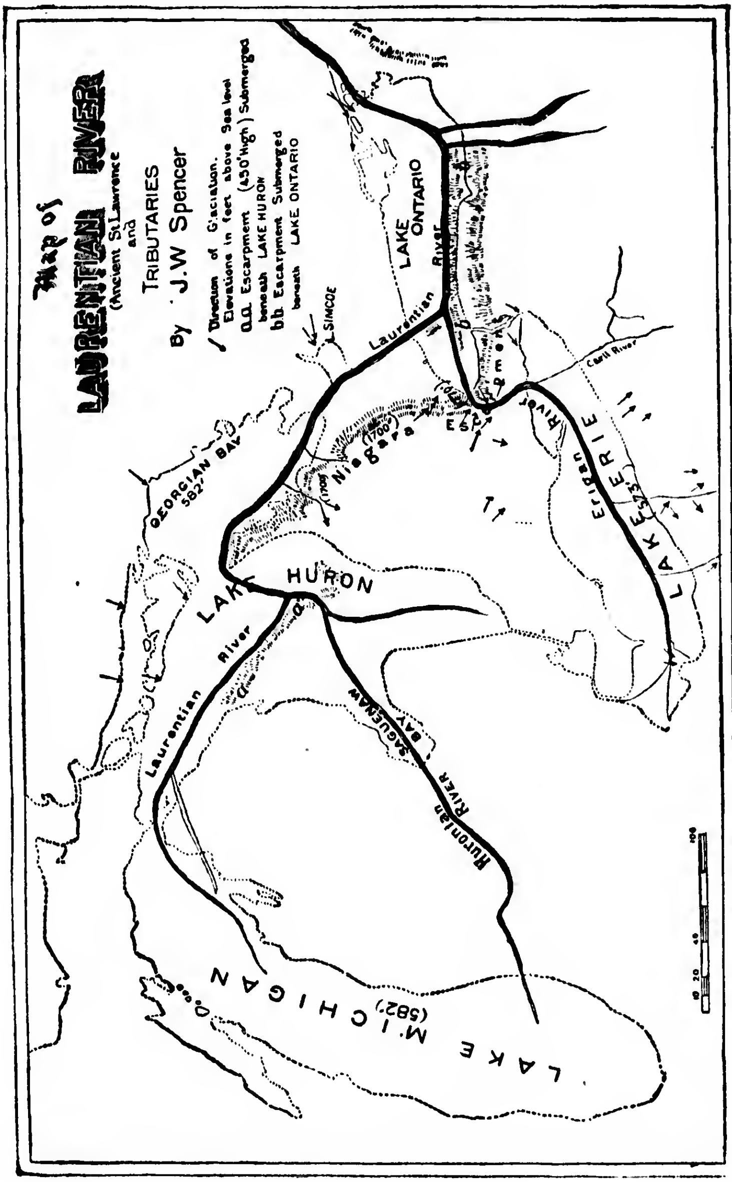


Fig. 2.—Map of the Ancient Laurentian River and its Tributaries.

Features of the Ontario Basin.

Lake Ontario, as was shown in an earlier publication,* is a basin bounded on its southern side by escarpments, often precipitous, of which some of the steps are now submerged. At the foot of the submerged escarpments a valley like that of an ancient river may be recognized from the western part of the lake to near the eastern end, but there it disappears, for reasons to be noted later. The deepest part of this valley is 738 feet beneath the surface of the lake. From this trough the floor of the lake rises gradually, or with occasional low steps, to the northern shore. In short, the basin was once an old land-valley traversed by a river. At the western end of the lake borings have revealed an old channel, having a lateral depth of 292 feet. This is the continuation of the cañon of the Dundas valley, which is about two and a half miles wide, bounded by rocky walls nearly 500 feet high, capped with Niagara limestone. Down this valley the waters of the ancient Erie basin once flowed.†

If the waters of Lake Ontario were withdrawn, its present basin would be a broad valley, continuous with that of the St. Lawrence valley, having a breadth of 30 or 40 miles. Into this plain, at a point about 20 miles east of Toronto, there is a channel, approaching the shore, whose bed is 474 feet below the surface of the lake,‡ but with boundaries submerged to only 200 feet. This depression trends southward and joins that at the foot of the submerged escarpment before mentioned.§

Features of the Erie Basin.

The floor of Lake Erie is a broad flat plain, now rarely submerged to a depth of more than 84 feet, and usually less. Only a small area, situated directly south of the western end of Lake Ontario, is of greater depth, and there the greatest sounding is 210 feet.‖ But from this region the Erie valley was drained by the Grand river and Dundas Valleys into the western end of Lake Ontario, as was shown in 1881; for the Niagara river did not then exist. Numerous tributaries of the modern shallow lake flow over deeply buried channels, the deepest of those discovered being 228 feet below the lake surface, as described by Dr. Newberry,¶ although the floor of that portion of the lake is nowhere over 84 feet below the surface of the water.

---

* "Discovery of the Preglacial Outlet of the Basin of Lake Erie into that of Lake Ontario," by J. W. Spencer; Proc. Am. Phil. Soc., Philad. 1881.

† See "Discovery of the Preglacial Outlet of Lake Erie," etc.

‡ See "British Admiralty Chart of Lake Ontario."

§ See U. S. Lake-Survey Charts of Lake Ontario.

‖ See U. S. Lake-Survey Charts of Lake Erie.

¶ Geology of Ohio.

Similar channels, buried to depths below the floor of the eastern end of Lake Erie, near Buffalo, have been described by Dr. Julius Pohlmann.* The borings into many others in the region of the western end of the lake have been recorded by Prof. T. Sterry Hunt,† and prove the existence of similar buried channels.

The original recognition ‡ of the valley-like character of the basins of Ontario and Erie was based upon the above-mentioned characters, and upon others now supplemented by a more perfect collection of facts; but the greatest difficulty in the way of explanation was in the occurrence of the rock-bound outlet of Lake Ontario,—a difficulty which observations have at last dispelled, as will be seen later on.

Features of the Huron Basin.

The southern half of Lake Huron is a plain traversed by valleys and submerged to form only a shallow lake. Northward of this shallow basin, and extending obliquely across the lake for 90 miles, there is a submerged escarpment rising to a height of from 300 to 450 feet, facing northeastward. The deeper part of the lake then trends northward in the direction of Georgian Bay. At one point the extreme depth of the submerged valley reaches 750 feet. The absolute depth of the rock in the deepest channel between Lake Huron proper and Georgian Bay is not known, but soundings show 306 feet; and as there is a deep channel upon the western side of Georgian Bay it becomes highly probable that a deeper and connecting channel is filled with drift, like those known to occur elsewhere, beneath the lakes. From the straits, between the islands, the narrow channel in Georgian Bay, just referred to, extends southeastward and is submerged to a depth of 510 feet. This is at the foot of the Niagara escarpment, which extends, as a strong topographic feature, from the head of Lake Ontario, and, rising in places to 1,700 feet above the sea, into the peninsula between Georgian Bay and Lake Huron proper. The channels at the foot of escarpments, submerged or otherwise, in Lake Huron and Georgian Bay are fragmentary records of the history of the lake-valleys. ‖

Features of Lake Michigan.

This lake is divided into two basins. The more northern and larger basin has a maximum depth of 864 feet. It is, in part, bounded by

* Paper read before the Amer. Assoc. Advance. Science, 1883.

† See Reports Geol. Canada, 1863-66.

‡ See "Discovery of the Preglacial Outlet of Lake Erie," etc.

‖ See U. S. Lake-Survey Chart of Lake Huron, and the Canadian Chart of Georgian Bay.

vertical submerged escarpments, one of which, upon the eastern side, has a height of 500 feet. While the deepest sounding at the modern outlet of the lake is only 252 feet, there are adjacent channels buried to unknown depths. But these have been imperfectly explored. Into this shallower portion of the lake, however, the fjord of Grand Traverse Bay has a northernly trend,—it is 612 feet deep. This and the smaller fjords indicate the existence somewhere of a deep channel connecting with the Huron basin, as much as the river-valleys buried beneath the drift materials of the modern floor of Lake Erie prove deep channels throughout that basin, although not shown by the soundings; for the Lake-Michigan valley is carved out of undisturbed and almost horizontal Paleozoic rocks, the newest of which are Coal Measures.

The southern basin of Lake Michigan is separated from the northern by a plateau submerged to a depth of from 300 to 342 feet; whilst the southern basin itself is now 576 feet deep. The area of this portion of the basin is now much smaller than that of the Prepleistocene valley, as its margins have been filled with drift, and now forms broad plains bounding the lake. Beneath these deposits is a deeply buried channel, leading to the valley of Lake Huron, and to be noted further on.

Buried Valleys Revealed by Borings.

The deep wells revealed the existence of the buried channel down which the waters of the Erie Valley orginally drained, and thus established the relationship of the Erie with the Ontario Basin. But the most important series of borings were those between Georgian Bay and Lake Ontario, for here we have the connecting link between the valleys of the upper lakes and that of Lake Ontario, and indeed the key to the origin of the valleys of the lakes.

Between Georgian Bay and Lake Ontario, a distance of about 95 miles, a portion of the country is comparatively flat composed of a series of rising plains; but there are also high transverse ridges of drift, having a general trend of east and west. It is upon the northern side of the drift ridges that Lake Simcoe, with a diameter of about 20 miles is situated. But upon the northern side of Lake Simcoe there is another series of drift ridges trending towards the northeast. Both of these series of ridges rise to between 200 and 550 feet above Lake Huron, these measurements being the extreme variation in their height.

From Georgian Bay to near Lake Simcoe, for a distance of 30 miles, the country is low and flat, with a known absence of rock to far below the level of the bay. Lake Simcoe is 140 feet above Georgian Bay, but upon its northern side, at Barrie, a well has been sunk in the Drift, without penetrating it, to a depth of 280 feet below its surface. Thirty miles further inland, south of Lake Simcoe, at Newmarket, a well was in the process of being bored. It had reached a level below Georgian Bay and was yet in drift deposits when visited. In another well several miles to the westward, near the side of the ancient buried valley at Beeton, rock was reached at 50 feet below the surface of Georgian Bay.

Between Newmarket and Richmond Hill there are several deep wells on the heavy drift ridges which cross the country. But at Richmond Hill, at a height of 217 feet above Georgian Bay, there is a well 400 feet deep without penetrating the drift. This proves the thickness of the Drift of the higher ridges crossing the old valley north of the well to be not less than 700 feet in the old channel. Southward of Richmond Hill the country falls away in a series of more or less rolling steppes to Lake Ontario, but these plains show the absence of rock along deeply-cut valleys to far below the level of the upper lakes. Upon the western side of this chain of borings, but a few miles distant, there is the Niagara escarpment. Upon the eastern side of Lake Simcoe the country is covered with flat limestones, rising to 150 feet above that lake. From the known absence of rocks along the line of borings and stream excavations, between a high mountainous escarpment upon one side and a rocky floor upon the other, and from these borings reaching to 200 feet or more below the upper lakes, without penetrating the drift but stopping in quicksand, there has been discovered the existence of the only channel of antiquity which could now draw off the waters of the upper lakes, if the drift were removed. Although none of the borings have reached the original rocky floor, yet the depth of the buried valley is suggested by the channel close upon the northern side of Lake Ontario, now submerged to 474 feet, which is deep enough to drain the last drop of water out of Lake Huron.

We have now found the ancient Laurentian channel from Lake Michigan through Lake Huron and Georgian Bay, and thence buried beneath drift deposits until it is again recognizable throughout nearly the whole length of Lake Ontario, being joined at the western portion by an ancient outlet of the Erie valley (the ancient *Erigan* River). But the relative maximum depression of the channels, as far as explored, is disturbed by terrestrial warpings, to be described hereafter.

Across the southern part of the peninsula of Michigan, between hills rising upon either side to heights of sometimes 800 or 1,000 feet above Lake Huron or Lake Michigan, there is a valley whose western portion is occupied by the Grand river, and the eastern by a small river emptying into Saginaw Bay. At the divide between these rivers the land does not exceed 100 feet above the lakes. The topographic features of the valley show its original opening as having been into the Huron Valley by Saginaw Bay; but a considerable proportion of the modern drainage is in a direction opposite to that of the valley, or flowing towards Lake Michigan — that is, the drainage has been reversed. The maximum depth of the western portion of this buried valley is not known, but there is an absence of rock, as shown in several borings, to between 100 and 200 feet below the lake level. But farther east in this trough there are several deep wells, in one of which the drift is 500 feet below the floor of the side of the valley, or 350 feet below the surface of Lake Huron.* Hence we have established the great depth of the buried valley between the southern part of Lake Michigan and Lake Huron, whose ancient river I name the *Huronian.*

Other buried valleys and channels submerged could be given, but they all indicate the origin of the basins of the lakes as the valleys of a great river and its tributaries — a river of such high antiquity that the rains and rills had already ground off the surrounding hills to broaden the valleys. But for all this evidence, there are now rocky barriers forming an apparent obstacle in the way of a complete solution of the problem.

The Glaciation of the Region.

At the present stage in the investigation this subject can be quickly dismissed. The question whether glaciers can erode great lake basins is hardly pertinent, for nowhere about the lakes is the glaciation parallel to the shores or vertical escarpments which are associated with the lakes. Indeed, the direction of the striæ is often at high angles, even to 90°, to the trend of the vertical walls of rock bounding or crossing the lakes. Nor are the faces of these great walls of limestone polished by an agent moving along their faces. That there are no striæ parallel to some local inlet or valley would be perhaps rash to assert; but, if so, it is a mere coincidence, with no bearing upon the origin or moulding of the Great Lake valleys. Hence we are forced back upon a conclusion that the lakes were subaërial valleys in spite of the barriers, and the fact that the floors of most of the basins are below sea-level — that of Ontario being nearly 500 feet.

* This is at the Sanitarian Well at Alma, Mich., the record being furnished by Prof. Charles A. Davis.

The Former High Continental Elevation of North America.

If the lakes and valleys originated from atmospheric and river erosion, then the continent stood at much greater elevation than at present, as shown by the depth of the lakes themselves. But there is much collateral evidence that in the later Tertiary days, probably during the Pliocene, the continent was very high. This is shown by the submerged valleys of the St. Lawrence Gulf, of the Gulf of Maine, off New York, at the mouth of the Mississippi river, upon the Pacific coast, and in Hudson Strait. These indicate that eastern America stood for long ages at between 1,200 and 1,800 feet above its present altitude; and the whole continent in more recent times, but for a brief period, at upwards of 3,000 feet.* Hence the former continental elevation was sufficient to satisfy all demands for the erosions of the lake-valleys; but the rocky barriers still demand explanation, both on account of the present obstructions not having impeded the erosion of the valleys, and on account of their subsequent closing the valleys, in part, into lake basins — the necessary observations for the explanation having long eluded investigation.

Deformation of Raised Shores and Beaches.

At the close of the episode of the newest till, the region of the Great Lakes was submerged to a depth of at least 1,700 feet, as is recorded in the beaches which overlie the till. These high beaches only remain as fragments about ancient islands; but if we descend to beaches of lower levels we find them well developed and containing all the necessary evidence for explaining the rock-barriers at the outlets of the lakes. Gen. G. K. Warren, Corps of Engineers, U. S. A. was the first to suggest the closing of the lakes by warpings of the earth's crust.† Portions of the high-level beaches about the lakes have long been noted. But it was Mr. G. K Gilbert who first connected the beaches upon the southern and eastern sides of Lake Ontario, and measured their great rise towards the northeast; but, as he did not apply his discovery to the explanations of the lake basins, it was first applied by the present writer.‡ The results of Mr. Gilbert's investigation of beaches in New York and Ohio, and of the writer's researches in Canada, Michigan, New York, and elsewhere, are sufficient to form a chapter by themselves, and are still only in part published, but I will

* "High Continental Elevation preceding the Pleistocene Period," by J. W. Spencer, Bull. Geol. Soc. Am. vol. 1, 1889; and Geol. Mag., May, 1890.

† Appendix 18, Report of Chief of Engineers, U. S. A, 1875.

‡ See "Notes on the Warping of the Earth's Crust in its Relations to the Origin of the Basins of the Great Lakes," Amer. Nat. Feb, 1887, pp. 168-71.

draw upon them only to the extent of explaining the barriers across the outlets of the old valleys.

The most important raised beach of the Ontario basin is the *Iroquois*.* At the western end of the lake it now rests at 363 feet above the sea, but rises slightly to the east and still more toward the north, until at four miles east of Watertown it is 730 feet above the sea. Still further northeastward, near Fine, on the borders of the Adirondack wilderness, it reaches an elevation of 972 feet above the sea, beyond which recent measurements carry it to 1,500 feet above the sea. At the western end of the lake the uplift is scarcely two feet in a mile in the direction of N. 28° E. At and beyond the northeastern end of the lake the uplift is found to have increased to five feet in a mile, and in the region of farther observation to seven feet in a northeastward direction. Thus in the deformed water level I have already measured a barrier of about 600 feet raised up at the outlet of the lake. Of this, about 530 feet is confined to the region of and beyond the eastern end of the lake, where the later Pleistocene barrier across the ancient Laurentian valley has appeared. While we know what are the maximum soundings in the river, yet the old channels are so filled with drift that their depths are not revealed. Still, we know that in one portion of the channel cut out of limestone and more or less filled with drift, the sounding is 120 feet. A short distance beyond, the channel across the Laurentian gneisses shows soundings of 240 feet. The maximum depth of the lake-basins is 738 feet. The deformation recorded in the beaches is more recent than the episode of the upper till. Consequently, if the continent were at a high level, with the warping, known to have occured since the drift was deposited, removed, as shown by the above figures, there would be not only no barrier, but a sufficient slope in the Laurentian valley for the drainage of what is now the Ontario Basin.

Furthermore, the presence of the rocky barriers of the Rapids of the St. Lawrence, further east, are wholly accounted for by the terrestrial warpings of the region. Hence I have demonstrated, after a decade of study, that no barrier existed across the Ontario valley when it was being carved out by the ancient St. Lawrence, and that this barrier is of quite modern origin.

Southeast of Georgian Bay the average measured warping is four feet per mile, in mean direction of N. 20° E. This will account for a portion of the barrier closing the Georgian outlet of Lake Huron. The

* "Iroquois Beach; a Chapter in the Geological History of Lake Ontario," Proc. Roy. Soc. Canada, 1889.

more elevated beaches in the region of Lake Huron record a still greater change of level.

At the outlet of Lake Erie, Mr. Gilbert and myself find a differential uplift of about two feet per mile, and this is sufficient to account for any rock basin to the recently formed basin of Lake Erie.

The warping affecting the Michigan Basin has been that towards the north and east; and even in the burried channels south of Lake Michigan there is no evidence of an ancient drainage to the south, as their beds were too high compared with those of the northern, although the latter have been elevated recently by warping.

Conclusions from the Observations.

The valleys of the great lakes here studied are the result of the erosion of the land-surfaces by the ancient St. Lawrence (named by the writer *Laurentian*) river and its tributaries, during a long period of continental elevation, until the streams had reached their base planes of erosion, and the meteoric agents had broadened the valleys. This condition was at the maximum just before the Pleistocene period.

The closing of portions of the old Laurentian valley into water basins occurred during and particularly at the close of the Pleistocene period, owing, in part, to drift filling some portions of the original valley, but more especially to terrestrial warpings of the earth's crust, which, to a sufficient degree, are measureable.

DISCUSSION.*

The Chairman noted that there were one or two Fellows who had a local knowledge of the area, but the question of the origin of lake-basins in general was raised in the paper.

Dr. Hinde did not think that Dr. Spencer's explanation of the origin of the American lake basins was the true one. The submerged deep channels of the alleged ancient rivers, to which the erosion was said to be due, were traced towards the east end of Lake Ontario, where they ceased; and their discontinuity through the barrier formed by the hard gneissoid region of the Thousand Isles was attributed to differential elevation, or so-called earth-warping. This assumed warping where barriers existed could always be brought in to account for them. He (the speaker) asked where the beaches existed near Kingston, at the east end of Lake Ontario, on the difference of level of which the supposed warping was based. From his own observations on the region, he doubted the existence of the alleged buried channel between Lakes Huron and Ontario, and he did not think that the acknowledged

* Before the Geological Society of London.

great thickness of Drift now covering the elevated area between these lakes should be regarded as proof of the presence of a former channel directly connecting them. With reference to the supposed old channel between Lake Erie and Lake Ontario, by way of the Grand river and the Dundas valley, the water of Lake Erie was supposed to have run *up* the valley by which the Grand river now came *down* to the lake. All these lakes and the elevated regions between them had been covered by glaciers, and their movement had been in a contrary direction to that of the present water drainage; and judging by the amount of drift material transported by the ice from lake-basins over the adjoining land surface, he believed that the glaciers had been important factors in their excavation. If, on the author's views, there had been a recent submergence to the extent of 1,700 feet, where were there traces of marine remains over the lake region west of the meridian of Kingston, though such were not uncommon in the clays of St. Lawrence and Ottawa rivers? Also on the author's hypothesis of a former great lake whose surface would be at a considerable elevation above the sea, what barrier was there at the south end of Lake Michigan, near Chicago, to keep such a lake from draining into the Mississippi valley?

Prof. Bonney thought that Dr. Hinde's criticism was not a valid one, as he had not understood that the author denied the occupation of the lakes by ice, though he did not uphold their glacial origin. He could not understand the formation of Georgian Bay by ice and the preservation of Manatoulin Island. He was struck with the similarity of the author's sections and those of the Lake of Como, published by the late Mr. J. Ball, which he had previously shown to be adverse to the glacial theory of the origin of the lake-basins. It was not safe to argue from the absence of remains of marine organisms; for elsewhere they were commonly wanting in deposits formed under circumstances similar to these, yet undoubtedly marine. He again could not follow Dr. Hinde in his objections to differential movements of the earth's surface, and insisted on the great movements of recent times, as evidenced along the Frazer river and in Norway. Only last autumn he had seen distinct evidence of comparatively modern depression along the Dalmatian coast. He suspected some changes even in historic times. The buried river channels described by the author were paralleled in Switzerland. He did not deny the efficiency of ice to produce such effect, but it did not bring about what had been attributed to it by some geologists.

Dr. Irving congratulated the author on the results he had placed before the society. He thought Dr. Hinde had not followed Dr. Spencer's arguments throughout, as, for instance, in the case of the connection between Huron and Ontario. He was glad to find the main points of his own theoretical conclusions as to the inability of ice to excavate confirmed by the author's observations in Norway and America. He saw nothing startling in the "warping" hypothesis.

Mr. Clement Reid had no objection to Dr. Spencer's views of "warping." He thought all turned on accuracy of observation in tracing the terraces, and he wished to know whether it was absolutely certain that the same terrace was traceable throughout the whole distance.

Rev. E. Hill called attention to the fact that tracts of Lake Superior were now below sea level, and yet no marine deposits are forming there. He called attention to the advantage of the Hydrographic Survey, which the author had utilized, and which we had in vain asked for in England. The depth of the Saguenay valley would be also accounted for by the author's explanations

Prof. Seeley was prepared to accept the ancient drainage of the Laurentian river as now set forth. But he did not think it followed that the ancient valleys had been excavated by the river any more than they were the work of ice. The general course of the Laurentian lakes followed the outcrop of the strata sufficiently to suggest that the lakes were originated by earth-movements. The main work of excavation seemed to him attributable to marine denudation in times when the level of the land was lower. And as tidal waters retired from the valley which they had cut out, the river drainage necessarily occupied these inlets after the land was elevated.

Mr. Whitaker asked why objection was raised by Dr Hinde to deductions from borings in America when in England they were accepted. No other evidence of buried channels was to be had, sometimes. He would like to have some idea of the number of borings on which the author relied.

The author, in reply, answered Dr. Hinde and Mr. Whitaker that he had only written a condensed account of the origin of the basins, not of the lakes themselves. There were no escarpments in the place where Dr. Hinde had asserted their existence. There were scores of deep wells sunk in the drift between Lake Simcoe and Georgian Bay, where deep drift was shown. Similar sections were shown at the southeast end of the lake. He gave fuller details of the extension of these borings to the S. E. He cited instances of modern buried channels of a similar nature to those which he had described, and which evidenced a high continental elevation. To Professor Seeley he replied that he had no objection to the assistance of sea-waves, in part, enlarging the valleys in some pre-Pleistocene times. The old Erie-Ontario channel has been warped two feet per mile, which would account for the obstruction of the ancient valleys. Mr. Gilbert and he had traced one particular beach continuously round Lake Ontario The elevations he had deduced from observations were founded on accurate instrumental measurements along this line, and similar observations had been made by him in other areas. There was no evidence of barriers in the Erie-Ontario valley other than such as were due to differential elevation or partial filling with drift. The pre-Pleistocene drainage of the Lake Michigan basin was not to the south; hence no barrier greater than at present was needed, as explained in the paper.

There were no beaches about Kingston, on account of the low altitude, but he had traced beaches in other parts of the region.

If we were to follow the differential elevation we should find that there were no Canadian highlands at the close of the episode of the upper till, but he could not now enter into the ice-hypothesis. He gave instances of the absence of marine organisms in undoubted marine beaches, and instanced the discovery of a whale in beach deposits upon which the evidence of warping was partly founded.

CHAPTER III.

Ancient Shores, Boulder Pavements and High-Level Gravel Deposits in the Region of the Great Lakes.*

I. Characteristics of Ancient Shore-lines in the Region of the Great Lakes.

The land features throughout the lake region drained by the St. Lawrence river owe their formation largely to the action of waves sculpturing rocky or modeling earthy shores. That the waves have not always been confined to the margins of the modern lakes is seen in the sea-cliffs and beaches, from which the waters have long since receded. These features, still remaining, are sometimes in the form of bold relief, and sometimes in the form of narrow sand or gravel ridges, delicately traced over a flat country. In some places these ridges approach near to the lakes; in other localities they are miles away, and at varying altitudes up to hundreds of feet above their present waters.

The raised shore-lines are no longer water levels, for terrestrial movements, since the lakes have receded from them, have commonly lifted them up to unequal altitudes. Whilst some of these old shores represent former lake boundaries, there seems to be little reason to doubt that the higher sea-cliffs and beaches formed the coast of brackish water inlets or arms of the sea.

Besides the deformation arising from the unequal terrestrial movements, the shores have been in many places defaced by the action of rains, rills, rivers and landslides, until their broken continuity renders them somewhat difficult to follow over long distances. The object of this chapter is to describe the characters of the old raised and deformed water-margins, by which they can be identified. The ancient coast-lines differ in no respect from the modern, but they are often easier to follow, as there are no waters to restrict one's footsteps. Were the lakes to be suddenly drained, but a few years would elapse before the deserted margins would be as difficult to mark out with precision as any of those from which the waters have long since receded.

* Reprinted from Bull. Geol. Soc., Am. Vol. I., pp. 71-86, 1889.

With notable exceptions, the lakes are generally bounded by banks of clay or sand, stratified or unstratified. The waves have in places cut into these deposits, leaving high clay bluffs; in other localities the coast rises gently from the water-line. In front of these shores, whether high or low, beaches often occur. The typical beach forms a ridge of stratified sand and gravel, rising from three to five feet, or even more, above the surface of the water. The ridge may vary from a few yards to as many scores, or even hundreds in width. In the more perfect form, there is a slight depression behind the ridge which is sometimes occupied as a bay, lagoon or swamp (fig. 3). Whilst the beach may

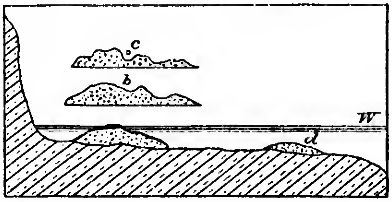


FIG. 3.—*Section showing the Floor of a Cut Terrace on which rests a Beach.*
b and *c* = Beaches broken into ridgelets. *d* = A frontal sand bar. *W* = Old water-level.

form a frontal barrier, in shallow water, distant from the shore, it may rest directly against the coast, forming a terrace (*a*, fig. 4), behind which there is no depression. In this case the surface of the terrace is apt to be defaced by landslides or washes; but the beach, whether in

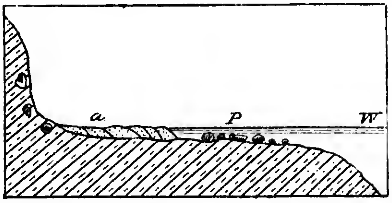


FIG. 4.—*Section showing the Floor of a Terrace of Construction.*
a = Terrace of construction resting on cut terrace. *P* = Frontal pavement of boulders. *W* = Old water-level.

the form of a terrace or off-shore barrier, is very often wanting when the currents are cutting into and washing away the coast (fig. 5). Under such a condition, if a beach be formed, it is narrow and temporary, as it is liable to be washed away or covered by landslides. The eastern and southeastern coast of Lake Huron commonly illustrate the absence of true beach structure. Another excellent example may be seen at Scarboro heights, a few miles east of Toronto, on Lake Ontario, where the clay banks rise to the height of more than 200 feet and extend for a distance of nine miles. Here the cliffs are being eroded. The waves are not forming a permanent beach, but the currents are drifting the materials several miles to the west to build up the barrier-beach in front of Toronto harbor.

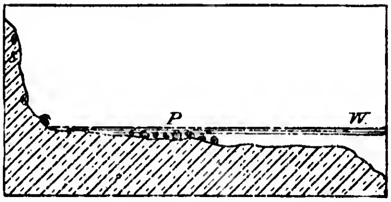


FIG. 5.– *Section showing the Floor of a Cut Terrace without Beach but with Boulder Pavement.*
P = Boulder pavement. *W* = Old water-level.

In the formation of beaches there is a tendency to straighten crooked coast-lines by the construction of bars in front of inlets, which are thus converted into bays or lagoons. Burlington bay, at the western end of Lake Ontario, is an illustration. Here, a narrow beach (*b*, fig. 6) cuts off a bay five miles long, whose depth is considerable, reaching to 78 feet. This is particularly a well-chosen example, for at the head of the bay there is a spit – named Burlington heights (*h*, fig. 6), rising to 108–116 feet above the lake — cutting off an older bay, now represented by the

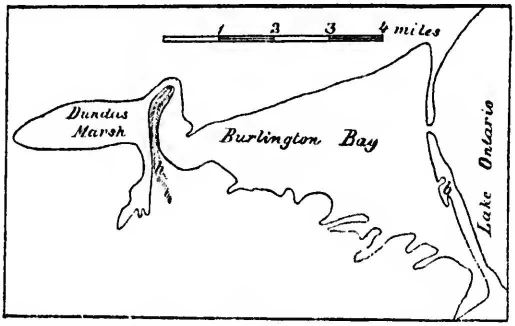


FIG. 6.— *Map of the Western End of Lake Ontario.*
b = Burlington beach, separating Burlington bay from the Lake. *h* = Burlington heights, an ancient beach 108-116 feet high, separating Dundas marsh from Burlington bay.

Dundas marsh. This spit, when the waters were at its level, formed a portion of an ancient shore (to be described in a future chapter) in the same manner as Burlington beach forms a portion of the modern lake-shore.

In places, where the waves break upon the more exposed coast, the beaches are apt to be piled up a few feet higher than their mean level. The opposite result is seen where the ridges are fashioned as spits and pass below the surface of the water in the form of submerged bars. The increase in the depths of the water in front of the beaches is usually very gradual.

The study of the modern and ancient shores is reciprocal. By the former, still washed by waves, we can identify the latter; and by the examination of the floor in front of the raised beaches, we can more fully understand the action of waves upon the modern coasts, than where the subaqueous deposits cannot be seen. The muds, derived from the encroachment of the waves upon the land, are assorted; the coarser materials being those which form the beaches, and the finer clay, that which constitutes the off-shore silt deposits, leveling up the inequalities of the lake bottom and forming very flat submerged plains, which are rendered apparent upon the withdrawal of the waters.

In the examination of old shores, the occurence of flat or very gently inclining plains, abutting at constant levels against rising hills, is as certain an indication of old coast-lines as if beaches were found there; but the exact height of the water-line cannot be recognized, as the water may have been five or it may have been twenty feet deep. When this condition obtains, there may remain here and there a fragment of a temporary beach (*c*, fig. 7), covered by a landslide (*s*, fig. 7), but exposed by a stream or artificial cutting into the hillside, or there may be a barrier in front of an ancient bay or lagoon (*h*, fig. 6).

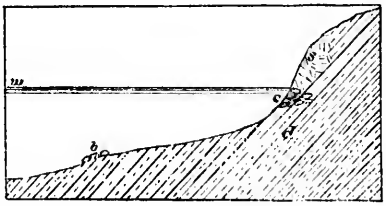


FIG. 7.—*Section showing a Cut Terrace with a fragment of Old Beach partly concealed by a Landslide.*

b = Boulder pavement. *c* = Fragment of old beach. *d* = Drift. *s* = Landslide. *w* = Old water-level.

While the greater proportion of the lake coast is composed of drift deposits, there are places where the water-margins are bounded by rocks. Here the structure is similar, although not so well developed, and the banks may assume the form of vertical cliffs. Generally speaking, the beaches in front of these rocks are not so well developed as where there have been shore deposits of boulder clay to supply the waves with pebbles. However, some of the higher and older coast-markings remain in the form of such "sea-cliffs," in front of which there are comparatively flat plains.

Another structure, when present, is very characteristic of many portions of the ancient shores, or, indeed, is occasionally seen in front of the modern beaches. This is a pavement of boulders (derived from adjacent shores of boulder clay), occupying a given zone (*P*, figs. 4 and 5). This zone is in front of and a few feet lower than the level of the true beach; the boulders having been left just below the water-level as the waves made encroachments upon the coast. Again, the boulders have been more or less pushed up to this line by the waves forcing up the coast-line to which these boulders have been frozen. When these deposits occur adjacent to the modern beach, they may be seen rising out of the water, but they are also found outward in the lake to the depth of several feet (figures 9 and 10, p. 38).

In front of an elevated shore, the boulders may be arranged in the form of a zone, even a few hundred yards in width, throughout a vertical range of a few feet, which may be increased to 30 or 40 feet where there is a succession of beachlets close together, marking the gradual recession of the waters. But the upper level of these zones never quite reaches that of the beaches. In traveling along a flat country these pavements of boulders are as certain indications of shore-lines as are any other forms of the beaches (fig. 9, p. 38). Boulders left on the hillsides by the action of rains, washing out the finer materials of the drift clay, are not arranged in belts of symetrical level. The boulder pavements do not usually occur where the adjacent coast is not composed of boulder clay, nor where the beaches are separated from the land by what is now or has been a bay or lagoon. Pavements of boulders are not as commonly seen in front of modern shores as in front of some of those more elevated and ancient.

Turning to the more typical form of the beach structure, as shown in the raised shores, there may be seen sand or gravel ridges, most frequently from 100 to sometimes 500 feet across, rising to 15 or 25 feet above a flat or very gently descending plain, whose surface is most commonly composed of fine clay. Sometimes this descent is so very gradual as to be inconspicuous; at other places the descent is quite sudden. The depression behind the ridge is generally less than that in front of it, and here also the floor may be composed of clay. Where the beach is broad, it is apt to be broken up in a number of ridgelets (*c*, fig. 3). Indeed, some of the larger and more important beaches mark the recession of the waters by being separated into several ridges, often at considerable distances apart, each a few feet below the preceding, where the lake floor is sloping very gently; but where the slope is more rapid, all unite into one large ridge. The beach has rarely a thickness of more than 15 or 20 feet, and rests upon the clay or drift deposits, which once constituted the floor of the former lake. As the plain recedes from the shore, the materials become finer and finer clay and freer from sand; but at varying distances, of sometimes a mile or more in front of the beaches, there may be found thin belts of sand resting upon the lake deposits. Again, the beaches may take the form of terraces of construction, resting against clay banks; or against these banks the ridges may abruptly (but not temporarily) end like the modern beaches (*b*, fig. 8).

In measuring the comparative altitudes of a beach at different points the summit of a well marked ridge should be chosen, rather than that of the beach in the form of a terrace (*a*, fig. 4) against the shore or the junction of the coastal plain back of a cut terrace (*c*, fig. 7) and the bounding hills, as the exact water-level can here be only approximately determined. It is more accurate to make the calculations as to the former water-levels at the foot of the beaches, as the slope in front

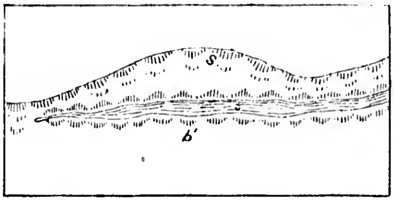


FIG. 8.—*Plan of Barrier Beach in front of a lagoon and overlooked by hills.*
b=Line of hills. *s*=Barrier Beach. The beach ends abruptly on the left.

of them may be steep in one place, and in another very gentle, but the summit is easily recognized. Where the beach itself is absent, by tracing the coastal line, there will be found sooner, or later, a bar or spit in front of some river or extinct bay.

In ascending from the modern lakes to the highlands, several old shores must be crossed. The country may be described as a series of terraces or steps, whose frontal margins are moulded into hills, and whose surfaces are plains, most commonly of clay, although sometimes of gravel or sand, at the back of which, there may be found the beach in some form. These gently rising terrace plains may each be several miles in width—and consequently the beaches several miles apart—or they may be narrow with the beaches close together. In many regions, the old shores behind these plains rise and extend across the country as conspicuous ranges of hills. The plains themselves are occasionally eroded by streams, until the whole country is very broken. This is more likely to be the case with terraces of the greater altitudes, and here the more recent surface erosion has often rendered the ancient shore lines hard to follow.

In crossing a series of beaches, the lowest is found to be composed of the finest gravel, or indeed perhaps of sand. In this case it is apt to be more or less heaped into dunes, by the action of winds. The ridges are often divided, but the branches unite again, or else send out spits ending abruptly. Occasionally the materials from which the beaches were formed was stony sand, in place of stony clay. Here, then, the extinct water-margins are difficult to determine, for there is no sharp lithological character, as where a beach crosses a clay plain — to mark the boundary between the sand beach, commonly heaped into hummocks or dunes, and the frontal plain composed of sand.

Many of the upper beaches overlie drift deposits, but those of the lower elevations are more likely to rest upon stratified clay — the sediments carried into the deeper waters whilst the lakes were at higher altitudes. The character of the materials underlying the beaches is commonly the same as that forming the surface of the plain in front of the ridges; but its structure is best shown in sections exposed by the subsequent erosion where streams cutting through the ridges cross the plain. When such streams have been large rivers, as has often been the case, there may be some trouble in tracing the continuity of the beach, especially across a broken country, as a portion of the valley may be older than the beach, which may swing around and skirt the embayment, or form a bar across it. Or again, the beach may be only represented by conical or other shaped sand or gravel hills, which were delta deposits at the mouth of former rivers. Such delta deposits may not rise to the level of the former body of water.

With the varying conditions here set forth, which the shore-line undergo, the traveler, in coasting around the old lakes, can rarely proceed more than a few miles without meeting obstructions. When the beaches were a considerable distance apart, with perhaps only 50 or 100 feet of difference in their altitudes, there is a liability of getting off one series and upon another. Consequently it is often necessary to resort to accurate leveling, allowing for reasonable variations in the height of the beach, and the differential elevation of the region, since the waters have receded from the former shores.

In some regions the former expansions of the lakes were occupied by archipelagoes. Consequently, there is an absence of continuous beaches, and the explorer must depend upon following the plain, which formerly constituted the lake floor, finding here and there a fragment of the ancient beach, either upon the coast of the mainland or upon that of an island. Here again, it may be necessary to resort to accurate leveling to identify the beaches.

Whilst steep coast-lines may be followed through wooded regions, it is most difficult to trace satisfactorily a beach across such a country. The greatest difficulties are found where the ancient beaches enter regions that are composed of hills of crystalline rocks, more or less wooded, and interspersed with numerous lakelets. In such places there are numerous gravel hills whose relationship to the old shores is not readily discernable.

In some places the surface of the beaches is composed of nearly clean gravel or sand; elsewhere, from some admixture of clay, it becomes more or less earthy soil, to a depth of two or four feet, somewhat obscuring the beach structure. Again, there may be coarse stones resting upon its surface, as if these had been forced up after the beach had been formed, by a slight rise of the waters, or by the action of coast-ice, pushing them up. However, these must not be mistaken for the more ancient gravel beaches, covered with drift, such as frequently exist, and will be described elsewhere.

The beaches, in the form of narrow belts of gravel or sand, crossing a flat country, were in many places used as trails by the Indian aborigines, and in some places these trails have been turned into roads, as they are always dry during the muddy seasons. These ridge-roads have attracted attention as ancient beaches for nearly a century. But the water long since withdrew from them owing to the elevation of the continent, which has been accompanied by their distortion from the water plain, on account of an increasing rise to the north and east.

The great geological value of investigating the raised and ancient coast-lines lies, not only in gaining a knowledge of the former expansions of the lakes and their relationship to each other, but particularly in being able to make use of them, as old water-levels in order to measure the amount of deformation or warping of the earth's surface caused by terrestrial movements, resulting in the development of the basins of the lakes themselves, and other features. While the old shore-lines record a great amount of unequal terrestrial movements, yet these movements have also left records in the older sea cliffs.

Boulder Pavements and Fringes.

In many localities of the northern part of our continent, the land surfaces are almost covered with loose boulders, varying from the size of cobble stones to masses commonly three or four feet long. Occasionally the blocks have a length of eight feet, but rarely longer. While some of the boulders are angular blocks of Paleozoic limestones and sandstones of local origin, a great proportion are Archæan rocks, which have been transported from the Canadian highlands, north of the great lakes, to distances of sometimes 300 or 400 miles. These crystalline rocks, although so hard and compact, have the angularities invariably removed. Blocks are frequently seen at altitudes of hundreds of feet above their original sources. Throughout the lake region, and the country north of the line of the southern limit of the drift, which is often fringed with them, the accumulation of boulders is not uniformly distributed. The country enclosed by that line is occupied by sheets and ridges of drift materials, through which the subjacent rocks occasionally protrude. Again, these plains and hills have their surfaces moulded by the action of the waves of vanished seas or shrunken lakes, often fashioning the region into a succession of broad terrace flats and hilly coast lines. It is upon the surfaces of these moulded features that the boulders are found. Whilst there are vast areas where there is not a single stone to be seen, and others where only an occasional block occurs, as dropped down from some meteoric source, there are other localities literally so covered with large boulders as to prevent agricultural pursuits. These boulder accumulations are superficial and do not penetrate the subjacent earths. They occur along certain zones, outside of which they are not found.

The presence of these surface boulder accumulations has been most commonly explained alike by those who believe in the glacial origin of the drift and those who do not, as having been dropped by melting icebergs at the close of the drift epoch. A few glacialists regard these boulders as having been deposited from glaciers where they now rest. It has also been hinted that they have been left upon the hills, as the finer materials of the boulder drift have been washed away by atmospheric agencies; but it was only since the recent systematic studies of the high-level beaches, compared with modern lake shores, have been made that the natural explanation of boulder pavements and distribution of erratics become possible.

There are three conditions under which boulder accumulations are found. The most important is where the boulders form pavements stretching as belts across a level country, usually in front of ridges which once constituted old shore-lines, or forming zones of stones resting upon hillsides or capping the summits of ridges. Of less importance is the occurrence of blocks scattered sparsely and irregularly on the sides of hills. Lastly, occasionally erratics are found alike over the hilly and over the flat country. That the boulders were brought from their original sources in the later Pleistocene days and dropped by either icebergs or glaciers where we now find them is an untenable hypothesis, for their birth places are now often covered with the older drift or are hundreds of feet below the elevations where they are now found. The relation of the boulders to the older drift are such that the erratics can commonly be recognized as of secondary origin, being derived from the earlier accumulations of boulder clay or sand. The manner in which the blocks have been brought to the surface has been by the removal of the finer earths from the drift, principally by the action of the waves or currents encroaching upon the hills or ridges of such materials, charged with occasional boulders. Thus the coast-line has been moulded into steep shores, in front of which there are the gently descending plains, once submerged — the floors of terraces since the recession of the waters (figs. 4 and 5).

Thus the boulders throughout the whole thickness of the drift, which were too large for transportation by the waves, were reduced to water-level and were accumulated upon the floor in the form of pavements or fringes along the former water margins. The removal of the earth beneath the boulders continued until they had settled to the maximum depth of wave action below the surface of the water, for at greater depths the fine earth would not have been removed from beneath the stones. The vertical range of the fringes is from 15 to 25 feet or more when the recession of the former waters was gradual, leaving a close succession of beaches. The width of the pavements varies from a few hundred feet to perhaps a half a mile, according as the slope is somewhat steep or very gradual. Where the finer materials were entirely washed out into deeper water, then the margins of the plains, at the foot of the old coast line, are simply fringed with boulders; but where the finer materials were assorted by the waves and currents, the sands and gravels have been formed into beaches, usually a few feet above the level of and behind the boulder belt.

tions are
avements
of ridges
ones rest-
Of less
nd irregu-
und alike
lers were
days and
hem is an
ered with
where they
drift are
secondary
ler clay or
ght to the
the drift,
hing upon
l boulders.
n front of
rged — the
l 5).
the drift,
reduced to
m of pave-
removal of
tled to the
ater, for at
oved from
from 15 to
as gradual,
pavements
ccording as
e the finer
the margins
ringed with
e waves and
ches, usually

FIG 9.—MODERN BOULDER PAVEMENT ON GEORGIAN BAY,
NEAR THE END OF BLUE MOUNTAINS OF COLLINGWOOD, ONT.

FIG. 10. ANCIENT BOULDER PAVEMENT OF ALGONQUIN BEACH,
WHOSE CREST RISES 189 FEET ABOVE GEORGIAN BAY UPON THE N. E. SIDE OF BLUE MOUNTAINS OF COLLINGWOOD, ONT.

But the story of the boulder pavements and fringes is not yet complete. Coast-ice has also played an important part in the arrangement of the paving stones. The waves, acting upon the coast-ice wherein boulders have been entangled, cause the stones to be forced up into more regular zones, as to height, than would be affected by the residuary deposition alone, as just described. Blocks of large size can thus be moved, not merely by the heaving action of modern frosts, but by the action of coast-ice itself; for boulders upon the margins of the St. Lawrence river, weighing 70 tons, are known to have been shifted by the spring movements of a winter's ice. Again, the writer has seen upon some of the shores of Shoal lake, in Manitoba, situated in a flat drift-covered country, modern beaches composed of huge boulders, piled up by the waves of the lake acting upon the ice in which the stones were enclosed, as otherwise blocks four or six feet long could not be gathered from the shores of the lake and accumulated into beach ridges, nor could they have been residual pavements as above described, for no high shores of boulder clay occur into which the waves could have made encroachments.

An excellent illustration of the modern formation of boulder pavements and fringes may be seen upon the shores of Georgian bay, between Thornbury and Collingwood, as shown in Plate II, fig. 9. There the lake waves are encroaching upon a shore composed of boulder clay. The larger stones standing out in the water are too heavy to be materially affected by the waves or ice action. Excellent illustrations of boulder zones are found a short distance from this locality, at an elevation of 187 feet above the lake, as shown in Plate II, fig. 10.

Other examples of fringes of boulders high above any modern waters may be seen a few miles beyond the eastern end of Lake Ontario. The same is true upon the northern side of the lake, as for example, back of Trenton and westward; these are parts of and in front of the finer gravels of an old beach, now more than 400 feet above the lake. Westward of Toronto, where the old shores are of Paleozoic rocks, in place of drift, the boulder pavements disappear from the front of the beach.

Upon the steep hillsides, as long the Mahoning valley, near the crossing of the Ohio-Pennsylvania line, there are zones thickly covered with boulders. There we find the records of old water-margins, as well as in the pavements associated with the well marked beaches and shore-cliffs facing the lake basins. The finer materials have been washed out of the associated drift to form bars, in the valley, which was once filled with water. On some of the higher hills between the southern part of Georgian bay and Lake Huron, to the west, the tops of ridges are covered with boulder pavements. These ridges were islands in a former expanded lake or sea, whose surfaces were encroached upon by the waves, until they were reduced to partially submerged reefs covered with great erratic blocks, as the finer mud was borne into deep water. That these were island shores may be seen from the boulder covered ridges, although miles apart, being reduced to a common altitude.

On the hillsides, behind the fringes, there are only here and there irregularly deposited blocks exposed by the action of rains. Besides, the meteoric effects upon any of the hills are small, compared with the encroachments of the waves, in exposing enough stones to make boulder pavements.

The occasional erratic blocks often reposing upon fine lacustrine deposits are of little importance, and indicate only an occasional stone entangled in old coast-ice from an adjacent shore, when the region was covered with water, just as the boulders resting upon the sunken ships in the mouth of the Baltic have been deposited from the coast-ice moving out of the sea.

The study of the relation of the pavements of boulders to beaches set at rest the speculation upon the origin of these fringes, and obviates the necessity for appealing to either icebergs or glaciers in later Pleistocene days to account for the erratics popularly called "hard heads," which are scattered over the country in the form of pavements or fringes; for these are mostly seen only where they can now be referred to some old coast line, or a succession of shore lines, acted upon, in former days, by frost and coast-ice.

High-Level Gravel Deposits in the Region of the Great Lakes.

Rather than rummage through the talus heaps of geological literature for the different kinds of gravel deposits which may represent beach structure, it is easier to go into the field of observation and investigate those forms which may be modified beaches, or be related to, or be mistaken for them. This method is the more satisfactory, as in geological literature different forms are confounded, and others are left unnoticed, or not considered in the light of the present investigation. The object of this chapter is to describe the various kinds of gravel deposits, which resemble or are related to beach structure, and not to consider their occasionally doubtful origin or distribution. Exclusive of the beds of sand, which are intimately connected with the stratified clays, or included in the drift accumulations themselves, and the ancient shores already described, the following groups of gravels and sands should be noticed, some of which are covered with the stony clay of the upper till:

A. *The gravels and sands which are buried beneath the upper drift deposits.*—These may be divided into (*a*) buried beaches; and (*b*) more or less irregular beds and ridges of gravel and sand, often of earthy texture, having a more or less tumultuous structure, and resting beneath accumulations of the upper till.

B. *Surface accumulations of gravels and sands, forming ridges, mounds and plains.*—These are in the form of (*a*) the so-called osars and kames; (*b*) other ridges and mounds resembling the last, but having a position corresponding to that of beaches, in front of more elevated plains or drift hills, or of the accumulations included in group A *b*; and (*c*) gravel plains

A *a*.—Hitherto, the buried beaches have not been distinguished from other beds of gravel and sand intercalated within the drift formations. As such accumulations, whose structure is the same as that of modern beaches, are only exposed in sections cut through the surface deposits by streams or artificial excavations, all of the knowledge that we can, at present, hope to acquire, is the recognition that there were beaches, now covered by drift, older than those upon the surface of the country. When beds of gravel and sand are met with in borings, it is not always possible to distinguish those which are buried beaches from others which are intercalated with drift deposits. The structure of the buried beaches does not show that tumultuous crumpling, so commonly seen in the next kind of accumulations (A *b*). In some places the gravels are found cemented into conglomerates. Thin layers of stony clay, constituting the upper till, which covers vast areas of the country throughout the lake region, often rest comformably upon the undisturbed surfaces of the buried beaches, that may have a thickness of twenty feet or more. Excellent examples of buried beaches may be seen along the Au Sable river, southeast of Lake Huron, where the overlying drift clay is only four or six feet thick. When the covering is thin, there is a liability of mistaking these older beds for those belonging to the beach epoch proper.

A *b*.—The internal structure of this kind of gravel and sand deposits shows stratification, which may be regular in one place, but the beds soon become tumultuous, that is, the beds become irregular, bent or twisted, and confused. The materials are apt to be somewhat earthy

Throughout these layers there may occur occasional boulders of large size, and pockets of gravel, whose outlines resemble those of boulders (as if the gravel had been cemented into masses by frost and then moulded into boulders, and afterwards deposited in the frozen state.) By the characters just given, these accumulations can be readily distinguished from those of true beaches. They are commonly overlaid by a few feet (perhaps 10 or 20) of stony clay or other materials of the upper till. Occasionally the covering may reach several times this thickness.

The external form of these deposits, with their clay mantle (which last is dependent upon the form of the underlying gravels), may be that of undulating plains, or these undulations rising to the magnitude of ridges and hills. In this case, the ridges rise in succession one above the other, until they reach an altitude of 100 feet, or even more, above the plains which are commonly in front of them. They may occupy a breadth of several miles across the country. The ends of the ridges often overlap, and at other times send out spurs, and inclose kettle-like depressions, which are liable to be confounded with or not separated from those of the next group. These ridges occur associated with some of the so-called moraines of America. These slightly covered sand and gravel deposits are not so commonly developed below the altitude of 700 feet above the sea as at higher elevations, for the lower country is more apt to consist of terraces, cut in the drift, and of silt deposits and beaches. But these accumulations cap the ridges of the great chain named the Oak hills, which extend for over 100 miles in length, parallel to the northern side of Lake Ontario, at an elevation of from 900 to 1,200 feet above the sea. Farther west, such are also the capping materials of the country, which is 1,700 feet above the sea. The same holds true for Michigan and other States.

D.—The gravels of this group are not only well water-worn but also well washed and free from earthy matter. Indeed, they are sometimes free from the finer sand. The pebbles are often coarser than in the lower beaches, in some cases forming accumulations of almost cobble stones. There are occasional boulders in the mass, but these are more common upon the surface. The materials are mostly of local origin, with a small proportion of transported crystalline stones. None of the materials have been derived directly from the subjacent Paleozoic rocks, but secondarily from the assortment of the stony boulder clays. The gravels, with their accompanying beds of sand, when these are present, are stratified as in beaches, without anything of the tumultuous structure of the last group. Still, there may be a false bedding, as in beaches; and when the deposits assume the form of ridges, the layers may dip in opposite directions, as in barrier beaches. The materials of this group are never covered with drift deposits, but often rest upon the till, or against hills of the tumultuous accumulations already described. In external form, the gravel deposits differ greatly, and it is upon this character that they are divided into the three series.

B *a.* *Osars* and *Kames.*—The osars (Anglicized from the Swedish word asar, meaning gravel hills) being the term in America applied to very narrow gravel ridges (often only a few score yards in width at the base) or chains of mounds, winding in a more or less serpentine manner across a comparatively flat country, above which they rise at nearly as steep angles as the loose material will stand to a height of 40 or 60 feet. They are also defined as generally extending from a higher to a lower country and following the course of the greater valleys—that is, at right angles to the coast lines. A beautiful example of an osar, as above described, is to be seen southeast of Lansing, Michigan. It trends into an inlet among the hills, oblique to the general direction of the ancient coast. Driving along the top of the ridge, which is scarcely wider than the road, it is seen to be composed of constantly and suddenly alternating stretches, each quite level, the one set being about 25 feet above the other. These so-called osars form a very limited proportion of the gravel ridges of this group.

The term kame (the Scotch vernacular for gravel hill), according to its use in America, is described by Chamberlin as "assemblages of conical hills and short irregular ridges of discordantly stratified gravel; between which are irregular depressions and symmetrical bowl-shaped hollows that give to the whole a peculiar, tumultuous, billowy aspect. * * * These irregular accumulations are, however, more abundant in connection with deep, rapidly descending valleys, being especially abundant where they are joined by tributaries or where they make a sharp turn in open portions of their valleys, and especially where they debouch into an open plainer country. In such instances they are usually associated with gravel terraces and plains. Precisely similar accumulations are very common associates, if not constituents, of terminal moraines. * * * They are transverse to the slope of the surface, the course of the valleys and the direction of the drift movement."* From observation in nature, as also from the description itself, it will be seen that the term kame is not specifically used, and that different kinds of gravel deposits are grouped under the same name. Indeed, from the above description, the term might be better applied to some of the deposits described above under group A *b*, which

* Third Annual Report of the U. S. Geological Survey, 1883, p. 300.

are more or less covered with clay. However, there are conical and tapering ridges in many localities without a tumultuous structure, whose relations to each other are not easily discernable, that may be placed here under the name of kame. Some of the kames in the valleys are doubtless river deposits, and others are the remains of uncovered buried beaches of greater age, exposed by subsequent erosion.

B *b*.— The internal structure of this series is similar to that of the other members of the group. The external form is that of intermittent ridges, sometimes rising to sixty feet above a frontal subaqueous coastal plain which is occupying the position as in front of a beach. The ridges may be replaced by cones, resembling delta deposits. The ridges are often scarcely less direct and scarcely more broken or more varying in height than beaches, especially when the subsequent erosion and unequal elevation, caused by terrestrial movements since the gravels were deposited, is taken into account. The ridges are often found to divide and enclose kettle-like depressions, sometimes dry and sometimes containing ponds or lakelets, just like similar depressions along modern beaches, but on a larger scale. Branches and spurs add to the undulating appearance of the country. In front of these hills the plains may be covered with gravel. It is very difficult not to see in these ridges the remains of beaches belonging to former shore-lines. A single ridge of this character occurs behind a plain just north of Stouffville, Ontario, rising to a height of 75 feet above the plain, which is about 1,100 feet above the sea. This deposit rests against another and somewhat larger ridge of sand and gravel belonging to group A *b*. Again, within a distance of 14 miles, stretching northwestward from a point near Flesherton (shown in fig. 11), there are three steps, each in the form of a slightly undulating plain, often paved with gravel, bounded by just such hills of gravel as are here described. These marginal ridges are much indented with kettle depressions (*k*, *k*, fig. 11), and are somewhat beneath the level of well-marked

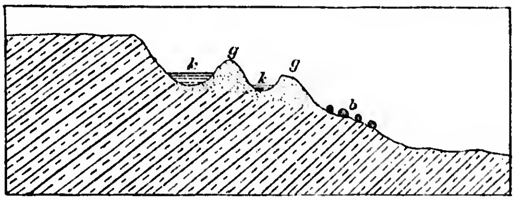


FIG. 11 — *Section extending northward from Flesherton.*

b — Boulder pavement. *g*, *g* Ridges of Artemisia gravel. *k*, *k* — Depressions behind the gravel ridges.

terraces, as if a somewhat off-shore deposit. The elevation of the country above the sea descends from 1,600 to 1,200 feet. The ridges (*g*, *g*, fig. 11) border a mass of land that was rising out of, probably, the sea. The beach-like character of these accumulations is further brought out by the occurrence of zones of boulder pavements at levels below and immediately in front of the ridges (*b*, fig. 11). These boulder pavements, which do not enter the mass of the drift but only rest upon its surface, are too characteristic of the action of waves cutting into stony drift and of the accompanying action of coast-ice not to be regarded here as additional evidence of the coastal formation of the surface gravel ridges, described in this paragraph.

"Artemisia gravel" is a name applied by the Canadian Geoleogical Survey to the gravels covering an area of 2,000 square miles of the highest land in Ontario, between the three lakes, Huron, Erie and Ontario, rising in places to 1,700 feet above the sea. But at that early date, geologists did not differentuate the various gravel accumulations. Indeed, the whole work upon the drift of Ontario was only pioneering, and now being somewhat antiquated and generalized, it needs to be revised and differentiated by modern investigations. Thus the term Artemisia includes sand, gravel, and even upper till deposits (the last, although occupying thousands of miles of the surface of the Province, was not formerly identified) of all kinds and ages mentioned in this chapter and in that on beaches. However, it was the accumulation of the gravels described in this group B *b*, in the township of Artemisia, that gave the name which was extended over such a wide range of materials and geological time as if all were one formation. At most the term should be restricted to the ridges occupying the position of very high-level beaches, just described.

B *c*.— Gravel plains are common in front of such high-level ridges as have been last described, representing the subaqueous floors when the waves beat upon the old shores. Some of them, however, may be the floors of terraces cut into the older gravel deposits. The plains are often very deeply eroded, owing to the high elevation of the country and the long action of meteoric agencies upon the incoherent materials. Thus, there sometimes remain of these plains only a succession of ridges, between ravines deeply excavated by the numerous streams and floods. Such plains occur in the typical region of the Artemisia gravel in Ontario, in Michigan, and in other States.

CHAPTER IV.*

Deformation of the Iroquois Beach and Birth of Lake Ontario.†

Upon receding from the lake and ascending the high country which bounds the Ontario basin, an observer is attracted to the wonderfully plain shore-lines which record the former expansion of the waters. The terraces, beaches, scarps, and spits across the mouths of valleys clearly represent the deserted shores. But they are no longer horizontal lines as when laid down at the level of the former waters. As distinctive features, the beaches were so striking as to attract the attention of the aborigines, who used them as trails across an otherwise, sometimes, muddy country. The early white settlers, in turn, used them as high ways and hence we find the "ridge roads" about Ontario as well as about the upper lakes. But the recognition of the shore-like characters of the raised beaches, by the early writers,‡ did not contribute much to the solution of the lake history.

Nearly fifty years ago, Professor James Hall observed that the beaches of New York were not horizontal. But Mr. G. K. Gilbert was the first who connected and measured the deformation of the beaches upon the southern and eastern margins of Lake Ontario, and the writer upon the Canadian side of the lake to beyond Trenton, whence the same beach swings around towards the north and passes into a broken country. The writer has further carried the survey of the same beach to the northeastern portion of the Adirondacks.

There are wide-spread remains of old shore-lines at altitudes so high above Lake Ontario, as to indicate that the same sheet of water

---

* Reprinted from Amer. Jour. Sci., Vol. XL, pp. 443-451, Dec. 1890.

† The forerunner of this paper — "The Iroquois Beach, a chapter in the Geological History of Lake Ontario" — was first read before the Philosophical Society of Washington, January, 1888, Proc. Phil. Soc. for 1888, and was subsequently amplified and published in full in the Transactions of the Royal Society of Canada for 1889.

‡ For reference to early writers, see "Iroquois Beach," etc., Transactions Royal Society of Canada, 1889, page 121.

(Warren water) covered also the basins of the other and higher lakes. After the dismemberment of this greater sheet of water, the surface of that occupying the Ontario–St. Lawrence valley was gradually lowered, and fell several hundred feet, without pausing long enough to deeply cut out or straighten its changing shore lines. At last, this shrinkage of the waters came to a pause lasting until the shore-line became more pronounced than that of the modern lake. It is this shore-line that forms the basis of the present chapter, and constitutes that water-margin which the writer has named the "Iroquois Beach,"* in memory of the aborigines who trailed over its gravel ridges.

The general structure of the ancient shore-lines is somewhat fully described in "Ancient Shores, Boulder Pavements, etc."† But let us here repeat some of the characteristics. Typically, the ancient beach consists of a ridge of gravel and sand rising sometimes to twenty-five or more above the frontal plain, which further descends lakeward (as in fig. 3, p 28). Back of the ridge, which rarely exceeds a width of 500 feet, and usually less, with a very narrow crest, there is often a lagoon-like depression. The beach may be broken into a number of ridges (*b* or *c*). The summit marks the heighth of the wave action. This barrier ridge may become a terrace, or it may pass into the form of a spit across some valley (*h* or *b*, fig 6). Again the ridge may be wanting, but the shore will be represented as a cut terrace (fig 4), in front of which a boulder pavement may frequently be seen (P). This pavement is also often found in front of gravel beaches. In places where the former waters were gnawing away the drift shores, or where rocky promontories rose out of deep water, true beach structure is wanting, or only represented by benches.

In the survey of the Iroquois Beach, the shore line has been followed by one or another of its characteristics, even across areas of broken physical features. The altitude of the highest ridge, where the beach is broken up into a series of ridges, is that which has been everywhere taken, for it is the one giving most accurate results. No elevations have been adopted except those of the summit of the crests (as in fig. 3), or of the spits (at *h* or *b*, fig. 6, p. 30). The measurements consequently represent the maximum height of wave-action, in place of the mean surface of the water, which was a few feet below. The writer's leveling has everywhere been done instrumentally.

---

* The name was first printed in Science, Jan. 27, 1888, p. 49.

† By the writer, in Bulletin of the Geological Society of America, vol. 1, 1879, p. 71.

The coast materials, out of which the Iroquois shores have been carved, are most boulder clay, or stratified clays or sands, deposited upon the floor of the lake when the waters were at higher levels. At a few places the shores rest against Paleozoic rocks, in which cases the materials of the gravel beach are more scanty, as the pebbles were mostly derived from the stony drift, or there may be an absence of the beach.

Except in spits across old valleys, the thickness of the sand and gravel of the beach does not usually exceed 20 feet, but in front of valleys it may reach a thickness of 100 feet (*h*, fig. 6). The internal structure always shows stratification, with such sloping and false-bedding as are characteristic of beaches.

There are frequent exposures which shows that the Iroquois Beach rests upon stratified stoneless clay — the silt washed into the waters when the waves were encroaching upon older and higher shore-lines, and assorting the boulder clay, which, at the higher elevations, formed the coast. Eastward of Watertown, the beach rests upon stratified sand in place of clay, as there was but little stony clay in the drift to furnish silt for the older lake floor.

From near Trenton to the head of the lake, and thence around the southern and eastern borders to near Watertown, the Iroquois Beach is not hard to follow; but eastward of that point the features are more complex. The old coast of stony clay is there replaced by stony drift sand, and hence there is but little lithological distinction between the frontal plain and the older sandy drift shores. Moreover, such a coast is apt to be defaced by the sand being heaped into dunes. Again, in the region beyond Watertown, the Iroquois Beach is interrupted by promontories of Paleozoic limestones and shales, rising out of deep water, upon which at most only benches were cut. Farther, north-eastward, the beaches trend among bold headlands and islands of crystalline rocks. Wave action, which carves broad terraces out of drift materials, can cut only moderately well-marked benches out of limestones. But when the same intensity of wave force is applied to hard crystalline rocks, especially when interrupted by islands, the benches become less conspicuous than when excavated out of lime-stones, or they may become very obscure. Still, upon the flanks of the Adirondack Mountains, the Iroquois Beach can be followed and identified by the remains of barrier ridges, terraces, bowlder-pavements, benches, and above all by the occurrence of spits across old valleys.

Combining the surveys of Mr. Gilbert and the writer, the position of the Iroquois Beach is shown on the accompanying map.

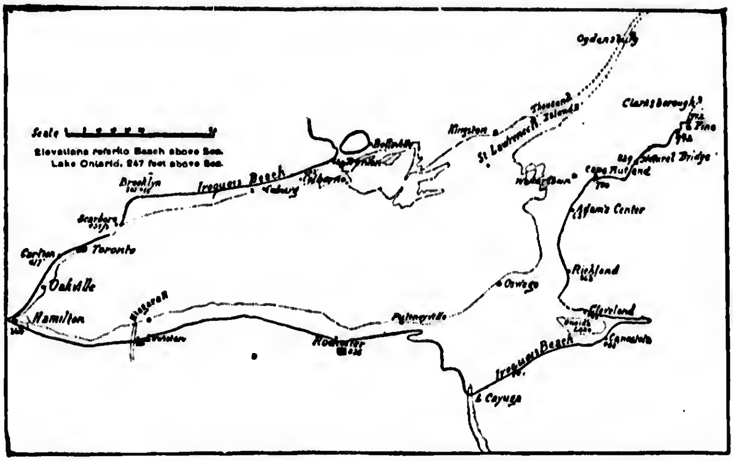


FIG. 12.—*Map of the Iroquois Gulf.*

The following table gives the elevation at salient points along the Iroquois Beach. The elevations given are those of the crest of

	Feet above the sea.	
Lake Ontario, surface of	247	(U. S. Lake Survey).
Hamilton	362	(Spencer).
Burlington Heights	355	"
Waterdown Station	363	"
Cooksville Station, about	400	"
Carlton Station	417	"
Kingston Road, crossing railway 12 miles east of Toronto	459	"
Whitby, 6 miles north of lake, near	507	"
Colborne Station, 2 miles north of	602	"
Trenton Station, 2½ miles north of	632	"
Lewiston, N. Y	385	(Gilbert).
Rochester, N. Y	436	"
Canastota, N. Y	441	"
Cleveland, N. Y	484	"
Constantia, N. Y	489	"
Richland, N. Y	563	"
Adams Centre, N. Y	657	"
Prospect Farm, 4 miles east of Watertown	730	(Spencer).
Natural Bridge	829	"
East Pitcairn, 1 mile northeast of	942	"
Fine	972	"

the highest ridge, where the beach is broken into a number of ridgelets, having sometimes a vertical range of twenty-five feet or more.

Thus we see that the Iroquois Beach has been deformed to the extent of 600 feet, between the western end of Lake Ontario and Fine, of which only 78 feet of rise occurs upon the southern side of the present lake, while the great proportion of the uplift is found west and northwest of the Adirondack Mountains. Upon the northern side of the lake, the eastern equivalent of uplift is more pronounced. At the western end of the lake, the mean maximum uplift is 1.60 feet per mile in a direction of N. 28 E. This rate increases towards the northeast. To give a mean rate of rise, at the eastern end of the lake, does not convey a correct idea, for the uplift increases in a progressive ratio. Thus in the region of Oneida Lake, the uplift is 3.5 feet per mile, while in the region of Watertown it amounts to 5 feet per mile; and farther northeastward the deformation reaches 6 feet per mile, in the direction of N. 60° E. This seems an extraordinary amount of measurable terrestrial movement, but the records are inscribed in the beach. It is not yet known where this upward movement ceases.

Upon the Erie beaches, outside of the Ontario basin, Mr. Gilbert found a considerable amount of warping recorded at Crittenden, N. Y., over the horizon at the western end of the same lake. I have traced the Erie beaches around to the southeastern side of Lake Michigan. Combining our results, I find the measured uplift between the two regions amounts to 324 feet. But the beach, where last observed near Lake Michigan, is 45 feet above its surface. Indeed, it is there difficult to trace, owing to the duny character of the sandy country. By the assistance of other beaches found in that region, the conclusion is readily arrived at that the shore-line under consideration must pass from 40 to 60 feet beneath the waters of the lake at Chicago. It is then evident that the terrestrial uplift, between Chicago and Crittenden, amounts to not less than 410 feet. Crittenden is nearly on the line of strike of the Iroquois beach (S. 62° E.), at its lowest point, at Hamilton The Erie beaches, eastward of the Niagara River, were deformed to the extent of 0.4 feet per mile before the Iroquois episode, the remainder of their uplift having been synchronous with that in the Ontario basin. But the pre-Iroquois differential uplift of the beaches farther west is reduced to almost zero, for the beaches south and west of Lake Erie have suffered very little deformation. Consequently a sufficient amount of deformation of the beaches has been measured to allow for inaccuracies when we take the elevation of the Iroquois Beach above the sea level (363 feet), as the amount of movement that must be added to the Iroquois plain in order to represent the terrestrial uplift of the Ontario basin since the Iroquios shore was formed. Therefore, it is apparent that *the great Iroquois Beach was constructed approximately at sea level.* The total amount of uplift since the episode will then be the height of the beach, at any place, measured above the sea level, which, at Fine, is 972 feet.

Were the Erie beaches recognizable in the Adirondack wilderness near Fine, they should be found at altitudes of 1,600 feet and more above the sea. But this is a calculation outside of our subject, which is based upon measurements.

The terrestrial movements recorded in the beaches have not been those of subsidence towards the west, but of uplift towards the east, in the same direction as those changes which have left unquestioned marine remains deposited at high altitudes in the St. Lawrence valley.

One focus of the warping about the western end of Lake Ontario and about Georgian Bay appears to have been in the region of lat. 48° N., long. 76° W. Another focus of uplift is somewhere beyond the last point of rise measured in the Adirondacks. Thus the axis between these foci appears to coincide, more or less, with the old Archæan axis of the continent, as suggested by Professor Dana.

The uplift of the Iroquois Beach has been since the episode of the uppermost deposits of drift or till, for higher and older beaches than the Iroquois rest upon the newest stony clays of Ontario, Michigan and and other states. The Iroquois Beach rests upon the mud floors of the earlier sheets of water which covered the till deposits. The rate of northeastward regional uplift has been gradually diminishing, for we find other beaches, lower than the Iroquois, whose rate of rise is much reduced below that of the great beach. But the Iroquois plain was the great event in the history of the Ontario basin.

In the rising of the land, after the Iroquois episode, there were pauses, but not of such duration as to permit of the formation of great shore-lines like that thus described. After the waters had fallen about 200 feet below the Iroquois plain, there was a conspicuous rest. This is recorded in a terrace near Watertown at 535 feet above the sea. At Oswego, we find a beach descending to near water level, at about 185 feet below the great Iroquois beach. Farther westward, it passes below the lake. The dip of the Iroquois Beach, between the region of Oswego and the western end of the lake, is about 78 feet; and accordingly we should find the remains of this younger shore-line (for a large proportion of the regional uplift has been effected since its formation) submerged to 65 or 70 feet at the western end of the lake. Behind the modern bars and beaches, the water of Irondiquois Bay (a narrow river like channel) is 78 feet deep; the Niagara River, 72 feet; and Burlington Bay, 78 feet. These conditions indicate that the lake covering these channels was at one time withdrawn, leaving only a few feet of water in the rivers which flowed through the otherwise dry valleys. Here, then, in front of the bay, submerged or buried by more recent accumulations (upon re-submergence), is the position of this lower beach extending westward of Oswego, which was formed at a level now 70 feet below the surface of the western end of the lake. Indeed, the uniformly narrow Burlington Beach (*b*, fig. 6), with a length of five miles across the end of Lake Ontario, is thus easily explained as having originated as a small barrier, in front of the shallow river flowing down the Dundas valley and across the now submerged floor of Burlington Bay. With the more recent backing of the waters of the lake, this bar grew to the proportions of the modern beach, built out of materials derived from the older shores and not from river deposits.

At the time when this young beach — now beneath the lake — was being formed, the waters had receded for only from three to five miles from what are now the western shores of Ontario, but they extended farther landward than at present upon its northern side, as shown by the raised beaches, and by the absence of submerged channels.

The Niagara River was about four miles longer than now, cutting its way over a projecting point of shaly rocks. But this channel is at present filled, and is again further submerged beneath the lake.

During the continued rise, the waters of the Ontario basin may have been even somewhat further shrunken at its western end, and the waves may have mouldered some of the submerged escarpments upon the southern side. The waters upon the southern side could have nowhere been more than about 200 feet below the present level, even if that amount of shrinkage, which represents most of the barrier holding the basin above the sea, ever obtained. However, no important geographical event is recorded in any of the possible coast-lines submerged at levels below that just described.

With the regional uplift, the barrier across the St. Lawrence valley eventually cut off free communication with the sea, at a common level. This uplift was continued until the Iroquois Beach now rests at 972 feet above the sea at Fine, and the modern lake at 247 feet. *Thus the modern lake had its birth.* This warping at the northwestern end of the lake, during the later and since the Pleistocene period, has been enough not only to account for the rocky barrier holding the lake above the sea, but to account for all the barrier across the St. Lawrence valley closing the ancient basin of Ontario to a depth of nearly 500 feet below sea level.*

In the Iroquois Beach no shells have been found. Only the remains of mammoth, elk and beaver have been met with.† Consequently, the question arises as to the freshness of the waters. Not far from the eastern end of Lake Ontario, the remains of a whale were found at 450 feet above the sea — at an elevation which would admit of the free access of oceanic waters into the Ontario basin.‡ Still no other marine or fresh-water fossils have been found in the beaches. It therefore appears to me that the absence of such organisms speaks no more in favor of fresh water conditions than of brackish or even salt when the Iroquois shores were being formed; and does not preclude the idea of free communications with the sea any more than when the whale came landward in waters 200 feet higher than the present lake surface. Indeed, I look upon the Ontario-St. Lawrence valley, during the Iroquois episode, as resembling the Gulf of Obi, which is a sheet of water from 40 to 60 miles wide, and 600 to 700 miles long, into which so much fresh water is discharging as to render even the Arctic Sea for 60 miles beyond the mouth of the gulf so fresh as to be almost potable,§ and sufficiently fresh to destroy marine life.

The only dam that has been hypothecated as filling the St. Lawrence valley is that of a glacier. As the Iroquois Beach was at sea level, no dam ought to be required to hold up the water, but at most only to keep out the sea. However, I have followed the beach for 100 miles within the margin of the hypothecated barrier without finding the traces of an ending of the old shore markings upon the confines of the Adirondack wilderness. Even the coincidence of the shallow and small channel, discovered by Mr. Gilbert, connecting the Iroquois waters with the sea, by the Mohawk valley, or of the broader and lower valley of Lake Champlain, does not prove the necessity of a former barrier across the St. Lawrence valley

* See origin of the Basins of the Great Lakes, by J. W. Spencer, Q. J. G. S., vol. xlvi, Part 4. 1890.

† Col. C. C. Grant of Hamilton has recently found other vertebrate remains, but not yet determined.

‡ Sir W. Dawson. Can. Nat., vol. x, p. 385. The remains are in the Redpath Museum at Montreal.

§ Nordenskjöld in "Voyage of the Vega," p. 140.

any more than the narrow channels among the gigantic islands north of Hudson Bay would prove the former presence of a dam holding in the waters of that bay, were the whole country elevated. For a glacial dam to exist across the Adirondacks, even at the narrowest point, it would need to be 80 or 100 miles wide. If it had no greater depth than the water north of Fine used to have, the ice would need to be thick enough to fill a channel of 800 feet depth. As the differential uplift probably continues throughout the Adirondack region, we would need to be prepared to accept a dam of at least 1,300 feet in thickness, and a hundred miles across. *Apparent beaches in Vermont at 2,100 feet above the sea (Hitchcock),** and the post-Pleistocene emergence of Mt. Desert, observed in the coastal markings to its summit of 1,500 feet (Shaler),† increase the probability of our regional uplift continuing throughout the Adirondacks.

Any water proof dam in front of the Iroquois Beach would have had to endure throughout the long period of its formation. But all known glacial dams are small and evanescent. Yet the one suggested as closing up the Ontario's basin would have had to retain a greater sheet of open water than that of modern Lake Ontario, receiving not merely the waters of the then upper lakes, but also those of the melting of the hypothecated glacial dam. It is questionable what thickness of ice would hold in the waters, for the modern glacial dams of Mt. St. Elias discharge beneath 500 feet of ice for a distance of eight miles.‡ As soon as the waters fell below the Mohawk outlet, the discharge of the glacial lake ought to have melted and lowered the ice on the one side and carved out terraces on the other, unless the river were 50 to 100 miles wide. And there are terraces upon the northern side of the Ottawa valley, as well as upon the flanks of the Adirondacks.

There seem to me to be no phenomena in the later lake history of Ontario necessitating the existence of a dam across the St. Lawrence valley. In short, the Iroquois water was a gulf. The Adirondacks and New England formed great islands. The Iroquois episode commenced almost synchronous with the birth of the Niagara Falls. And the history of Lake Ontario records interesting and great changes which now form a simple story.

***NOTE.—Subsequent investigations confirm the absence of glacial dams.**

**Geology of Vermont.

†Geology of Mt. Desert. Eighth Annual Report of U. S. Geol. Survey.

‡Harold Topham in Proc. Roy. Geog. Soc., 1889, p. 424.

APPENDIX TO THE IROQUOIS SHORE NORTH OF THE ADIRONDACKS.

In previous papers on the Iroquois shores of the Ontario basin, their position was definitely located only to a point near Belleville, on the northern side of Lake Ontario. But, from the general character of the country, I pointed out the necessity of extending the Iroquois water across a broad expanse of country to the highlands north of the Ottawa river, on the flanks of which shore deposits are known at various localities. I have also shown that the Iroquois water stood at or near sea-level; and in my working hypothesis considered the Iroquois water as an extension of the gulf of Saint Lawrence into the Ontario basin, although more or less obstructed by ice. Since the last paper was written, Mr. G. K. Gilbert and myself have revisited the region as far as a point 100 miles northeast of Watertown. Owing to Mr. Warren Upham's recent acceptance of the extension of the open Iroquois water as far as Quebec, it becomes desirable that the old shore line, so far as definitely surveyed, should be published.

After a long stretch of unbroken continuity, the Iroquois beach is abruptly interrupted by rocky cliffs on the side of the escarpment about five miles east of Watertown. Beyond this point, owing to the broken continuity, the remmants of the ancient shore are more or less fragmentary. The old subaqueous plain extends up the broad Black river valley far above Carthage, with gravel deposits characterizing portions of its margin. The northeastward elevation of the Iroquois beach in this region rises at over six feet per mile. Beyond Carthage, the country becomes more broken, being traversed by ridges of crystalline rocks, forming a late extension of the archipelago of the Thousand Islands at a higher level. The drift deposits become more sandy, with very little clay, and consequently are less favorable for the production of well defined beaches. The island character of this region is particularly unfavorable for the development of well defined shore markings. But wherever valleys enter the archipelago, their outlets are characterized by delta deposits of terraces, whose hypsometric position can be predicted in proceeding eastward.

At Mr. Frank Wilson's, four miles east of Watertown, the unquestioned beach is broken into ridgelets between 730 and 704 feet, with a frontal gravel-bearing terrace at 682 feet. Below this horizon there is an extensive terrace plain east of Watertown at about 535 feet. At the mouth of Indian river, at Natural Bridge, these delta deposits form terraces, with more or less beach structure, at an elevation between 829 and 802 feet, with a frontal gravel plain descending from 787 feet downward. In both cases, the waves, in carving out the lower terraces, have removed portions of the higher ridgelets. Between these limits there is no strongly marked terrace, but the lower is more confined to this regional topography than the upper; and where gravelly, the pebbles are subordinate to the sand. For quantity and size of water-worn pebbles, the gravel deposits at Natural Bridge are physically the equivalents of those of the Iroquois beach to the southwestward. Above and below this level, at Natural Bridge, there are no fragments of ancient water lines liable to be mistaken for the Iroquois shore. The elevation of these deposits is that which would be expected from the measured warping recorded about Watertown. Beyond Natural Bridge there are extended gravel plains, in height conforming to the terraces at the old mouth of Indian river; but these are often more or less pitted.

These plains appear to me as due to the presence of floebergs or other masses of ice stranded upon the old shore. Even if they were shore deposits formed in glacial lakelets, their elevation is such as to show a common water level. They now face a lower descending country to the northwestward, and are deformed by the gradual warping toward the northeast. At Pitcairn, the valley is 200 feet or more in depth, forming a deep channel in the late expansion of the Laurentian archipelago. High on the sides of the valley zones of boulders, which are so often characteristic of old shore lines, are found at heights in keeping with the deformed Iroquois beach.

A little north of East Pitcairn, there is a fine display of terraces, with beach structure. These are partly in front of a now unimportant valley. There are several ridgelets, the highest being 942 feet; but the most important is 930 feet above tide. These ridgelets descend to a terrace or frontal plain 60 feet below. A short distance beyond, the terraces of Oswegatchee river are seen. Just north of Fine, they close around and connect a rocky island with the eastern side, and form a sort of barrier beach. This bar has an elevation of 972 feet. All of the above recorded terraces were leveled. The following are of barometric measurement. The rise in height in these beaches corresponds to the deformation of the Iroquois beach, increasing from five to six and seven feet for miles toward the northeast, which amount ought perhaps to be slightly modified, owing to imperfect

Reprinted from the BULL. GEOL. SOC. AM., Vol. III., p. 483–191, 1891.

identification in the crests of these terraces or the absence of some portions of the highest ridgelets.

The next great valley is that of the Grassy river. At Clifton Forge (Clarksboro), the old mouth of the valley is well defined by a beautiful gravel terrace at 1,055 feet (bar.), with an inferior terrace or ridge at 45 feet below. Lower than this no well marked gravel terrace occurs; but at 850 feet there is an extensive sand plain, forming a terrace confined to the valley. The terrace in the last valley is nearly due north of that at Fine, and appears to represent a warping of eight feet per mile, but probably the barometric measurement is responsible for the apparent increase in rate of elevation. Still, the northern uplift may probably exceed that to the northeast.

The chain of observation was continued by Mr. Gilbert and myself to Racket river. The elevations were not satisfactorily obtained, as the changing weather greatly affected the barometer, especially above South Colton. At South Colton there is a sandy plain at about 940 feet (bar.), apparently corresponding to the plains below Clifton Forge and Fine. Racket river presents an interesting change of channel near Stark post-office. Its old course was in a broad valley, now occupied by Coldwater creek as far as South Colton; but after the Pleistocene revolution, it cut across hard rocks and deserted its old channel. Following up the Coldwater valley, we reached a broad sandy terrace underlain by gravel. This plain forms terraces extending northward along the sides of the valley. Its elevation is 1,215 (?bar.; the weather was very threatening). Other deposits were noted at 1,350 feet, which were probably older valley terraces. Again, on the brow of the plateau facing Potsdam, there was a plain at 1,160 feet with a boulder pavement in front of it. The value of these measurements is impaired that they are only important in identifying continued elevations of the terrace plains near the late outlets of the valleys as far eastward as Racket river. In descending from the last plain there was no extensive valley terrace below the level of South Colton of magnitude corresponding to those at Watertown or at Clifton Forge. It might be noted that throughout this high region all of the pebbles are of local origin and none that could be identified as Canadian. The Paleozoic rocks were absent from the drift above South Colton and Parishville. Indeed, some of the apparent sandstones are cleavable quartzitic gneisses, and require close observation to prevent mistake.

Along the whole northern flank of the Adirondacks, there is a great poverty of glaciated surfaces. Near Natural Bridge the direction of the striæ was south 75° west and south 55° west. On the hills farther south the direction was south 20° to 25° east, and near Harrisville south 10° west. Boulders were of large size. One, at a school house three miles southwest of South Colton, showed at least 6,000 cubic feet above surface of the ground.

From the recent explorations, allowing for errors in observation and measurement, it appears that shore deposits occur at the mouths of all the valleys which entered the Laurentian archipelago of the Thousand Islands. Throughout a considerable range of altitude, there is only one set of terraces or delta deposits, *always* occurring at the mouths of old valleys, with occasional connecting gravel plains or terraces of beach-like structure, composed of coarse pebbles, in magnitude comparable to the physical development of the Iroquois beach farther westward; the lower terraces being mainly sandy and confined to the valleys; and the higher, if known at all, much above the possible altitude of the Iroquois plain. These terraces form sets of ridgelets ranging downward from their crests about 50 feet to the gravelly deposit of their frontal terraces. This holds true alike for the exposures of the Iroquois beach east of Watertown and for the recorded terraces at the mouth of the valley. The next great terrace plain below these gravel shores is about 200 feet and mostly sandy, alike near Watertown and along Grassy river and elsewhere. The differential rise of the Iroquois beach increases toward the northeast. Southeast of Lake Ontario it is three feet per mile. Near Watertown it is five or, rather, nearly six feet, and eastward the terraces at the mouth of the valleys rise from six to perhaps seven feet per mile in a constantly increasing ratio, as would be expected.

Of all this cumulative evidence, there seems but one explanation, namely, that these shore accumulations at the mouths of the old valleys are identical with the Iroquois beach further westward and formed [illegible] water level. The warping of this region is established, and can not be discarded in order to have glacial dams at various elevations, which of itself appears unnecessary and illogical. But ice obstructions between these valleys at the same level would not permanently affect the water level of the whole; for glacial lakes are evanescent, and some of such, if they existed, would not have been more than narrow tongues, as as shown by the incomplete surveys. I do not here accept or deny the occurrence of local glacial dams; only the identity of these deposits as the equivalent of the Iroquois shore seems well established for a hundred miles east of Watertown.

Mr. Upham's recently adopted hypothesis* of the extension of open water as far as Quebec during the Iroquois history, and the consequent shrinkage of the theoretical glacial dams 400 miles to the northeastward, is in harmony with my views previously set forth. The details in the present paper only locate the approximate positions of the old shore as far northeastward as they have been definitely explored. Where the upward warping ceases or is replaced by a descending movement toward the sea has not been discovered, so that it may be found that the Iroquois shore is lower in the region of Quebec than in the Adirondack region. This idea of a lesser continental uplift in the northeast than farther southwestward has already been hypothesized in one of my previous papers and subsequently pointed out by Baron de Geer.

That much drifting ice occurred in the northwestward extension of the Iroquois water is probable on account of its pitted shores, boulder pavements and broken features. It may be even possible that this body of water, which was at sea-level, was cut off from open water by local glaciers descending into the lower St. Lawrence valley, but there could not be sufficient to hold for ages a body of water 600 miles long and in part over 100 miles wide much above sea level.

In Mr. Upham's paper on lakes Warren, Algonquin and Iroquois he has given definitions differing from those of my original descriptions. I describe lake Warren as extending over the Ontario basin as well as over the basins of the upper lakes, for I know of terraces and other shore phenomena belonging to the elevation. The only systematic work on the Algonquin water was originally done by myself and recently continued by Mr. Taylor, and I have shown that its level was about 300 feet above the Iroquois plain. The dismemberment of the Warren water was first pointed out by myself and, from the evidence, there appear to have been many outlets — that at Chicago being only one of them and not the outlet of a separate glacial lake.

Mr. Gilbert's interpretation of the phenomena north of the Adirondacks as being attributable to glacial lakes does not seem to me to be tenable, from the immense amount of cumulative evidence set forth in this paper; but all the glacial characteristics of the terraces and pitted plains may be easily explained by floating ice, acting in the Laurentian archipelago upon the Iroquois shore; which would only be located as above described even upon Mr. Upham's explanation of the closing of the Ontario basin by a glacial dam at Quebec.

---

* Mr. Gilbert informs me that Mr. Upham refers to beaches lower than the Iroquois as defined by me in naming that shore. One is scarcely expected to alter a definition. However, it makes but little difference which of the Ontario beaches he extends to Quebec, as all are far above the Champlain level.

CHAPTER V.

Deformation of the Lundy Beach and Birth of Lake Erie.*

The history of Lake Erie is a natural sequel to the birth of Lake Ontario and the birth of Lake Huron,† which have already appeared in this journal. Deserted strands about Lake Erie have also been made known,‡ but all of them extended beyond the Erie basin, and formerly embraced the greatest of the inland sheets — the Warren water or gulf — which probably covered 200,000 square miles, or more than the entire area of the modern lakes. The last of the deserted shores of that body of water was the Forest beach (fig. 13). The subsequent rise of land or subsidence of the waters has been intermittent with episodes of rest long enough for the waves to carve out broad terraces or build up heavy beaches. Still, the instability of the waters is marked by the greater beaches being composed of a series of breachlets rather than one individual mass. The series is remarkably persistent, although there may be imperfect developments of the component parts. Between the different sets of deserted shores, there are often only traces of the receding water-levels.

In the survey of the Forest beach, fragments of old coast lines were observed below that level, and these have recently been found to form part of a great Erie shore, in age synchronous with the Algonquin beach of the higher lakes. This Erie beach, first described here, may appropriately be called the Lundy shore, after the spit near Niagara Falls, which has long been used as a ridge road, and known as Lundy Lane, and where the interpretation of the strand was discovered. The Algonquin and Lundy gulfs were the successors of the Warren water after its dismemberment by the level falling below that of Forest beach.

---

* Reprinted from Amer. Jour. sci. xlviii, p.p. 207-212, March, 1894. †"Deformation of the Iroquois Beach and Birth of Lake Ontario." Am. Jour. Sc., vol. xl, p. 443, 1890.

† "Deformation of the Algonquin Beach and Birth of Lake Huron." The same, vol. xli, p. 12, 1891.

‡ "High-level Shores in the Region of the Great Lakes and their Deformation." The same, vol. xli, p. 201—all by J. W. Spencer.

Between Front-hill and Ebenezer (fig. 13) there was an extension of the Erie waters into the Ontario basin through a strait, if such it can be called, as it was over 30 miles across. The country in the Niagara district is a plain from 10 to 15 feet above Erie Lake. It is

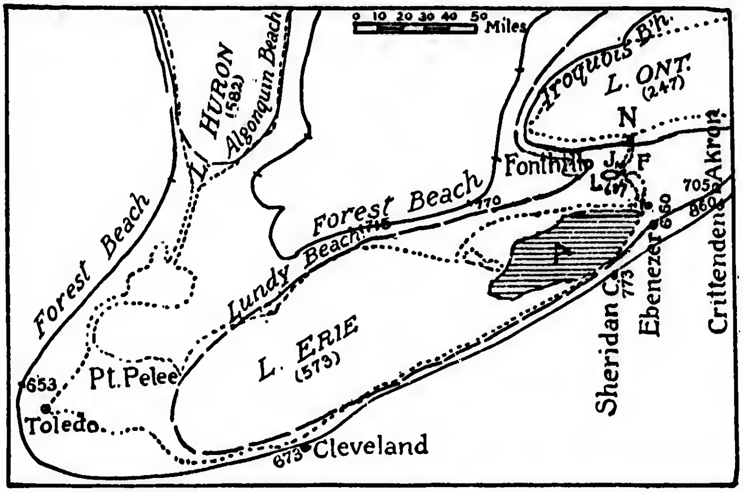


FIG 13.—Map of Lundy shore, enclosing Lundy Gulf. A, Infant Lake Erie. N, mouth of Niagara River. F, Niagara Falls. L, Lundy beach near the Falls. J, Johnson's ridge. Elevations refer to sea-levels.

rendered somewhat undulating by a few ridges of drift rarely rising 30 feet higher. A rocky ridge of 20 or 30 feet above the lake is parallel with the shores of Ere, a mile or two to the north of its outlet. But the most notable ridge culminated in Drummondville, near the falls, at 144 feet above the lake level. This is a small knob at the end of a long spit which is the historic Lundy Lane. The surface of this strand is 30 feet below the knob just noticed. This ridge formed a spit which was the first barrier that appeared between the Erie and Ontario basins, and here the waters last lingered before they subsided within the lower basin. The knob at Drummondville is not an undulation of the Lundy shore, although it is made up of beach-material, but belonged to a higher level. Whether a fragment of an older strand or not, still equivalent remains of deserted water-lines are found at Fonthill, Akron and elsewhere.

The crest of the Lundy beach is from 100 to 200 feet wide and forms a conspicuous sand and gravel ridge of more than double this width at the base, to which it slopes — 20 or 30 feet below, and bounds an extensive plain on both sides, as it constituted a spit between the Erie and Ontario basins, which were connected by a broad sheet of open water. After extending westward from the Niagara river for two or three miles, the Lundy beach is interrupted by a low plain, but again the strand skirts Font-hill (which rises about 300 feet above Lake Erie) and trends southwestward. On the southeastern side of the strait, the beach is equally characteristic, near Ebenezer. It has been traced to Akron or about five miles due north of Crittenden, where the Forest beach was surveyed several years ago by Mr. Gilbert.

At Ebenezer, the Lundy beach has an altitude of 660 feet (bar.) above tide (Lake Erie being 573 feet); at Lundy Lane the elevation is 687 feet (and the older knob 30 feet higher); at Font-hill it is 675 feet (bar.) or equivalent to the lower at 705 feet. Fragments of beaches and terraces have been made known about the head of Lake Ontario and also about the Erie basin, but they have not been previously correlated with the Lundy shore. The Lundy strand is between 140 and 155 feet below the plain of the Forest beach, and it is usually from two to five miles lakeward of it. Between the different strands of Warren water there is a slight deformation of the deserted shores, owing to the unequal terrestrial movement. A somewhat greater amount of warping is recorded between the Forest and the Lundy beaches, but the greatest amount of deformation was after the dismemberment of Lundy Gulf. West of Cleveland, very little deformation of the old water lines has occurred. From the relation with the Forest beach, the extension of Lundy Gulf towards the west can be approximately delimited. The lake reached to Point Pelée and the islands opposite. The eastern extension beyond Akron has not been surveyed. But enough is known to mark the boundary in the Erie basin; and here we find the counterpart of the Algonquin beach, of the basins of the upper lakes, whose water plain was at substantially the same levels as the Lundy, or about 150 feet below that of the Forest beach. The Lundy water gives us the history of the lake basin between the Warren episode and the nativity of Lake Erie.

After the Lundy rest, the waters were gradually drained to lower levels, until they were held in the Erie basin by a Devonian limestone escarpment, rising 20 or 30 feet above the present outlet of Erie. The remains of another rocky barrier, of 40 feet, now occurs over a mile north of the present site of Niagara Falls. The country between these ridges is low, so that there were pond-like expansions of the Niagara until a recent date, when the falls cut through this William Johnson*

* Named after Sir William Johnson, who took possession of the falls about 1760.

ridge. Below this ridge, for six miles, to the brow of the escarpment, the Niagara river drained the Erie waters, and boats might have sailed from lake to lake. The waters in the Ontario basin did not pause long at this high level, but gradually sank to the Iroquois plain 300 feet below the plain of Lundy beach. The Iroquois beach marks a long rest during which the early Niagara cascaded only 200 feet from the upper to the lower lake, and Erie formed only the lakelet as shown on the map (fig 13).

Upon the dismemberment of Warren water, the Algonquin basin emptied its waters, at first through a strait by way of Lake Nipissing, and later by a river in the same region into the Ottawa valley. There was no connection between the Huron basin and the Erie until after the terrestrial deformation following the Iroqouis episode. Then the Huron waters overflowed the southern rim of its basin and emptied into the youthful Lake Erie. The outlet of the Erie basin was also raised so that the plains at the head of its basin were flooded. This tilting has continued until the beach in the vicinity of the falls is now raised about 160 feet above its submerged extension near Point Pelée. Of this amount of tilting, only 46 feet have contributed to the ponding back of the waters so that the lake now extends to Toledo. The deformation of the Lundy beach in the Niagara district amounts to 2·5 feet per mile in direction N. 10°–15° E. More detailed measurements* may possibly show that the warping may reach nearly three feet per mile. The deformation of the Iroquois beach, which is newer than the Lundy strand, amounts to somewhat more than two feet per mile north of the mouth of the Niagara.

Had the falls receded past the Johnson ridge before the deformation of the region had reached the present amount, the Erie drainage would have been turned into the Mississippi at Chicago, just as the warping has changed the direction of the outlet of Lake Huron from the Ottawa to the St. Clair river. This brings us to the first possible computation of the rate of the terrestrial deformation of the old shore of the lake region.

A rise of seven feet in the level of Lake Michigan would send the waters of that lake over the rocky divide to the Mississippi. A rise of 16 feet in the Erie level would effect the same result; but the silt covering this rocky floor rises three or five feet higher and the Johnson ridge has been raised so that the deserted banks indicating the old surface of the Niagara river are now 40 feet

*Some of these measurements were barometric from adjacent known levels, and consequently closer calculations were useless.

above the Erie level. Thus it becomes apparent that the elevation of about the last 20 feet has taken place since the recession of the falls past the Johnson ridge, for otherwise such a large river with a great breadth would have emptied the lakes and the recession of the falls must have ceased. That the water was recently higher about the head of Lake Michigan than now, the swampy flats bear witness, and the low lands continue far southward, so that the rocky floor of the country — only seven feet above the lake level (Ossian Guthrie) is 25 miles distant from the lake. Over this extensive plain, the low country has been a swamp, and drained sluggishly in both directions while silting over, to the extent of a few feet, the rocky floor of the country. But the entire drainage of Lake Michigan to the southwest could not have been established. The lowering of the water by a few feet in the Michigan basin as well as in the Erie has been produced by the recession of the falls past the Johnson ridge.

From the modern rate of the recession of the falls, which is about four feet a year, and the distance of 6,000 feet which the falls have receded, since passing the Johnson ridge, we find that the terrestrial warping in the vicinity of Niagara Falls could not have exceeded 24 feet in 1,500 years, or 1.5 feet a century. But with the silting up of the Chicago (more correctly Lemont) overflow not more than 20 feet (or possibly 15 feet if the waters were deeper) of the last uplift of the Johnson ridge have been developed since the recession of the falls through that ridge. Thus the rate of terrestrial deformation or uplift in the Niagara district does not exceed 1.25 a century, with a possible reduction to one foot in the same time, if the secular rate were uniform. But there have doubtless been episodes of rest and others of uplift, so that the actual rate of movement might have been more rapid, but the above estimate is the average during these times of elevation and intervening repose.

The agents of the deformation in the Erie basin have not been so continuous or so active as in other portions of the lake region; but if a mean rate for long epochs can be taken as here indicated, then nearly 13,000 years* have elapsed since the Lundy beach commenced to be deformed. The Iroquois beach is, however, more accurately measured. In the vicinity of the outlet of Lake Ontario the deformation is double that in the Niagara district. At that outlet the tilting has amounted to 370 feet by the post-Iroquois movement, and at 2.5 feet a century about 14,800 years have elapsed since the close of the episode

* 160 feet divided by 1 to 1.25 feet a century.

of the formation of that deserted shore line. The conjectural mean deformation over long epochs closely accords with our best computations of the age of the falls, which will make another chapter in the lake history.

The inferred rate of terrestrial deformation in the Niagara district is 1.25 feet a century; 2.5 feet at the outlet of Lake Ontario; and 2 feet northeast of Lake Huron. These figures may be of use in reading the future of Lake Erie.

Applied to the Erie basin, the indicated deformation continuing, it appears that before Niagara Falls can have receded past the Devonian ridge near Buffalo,* the drainage of the upper lakes will have been turned into the Mississippi Valley, just as the Huron waters have been turned from the old Nipissing channel and Ottawa river to cascade over the falls; and thus may require 5,000 or 6,000 years. In this case the future life of the lakes will be very long; as their drainage will only be effected by the excavation of a deep valley backward from the Mississippi river into the lake basins.

* These estimates will be more fully explained in a following chapter upon the history of Niagara Falls.

CHAPTER VI.

Deformation of the Algonquin Beach, and Birth of Lake Huron.*

From the ship's deck, my attention to the high terrace, which skirts the coast of Georgian Bay, was first attracted. But long before, fragments of this ancient shore-line were used by the Algonquin Indians, in the same manner as the Iroquois tribes had trailed over the "Ridge Roads" of Ontario and Erie. Mr. Sanford Flemming, C. E., described, in 1853, some of the drift ridges at the head of Georgian Bay, and recognized certain high level beaches.** Later the Geological Survey of Canada measured the elevation of some of the raised terraces.† But those early investigators did not recognize either the extent of the beaches or their deformation from the water level. No systematic explorations of the old shores were made until the summers of 1887 and 1888, when the writer, assisted by Professors W. W. Clendenin and W. J. Spillman, surveyed portions of them. In the autumn of 1887, Mr. G. K. Gilbert visited some of the Canadian terraces. In August, 1888, I abruptly left the field and reported some results before the Cleveland meeting of the American Association for the Advancement of Science.‡ Some reference to the Georgian Bay beaches were made in "The Iroquois Beach," etc., § and later Mr. Gilbert generalized upon the history of the Upper Lakes, in an interesting paper entitled "The History of the Niagara River,"‖ wherein some of his raised shore lines were taken from my survey, unpublished portions of which having been furnished to him.

Upon the Canadian side of the lakes, there are well preserved shore-lines, marking the same episodes as those upon the American side, when all the lakes were covered by a common sheet of water (the Warren water or gulf). These raised beaches have been more or less surveyed, but they belong to an episode earlier than that recorded in the beach, which confined the waters to the Upper Lake basins not

---

* Reprinted from Am. Jour. See vol. xli, pp 11-21. 1891.

** Valley of Nottawasaga, Can., Jour. Toronto, vol. 1, 1853. † Geological Survey of Canada, 1863.

‡ "Notes on the Origin and History of the Great Lakes of North America," by J. W. Spencer, Proc A. A. A. S., vol. xxxvii, 1888.

§ "The Iroquois Beach, a Chapter on the Geological History of Lake Ontario." Read before Phil. Soc. Wash., Jan. 1888, and Roy. Soc. Can., May, 1889. Trans. Roy. Soc. Can., 1889.

‖ Sixth Annual Report of the Commissioners of the State Reservation of Niagara for 1889.

embracing that of Lake Erie. This beach, which skirted the head of Lake Huron, cutting off the waters from the Erie basin, is now submerged at its southern end, but it rises as a conspicuous feature in the topography of the country. I have named it after the Indians who long ago, used it for a trail — the Algonquin Beach.* It forms the basis of this paper.

Between Lakes Huron, Ontario and Erie, at respective altitudes of 582, 573, and 247 feet above the sea, the land rises to 1,709 feet. It shows water action to within 20 feet of its summit. From the highest ridges or plains, the land falls away towards the lakes, sometimes gradually, but often by abrupt steps, especially upon the northeastern side. Over this peninsula, there are many ridges of drift. Exclusive of the ridges, the general surface of the country is composed of fine stony till, or of modified drift, — the product of wave action upon the stony clay, the result of which has been the formation of beach ridges of sand and gravel, separated by plains of silt or clay soil. In many cases, these floors slope so gently as to appear level, and from two to five or six miles may intervene between successive beaches, whose altitudes do not differ by more than 50 or 60 feet. The silt on these plains is that which was washed out into the deeper water, by the assorting action of the waves that were building sand or gravel beaches in front of their coast line, composed of the older stony clay. In such cases, the lithological recognition is striking. Upon surveying, the beaches are all found to rise in altitude toward the north and east, with a slightly increasing divergence between the ridges in the same direction, for the differential uplift has always been greater toward the northeast, than in the opposite direction

The methods of investigation have been similar to those pursued in the survey of the Iroquois Beach. Boulder pavements are rather more important features of the Algonquin Beach than of the Iroquois. About the head of Georgian Bay the country is sandy. East of Georgian Bay, there is the same kind of broken wilderness as that among the Archæan rocks of the Adirondack Mountains of New York, with more or less stony sand in place of stony clay.

The waves of the lake are encroaching upon the eastern coast of Huron, and consequently modern beach-making is not a characteristic feature, except in proximity to the mouths of some streams or in sheltered places, where terraces or bars are constructed. The encroachments of the lake upon the land have washed away, in many places, the bluffs upon which the Algonquin Beach rests. But a sufficient number

* The name was first printed in Proc A. A. A. S., p. 199, 1888.

of fragments remain, for its identification, especially as the position relative to its elevation, compared with the next higher shore-lines, which are well marked by beaches, is known.

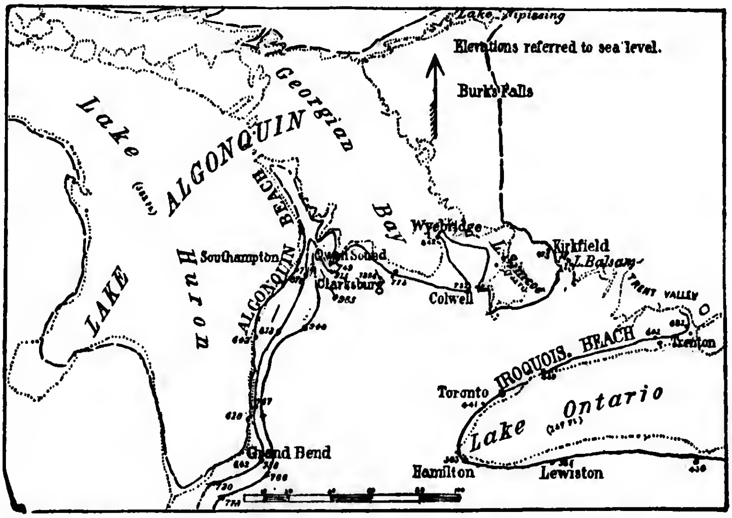


FIG. 14. — Map showing the Algonquin Beach about the eastern portion of Algonquin Gulf. Other beaches are also shown.

The following table gives the levelled elevations of salient points along the Algonquin Beach, at or near the places mentioned:

	Feet above the sea	
Surface of Lake Huron..................	582	(U. S. Lake Survey.)
Beach at one or two miles lakeward of modern outlet of Lake Huron, calculated,	562	(Levelled.)
Grand Bend (of Au Sable River)..........	602	"
Wilson's (14 miles northward, terrace at 608 feet, calculated)..................	618	"
Eighteen Mile Creek (terrace 637 feet, calculated)............	647	(Barometer.)
Southampton (back of which a sand dune rises 13 feet higher)............... ...	714	(Levelled.)
Thence the beach skirts Indian Peninsula, and at Owen Sound....................	749	"
Clarksburg...........................	773	"
Collingwood, 4 miles west of	767	"
Colwell	752	"
Elmsvale	802	"
Wyebridge, east of.....................	842	"

	Feet above the sea.	
Orillia, about	800	(Barometer.)
Thence the beach descends and swings around Lake Simcoe and again rises at Kirkfield	875	(Levelled.)
Burk's Falls (+ or −) (?)	1171	(N. W. & N. Ry.)

Beyond Kirkfield, the survey was not carried, but from the topography of the country and from the fragments of the beaches, the position of the Algonquin Beach is approximately that of the broken line on the map. The gravel ridge at Burk's Falls is probably part of the beach, as the mean rate of northern rise would represent its position near this point.

For comparison with the Algonquin Beach, the positions and the elevations of the two next higher beaches, east of Lake Huron, are given in fig. 14, and the tables of elevations are here added. Of next beach, at or near:

	Feet above the sea.	
Forest	720	(Spencer.)
Parkhill, east of	736	"
Bayfield, east of	767	"
Ripley	813	"
Walkerton (terrace)	825	"
Paisley (terrace)	860	"
Burgoyne (east of Southampton)	876	"
Rockford, north of	915	"
North coast of Lake Simcoe (probably that) on the insular ridge, north of Barrie	910	"

Of the second beach, above the Algonquin, at or near:

Watford	773	"
Ailsa Craig	789	"
Varna	845 (+)	"
Walkerton	944	"
Chatsworth	985	"

A still higher beach has been surveyed for many miles, and several fragments of even more elevated shores are now well identified. Some of these upper beaches have been traced over long distances, and have been found resting upon the land north of Lake Erie, and even extending to the high country between Lake Ontario and Georgian Bay.

From the figures recorded in the three tables, it will be found that the mean rate of warping in the Algonquin Beach, from the southern end of the lake to near Southampton, is 1.33 feet per mile; of the next beach, between Parkhill and Burgoyne, 1.5 feet; and of the higher beach, betweed Watford and Walkerton, 1.71 feet. These rates of differential uplift are reduced at their more southern extensions, but increased to two feet, or somewhat more, at the more northern.

After skirting the Indian Peninsula, the position of the Algonquin Beach surrounding the head of Georgian Bay is such that it can be triangulated, and hence the average amount of uplift, as well as its direction can be obtained. Accordingly, it is found that the uplift upon the more southwestern portion of the beach, at the head of the bay, is about 3 feet per mile, in a direction of N. 20° E., with an eastern equivalent of about one foot per mile. The uplift increases so that east of Georgian Bay the mean rise is 4.1 feet per mile in a direction of N. 25° E., with the eastern equivalent of 1.7 feet per mile.

At Grand Bend, the beach rests upon a fine stony drift clay — the latest deposit of till in that region — which is charged with numerous scratched stones. It is also indistinctly stratified. The same holds true at Wilson's and other places. About Georgian Bay, it also rests upon the upper till. In short, the waves, which formed the beach, have commonly removed the silt deposits that covered the floor of the lake during the earlier episodes of the higher beaches, and cut into the underlying drift deposits during the Algonquin episode, before the beach structure was laid down. In many places, especially about Georgian Bay, the boulder-pavements are well developed, especially between the different ridges of the Algonquin Beach, for it is often broken up into a series of prominent ridgelets, the lowest being, where developed, as much as 28 feet below the upper.

There are several beaches about Georgian Bay, at lower altitudes than the Algonquin, but these rise less rapidly toward the northeast than the greater named beach. At Clarksburg, there is a beach at 81 feet above the lake, and terraces at 62 and 45 feet, besides a numerous series of beaches extending from 28 feet down to the water level. Near Wyebridge, the more conspicuous terraces are at about 183, 73, 55 and 11 feet above the lake; and there are numerous fainter shore-lines These all show that the time of the subsiding of the waters was marked by numerous pauses.

Between Kirkville and Balsam Lake, there is a depression a few feet below the level of the upper part of the Algonquin Beach. But of this later.

No animal life has been found in the beach itself. But in a terrace, adjacent to the Saugeen River (bridge east of Southampton), where there is an embayment of the Algonquin Beach, there is a bed of fresh-water shells, discovered by Mr. Spillman. This is an altitude of 90 feet above the lake, or over 40 below the beach. This deposit may have been on the floor of the lake during the Algonquin episode, or it may belong to a lower water-level. The river has now cut down its bed far below this level. At the head of Georgian Bay, fresh-water shells have been found up to 78 feet.*

There are several depressions across the Laurentian tablelands, between Lake Huron and Hudson Bay which do not rise much more than 900 feet above the sea. But towards the north-east, the altitude of the land is everywhere high, except along the depression in which Lake Nipissing lies. The barrier there descends to 707 feet above the sea. Beaches and shore lines are known to exist upon the land north of the lakes, and I have seen such upon Manitoulin and Mackinac Island. But they have not been directly connected with the more southern beaches. Consequently, all deductions, in the study of the lake involving that district, must be somewhat provisional. From the character of the terrestrial rise increasing towards the east, it is probable that there are no depressions north of Lake Huron, lower than the plain of the Algonquin Beach. This beach (by calculation from the mean rate of rise) should be found in the vicinity of Lake Nipissing, at the from 600 to 700 feet above that depression.

Combining the Canadian series of beaches about the upper lakes with corresponding series on the southern side of the lakes (my survey of those in Michigan appears in chapter VII), I find that there has been a differential elevation, since the Algonquin episode, between the southern end of Lake Michigan and the vicinity of Grand Bend, on Lake Huron, amounting to about 290 feet. Hence, we know that the Algonquin plain was down to a level, at least, of less than 300 feet above the sea. By a triple series of calculations, the Algonquin plain is found to have had a position somewhat less than 300 feet above the Iroquois plain. The Algonquin water filled the Huron basin to within a mile or two of its southern end, where the beach is now submerged to about 20 feet, (calculated). Hence, the waters did not flow by the modern St. Clair River to the south. At the time a considerable area of the southern end of Lake Michigan was laid dry, as the beach bounding the Algonquin water should now be submerged to 290 feet below the waters at head of lake. But the northern part of the Michigan and Huron basins was filled to an elevation far above their present surface, as the basins had not yet received that great tilting

* Geology of Canada, 1863.

which partly overflowed their southern margins and lowered their surfaces toward the north.

There is a well-marked terrace and beach deposit on Mackinac Island, at about 190 feet above the lake. This is nearly in the line of strike, or line along which there is no differential elevation, of the lowest part of Algonquin Beach about Georgian Bay. This old shore line, on the island, is better developed than any of the Huron Beaches, situated elsewhere, except the Algonquin. From its position, there seems no reason to doubt that the waters of Algonquin Gulf stood at that elevation in the strait between the Michigan and Huron basins. Accordingly, tilting in the Michigan basins has amounted, since the Algonquin episode, to about 430 feet in 300 miles, or a little more. This approximation is close upon the mean rate of uplift measured east of Lake Huron. Parenthetically, it may be added that President Chamberlain found clays upon the western side of the lake which represent a differential uplift of 400 feet (although they belong to an older episode), which were in part involved in the earlier Pleistocene movements.

The Algonquin water also covered most of Lake Superior, probably to within a short distance of its southwestern end, as that basin is so deep; yet the waters must have been very much shallowed. Indeed, the recent backing of the waters towards the head of Lake Superior is apparent in the open bays behind the bars, which cut off Fond du Lac, at Duluth. The area of the Algonquin Gulf or water may be seen from what has been written, to have been vastly greater than now, filling the upper lake basins, nearly to their extreme margins, and overflowing the land northeast of Georgian Bay, as shown on the map. On Mackinac Island and adjacent portions of the mainland, there are several shore lines lower than that assigned to the Algonquin plain and of inferior importance.

In the early history of the Algonquin water (gulf), there was an overflow by way of Balsam Lake and the Trent valley. My first impressions of the importance of this outlet were overdrawn in the preliminary communication * of observations from the field, before all of the relations had been explored. At first I attached as much importance to the Balsam outlet of the Algonquin basin as Mr. Gilbert did to his Mohawk outlet of the Iroquois basin. As both are too shallow, the demands are satisfied in neither case. Only at its highest level did the Algonquin Lake overflow into Balsam Lake. Even the

* Proc. Am. Assoc. Adv. Sci., 1888, p. 197.

overflow was sluggish, permitting of the formation of beaches about the outlet. Before Algonquin water sank to the level of its lower beaches, its discharge was by a channel below Balsam outlet. The occurrence of an overflow in this last direction, is only one of the coincidences, as in other cases, in the growth of the lake. The outlet of the Algonquin Basin, by way of Lake Nipissing and the Ottawa valley, was through a depression, which now rises to 707 feet above tide. This trough has an absolute depression of 168 feet feet below the Algonquin Beach at Kirkfield. But the altitude of the beach, in the region of the old Nipissing outlet, is estimated at 600–700 feet above its floor. In short the outlet was a broad strait leading into the Iroquois Basin, or like the modern connections between Lake Michigan Lake Huron, and Georgian Bay, unless the basin were closed by a dam, and that of ice. The case is not settled so easily as that of the Ontario basin, for we have not yet the instrumentally measurable proof that the Algonquin plain was lower than 300 feet above the sea, although it probably was, and against which probability there is not the slightest evidence, for we do not know what was the initial plain of upward movement. Without applying the objections made to an ice dam closing the Ontario basin during the Iroquois episode, let us examine some conditions of the Algonquin basin.

The Algonquin plain stood at an elevation of about 300 feet above the sea, when the lower Iroquois Beach commenced its growth. Were its waters held up to that altitude by an ice dam, or had they shrunken to the lower level (which, however, would not have dismembered the upper lake) and where they connected with Gulf of Iroquois by a strait 300 or 400 feet deep, like the modern outlet of Lake Michigan? Up to this time, there had not been any warping to separate the lake basins, for the greater part of the barriers has been uplifted since the episodes of the Algonquin and Iroquois Beaches. I have shown that the greater proportion of the differential movement, even in the higher beaches about Lake Erie has been since the Iroquois episode.* In the earlier part of this paper, it has also been shown that most of the warping of the beaches, east of Lake Huron, has been since the Algonquin episode. Now these higher beaches are identical with those south of Lake Erie, whose movement have been compared with those of the Iroquois Beach. Hence, it is not difficult to understand that the unequal uplift of both the Algonquin and Iroquois plains has been mostly, since the completion of the latter beach. I speak only of the differential movements that have deformed the old water levels,

* "Deformation of the Iroquois Beach," etc. Am. Jour., Sc., vol. x, page 443, 1890.

and not of the absolute rise, which lifted the Algonquin plain above the Iroquois, unless the waters which made the former beach were retained at the higher altitude, for long ages, by an ice dam.

At most, no ice barrier could have longer blocked the Nipissing outlet than the episode of the lowering of the waters, 300 feet, to the level of the Iroquois Beach, for at that time, all glaciers had shrunken back beyond the Ontario basin, and the two basins were connected by the deep Nipissing Strait. And of such a dam we have not proof, or probability, to even as great an extent as in the case of a hypothetical Iroquois dam. With the continued regional uplift, the waters of Algonquin Gulf were further lowered, as is shown by the numerous beaches, until the lake was dismembered, and *Superior, Michigan, Huron and Georgia had their birth* and drained through the last, at the level of the Nipissing outlet, only by a river flowing into the valley of the Ottawa.*

As we ascend to the elevation of the higher beaches, the question of glacial dams becomes more difficult, for we must assume them to have been hundreds of miles long and at enormous altitude, damming up bodies of water which had the proportions of inland seas. Such I do not here propose to construct or dissipate, but I am compelled to assume the initial plain of the Algonquin Beach at sea-level, irrespective of glaciers which may then have been moving into the St. Lawrence valley, and obstructing open communication with the sea, but not damming the waters at high levels. There is as much evidence of submergence in these deserted beaches as there is in Professor Shaler's beaches† up to 1,500 feet, on Mt. Desert Island, without the intervention of dams, or of Mr. McGee's Columbia formation‡ which I have seen in Alabama, at altitudes of about 700 feet, without the support of dams. Indeed, there is additional evidence, for crustaceans of marine species have so adapted themselves as to still live in the depths of Lake Superior,§ as also maritime plants upon its shores.‖

As Algonquin water received so much fresh water, the marine conditions, indicated above, were modified, so that almost immediately after, if not during the formation of the Algonquin Beach, the waters

*See also History of the Niagara River, by G. K. Gilbert.

†Geology of Mount Desert, by N. S. Shaler. Eighth Annual Report of U. S. Geological Survey, 1888.

‡By W. J. McGee. Bull. Geol. Soc. Am.. vol. i, 1889.

§"On the Deep-Water Fauna of Lake Michigan" (Stimpson) Am. Nat., Vol. iv., p. 403, 1870; also "The Crustacea of the Fresh Waters of the United States." (Sidney I. Smith). Rep. Fish Commissioner, 1872-3, p. 643.

‖"The Distribution of Maritime Plants in North America." (C. H. Hitchcock). Proc. A. A. A. S., 1870.

became sweet, as is shown by shells referred to above. With the continued emergence and northeastward warping of the continent, a rocky barrier across the Nipissing outlet was raised which eventually caused the waters of Georgian, Huron and Michigan Lakes to unite and overflow the southern extension of the lower beaches. Finally, this warping, as before pointed out,* so tilted the basins of the lakes that the waters overflowed the rim of the Huron basin, and established the modern drainage of the upper lakes by way of Lake Erie. Not until this event did the lakes assume their present form.

---

*Notes upon the Origin and History of the Great Lakes of North America. Proc. A. A. A. S., vol. xxxvii., p. 197, 1888.

CHAPTER VII.

High Level Shores of Warren Water (Gulf) and their Deformation.*

CERTAIN of the deserted shores about the Great Lakes have been already described in the author's papers on the Iroquois and Algonquin Beaches † The Iroquois Beach is confined to the Ontario basin, and the Algonquin Beach still defines the deserted shores of the lake which embraced Georgian Bay and Lake Huron, Michigan and Superior during the episode when they formed one expanded sheet of water. But above these beaches there are others not confined to any of the existing basins, but at elevations which required all of the lakes to have been united into one sheet of water. This sheet, whose dimensions have only in part been surveyed, I named Warren water.‡ As the southern and southwestern shores have been surveyed for a length of 800 or 900 miles, and several hundred miles of the coast line about the former large island, now represented by a part of the Province of Ontario, are known, the work seems to justify this publication without further delay (see map, p. 75).

In the investigation of the high beaches, I acknowledge with great pleasure the assistance of Prof. W. W. Clendenin and Prof W. J. Spillman, who accompanied me in the researches. Respecting the beaches upon the Canadian side of the lake, no other systematic exploration has been made. Four or five years ago, some of our friends put ice dams, where beaches are well developed, to hold up the waters whose waves built up the beaches upon the southern side of Lake Erie. In Michigan, the record was nearly as meagre, although some of the beaches had been used as roads since the days of Indian habitation. But in Ohio, more or less work had been done, which will be referred to in its proper place. Upon both sides of the St. Clair River, a succession of beaches may be seen, in ascending inland over the

* Reprinted from Amer. Jour. Sci. vol. xli, pp. 201-211, 1891.

† The Iroquois Beach: A chapter in the Geological History of Lake Ontario. Trans Roy. Soc. Can., p. 121, 1889. Deformation of the Iroquois Beach and Birth of Lake Ontario. Am. Jour. Sc., vol. xl, p. 443, 1890. Deformation of the Algonquin Beach and Birth of Lake Huron. Ibid., vol. xli, p. 12, 1891.

‡ See Notice of Iroquois Beach, Science, vol. xi, p. 49, Jan. 27, 1888.

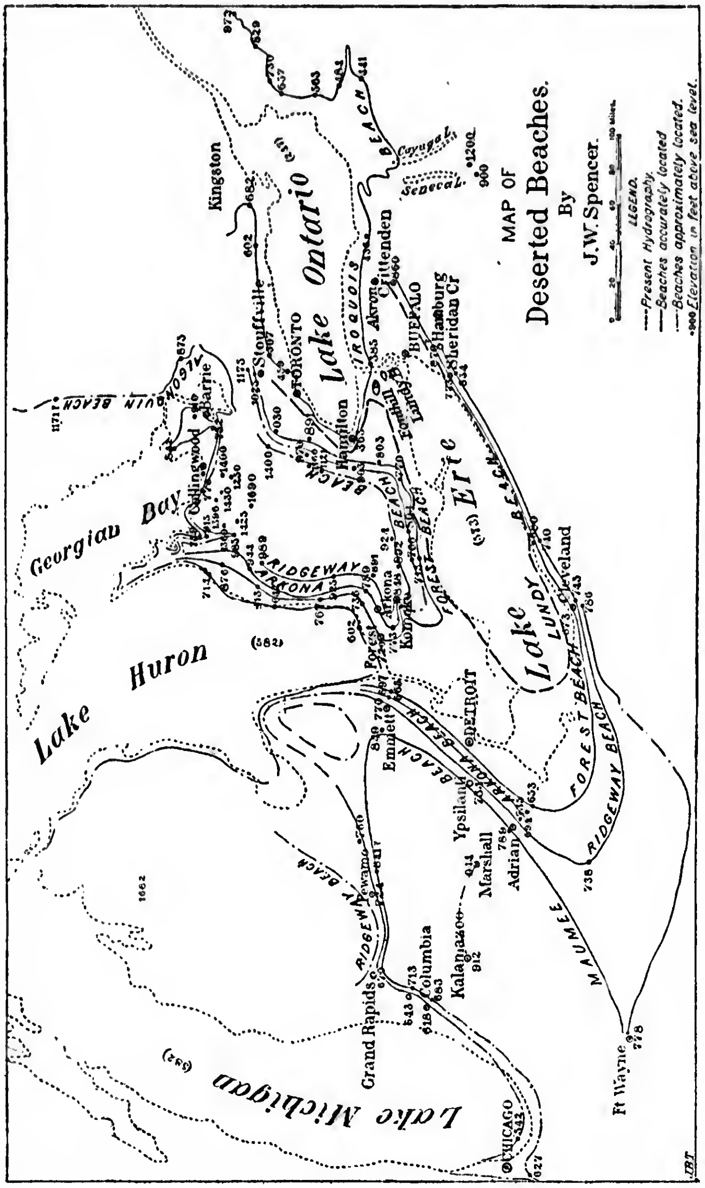


Fig. 15.—Deserted Strands of Warren Gulf.

slowly rising plains. The beaches are of the same character as those described in the author's earlier papers upon ancient shores. But they appear to represent a rather shorter time in formation than the Iroquois and Algonquin Beaches.

The Forest Beach.—Upon the Canadianside of the St. Clair River, the first important deserted shore line, above the Algonquin Beach, may be seen at Forest—and hence I will name it the Forest Beach. This has been explored in both directions from Forest, shown on the map, with elevations as in the table—these being instrumentally levelled.

	Feet above the sea.
Lake Huron	582
Forest	720
East of Parkhill	736
Near Bayfield	767
Ripley	813
Walkerton (terrace in valley)	825
Paisley (terrace in valley)	860
East of Burgoyne	876
Rockford (spit across valley)	915
Barrie (on insular ridge)	910

East of Rockford the country is not favorable for the identification of the old beaches, as they were interrupted by the promotory of Blue Mountains extending into the former sheet of water, but on it various rock-terrace shore-lines are engraved. On the drift hills farther east, ridges reappear at elevations above the Algonquin Beach, which would point to their identification with the Forest Beach. In this northeastward direction our survey was discontinned.

From Forest, the beach has been explored, upon the northern side of Lake Erie, and the equivalent terraces traced to north of Lake Ontario. The measured elevation at various points are:

	Feet above the sea.
Komoko (terrace in valley)	722
White Station (south of London)	715
Near Waterford	770
Brantford	805
Pushlinch Church (rock-terrace)	840
Georgetown (terrace)	891
Mono Road (terrace)	930
North of Stouffville (terrace)	1,025

The terrace is a strong topographical feature, especially after passing over the Niagara escarpment near Georgetown. The differential elevation of the Forest Beach, in the extreme southwestern part of the

Province of Ontario, is 1.44 feet per mile in a direction of N. 28° E. But northeast of Toronto this warping has increased to three feet per mile as it trends north of east, with the direction of the maximum rise not determined. This warping is in harmony with the deformation of the Iroquois Beach, in the same region, being only slightly in excess, as it should be. No attempt has been made to explore the extreme eastern and northern portions of the Forest Beach, around the island of the Province of Ontario.

The Arkona Beach.—This beach is less perfect than the Forest Beach. It is prominent at Arkona, rises to 789 feet east of Ailsa Craig, passes by Varna and Ripley, and near Walkerton has an elevation of 944 feet. At Chatsworth, the spit across the valley at 985 feet, probably belongs to this shore-line. No further explorations have been made in this direction. Southwest of Arkona, the beach has an elevation of 773 feet at Waterford; 754, on a river terrace near Komoko; 735 (?) at Taylor; 776, on the plains at St. Thomas; 792 at Cornith; 804 at Delhi. Beyond this point there are shore remains, at 903 feet near Paris; a terrace at Limehouse, at 9˚0, and at Stouffville, a gravel ridge skirting higher land, at 1,175 feet. These latter fragments may be the equivalents of the Arkona Beach. But these last named shore-lines continue the upward succession of deserted water-lines even if not identical with the Arkona Beach. This beach is imperfectly explored, and is more or less interrupted, like other shore-lines, in the lake region as well as those nearer the sea coast, such as on Mt. Desert Island.

Ridgeway and Higher Beaches.—Above the Arkona Beach, the next shore-line is here named Ridgeway Beach, (as this a suitable name for its counterpart in Michigan). Its elevation, near the following places, is:

	Feet above the sea.
Komoko	848
Lucan Junction	891
Hensall	925
Lucknow	989

As the object of our surveys was for the more especial investigation of the lower beaches, the explorations were not carried throughout the distribution of the higher beaches. But beaches, spit across valleys, and terraces carved out of the Niagara escarpment were seen in many places at altitudes which would correspond to the continuation of this shore-lines. Back and above this beach, there is a belt of flat plains, corresponding to the frontal plains of still higher deserted coast-lines. Indeed, in the fragments seen, several other still high coast-lines are recorded. The altitudes of several of these are here given, and those marked with an asterisk are in topographical positions that would permit of their identity with the Ridgeway Beach, which has not, however, been continuously traced between all the points.

	Feet above the sea.
Seven miles south of London	*882
Seven miles south of London	872
Seven miles south of London	862
Near Ingersoll	*924
Near Ingersoll	911
Near Ingersoll (terrace)	903
Corwhin (rock-cut terrace with gravel floor)	*1,127
Acton (rock-cut terrace with gravel floor)	*1,160
Near Mono Mills (rock-terrace)	1,400 (bar.)
Near Mono Mills (gravel terrace)	1,375 (bar.)
Near Mono Mills (terrace)	1,200 (bar.)
West of Collingwood (rock-terrace)	1,400 (bar.)
West of Clarksburg (beach)	1,396
West of Clarksburg (beach)	1,372
West of Clarksburg (rock-terrace)	1,262
West of Clarksburg (rock terrace)	1,225
Duncan (rock terrace)	1,260 (bar.)
N. E. of Flesherton (terrace with gravel floors)	1,430 (bar.)
Dundalk (beach remnant)	1,690
Proton (plains)	1,630
South of Markdale (terrace)	1,425 (bar.)
South of Markdale (terrace)	1,400 (bar.)
Markdale station (terrace)	1,360
Two miles north of Berkley (gravel pit)	1,260 (bar.)
Arnott (terrace)	1,067

The beach remnant, in the region of Dundalk, is only 20 feet below the highest point of land, which once formed a small island. From this point down to sea-level, there is abundant proof, in the beaches, spits, sea-cliffs, and cut terraces, that there was a long succession of intermittent episodes of subsiding waters from the highest lands of the peninsula of Ontario — lands often higher than the highlands north of the Great Lakes, which now constitute the Laurentian mountains — care having been taken to distinguish these named structures from those gravel deposits belonging to the older drift episodes. Even after allowing for the amount of more recent terrestrial warping, these higher shores of Ontario rise far above much of the land to the south of the lakes. All of the deserted water-margins are more recent than the drift deposits, and some of them are cut out of the third series of till, which covers ridges and plains of much of the highlands of Ontario. The highlands of the peninsula then rose up as a growing island out of the receding Warren water.

The position and relative heights of the beaches of the two sides of the St. Clair River are seen in the following section, which represents

FIG 16.—Section across St. Clair valley.

a profile across them along a nearly east and west line. Making allowance for the terrestrial deformation between the beaches themselves, it will be readily seen that there is only a slightly greater amount of rise between members of the series upon the eastern side than upon the western, and this is in harmony with all the observations elsewhere about the lakes. Hence, I have been forced to accept the identity of the two sets on the opposite sides of the St. Clair river, as there are no important intervening shore-markings on the plains between the named ridges, although those upon the western side are more sandy than on the eastern.

The Forest beach skirts the plains at the head of Saginaw Bay and passes around the thumb of Michigan.

	Feet above the sea.	
Five miles west of Port Huron, duny beach with elevation of,	665	
East of Berville	668	
Sylvania	663	
East of Defiance (Gilbert)	653	
Cleveland	673	(bar.)
Madison	680	
Sheridan Centre, N. Y. (Gilbert)	773	
Crittenden, N. Y. (Gilbert)	860	

The Arkona beach has an elevation of —

Goodall, near	697
Denton	694
Blissfield (ridge duny)	694
Cleveland	708

A record of this shore-line is more meagre than the last. Both of these beaches have been more or less surveyed in Ohio by the late Geological Survey of that State,* and Mr. G. K. Gilbert has measured

* Geology of Ohio, vol. i, map, p. 519.

the continuation of the lower for some distance beyond the State line, into New York. The Lower, or Forest beach, is identical with that numbered four of the Ohio Survey, at the head of Lake Erie. Spits and spurs are frequently given off from these beaches, and add some difficulty to the surveying, especially in Ohio.

The Ridgeway Beach, or next highest shore-line, is the most important of the whole series, as it has been explored for the greatest distance, and is perhaps the easiest of identification. On it, many long stretches of dry roads, bounded by muddy plains, have been used from the first settlement of the country. The other ridges have also in places been used for roads, but to a less extent.

Elevations on the Ridgeway Beach determined by Leveling.

	Feet above the sea.	
Lake Michigan and Lake Huron	582	
Lake Erie	563	
Beach near Chicago (calculated)	526–542	
Near Columbia, Mich	618	(bar)
Allegan (terrace) in valley	643	
Grand Rapids	670	
Pewamo	724	
Chapin	760	(bar.)
East of Emmett	770	
Near Berville	753	
East of Ypsilanti	734	
West of Lenawee Junction	735	
Defiance, Ohio	738	(Gilbert.)
Cleveland	743	(Geol. Ohio.)
Madison	740	(bar.)
Sheridan Centre, N. Y.	834	(Gilbert.)
Hamburgh, N. Y.	870	(+ or — 20) (Gilbert.)

Throughout the windings, this coast line has been explored for eight or nine hundred miles. The highest beach south of Chicago is only 42 feet above the lake, and this probably belongs to a series to be noted hereafter, and from it the position of the Ridgeway Beach is calculated. The country southeast of Lake Michigan is very sandy and duny, and thus it is more difficult to recognize the exact water-margins than farther east where the beaches are narrow ridges between clay plains. From Grand Rapids to Pewamo the beach passes through a straight between high lands on both sides. This depression is now occupied by the Grand River, between the head waters of which, and those draining into Saginaw Bay, the divide does not exceed a height of 100 feet above the lakes, although the land rises many hundred feet on both sides. Indeed, from even west of Pewamo the low embayment widens and forms the broad flat plains at the head of Saginaw Bay. But these plains, for half their length, are drained to the west by the Grand River, although they were formerly the floor of the lately enlarged Saginaw Bay. Hence, the topography shows the reversal of the drainage, by a slight uplift towards the east and north, which in the region of Pewamo amounts to about a foot per mile. This rise continues to Chapin, whence the beach rises towards the northeast and passes around the thumb of Michigan, and descends to about a mile east of Emmett. From the crossing of the beach, east of Ypsilanti, to Lenawee, there is no terrestrial warping as shown by instrumental measurements. The occurrence of this beach, although not identified throughout any distance, was described by Prof. A. Winchell.* From Lenawee, the Ridgeway Beach extends into Ohio, and becomes identical with the beach of the Maumee Valley, called by Mr. Gilbert number three † Thence it extends eastward with natural interruptions. From Ohio it has been traced into New York by Mr. Gilbert. The portion south of the western half of the lake practically shows no deformation, but between Madison and Sheridan Centre, it rises about a foot per mile, while the lower, or Forest Beach rises in the same distance only about three-quarters of a foot, although eastward of that point the last named beach rises two feet per mile.

At the head of the Maumee valley, a fragment of beach, about 30 feet higher than the Ridgeway Beach, was described in the Geology of Ohio ‡ This, however, is only occasionally met with. A beach at Grand Rapids, Mich., at 700 feet, and a terrace near Allegan at 689, may be the equivalent of that in Ohio.

The Maumee Beach.—This is the next highest of the well defined beaches which have been studied. That, at 42 feet above the lake at Chicago, is probably identical with the beach, which has been traced from the southeastern side of the lake, as it is in the topographical position in which we would expect to find it. But the country is very sandy and duny.

The beach is identical with Mr. Gilbert's number one at the head of the Maumee valley, and hence the suitability of the name. When the water was at this level, Mr. Gilbert regarded the outflow of the lake as by the Wabash River. The divide, at the head of this river, from the Maumee drainage was nearly 50 feet below its surface.§ But it was

*Geology of Washtenaw County, by A. Winchell, 1881.
†Geology of Ohio, map, p. 549 ‡Ibid.
§Geology of Ohio, vol. I., p. 551.

not then known that this desert shore extended throughout the Saginaw valley to the Michigan basin. Nor had the moderately complete and accurately measured Ridgeway Beach been surveyed, and the warping movements measured therefrom. From the present information, it will at once be seen that the same sheet of water had also access to the Mississippi drainage by the depression at the head of Lake Michigan, which is twenty feet or more below the highest beach in the vicinity, the probable equivalent of the Maumee Beach, east of the lake, now about a hundred feet above its surface, near Columbia.

Elevations of Maumee Beach, near :

	Feet above the sea.
Columbia, Mich. (dunes rise to 699 feet)	683
Allegan (dunes to 740, terrace)	713
East of Pewamo (barometric)	841
Imlay	849
Berville	817
Ypsilanti (terrace)	784
Adrian	789
Fort Wayne (Gilbert)	788 to 778
Cleveland (Geol. Ohio)	786

Amount of Warping in the preceding Beaches.—Across the State of Michigan, the Maumee Beach records a differential eastward or northeastward elevation of scarcely more than a foot per mile, while that of the Ridgeway Beach, in the same direction, is a little less than a foot per mile.

West and south of Lake Erie the unequal movement is reduced to almost zero. But east of Lake Erie the uplift reaches two feet per mile, as recorded in the Forest Beach.

East of Lake Huron, the Arkona Beach rises to the northeastward at 1.71 feet per mile, and the parallel and younger Forest Beach at 1.5 feet. The still younger Algonquin Beach * rises 1.33 feet east of Lake Huron. This warping increases so that east of Georgian Bay it amounts to 4.1 feet per mile, in direction N. 25° E. The explored beaches north of Lake Erie have an accelerated rise, so that, northwest of Lake Ontario, it amounts to 3 feet or more per mile, in the higher water margins. If the higher shore-lines in the Adirondacks could be and were surveyed, we would expect a differential elevation to the northeast of more than six or seven feet per mile, as that amount has been measured in the lower Iroquois Beach.† But most of the differential crust movement has been since the Iroquois and Algonquin episodes.

* "Deformation of the Algonquin Beach," etc., Am. Jour. Sci, vol. xli, 1891, p. 15.
† "Deformation of the Iroquois Beach," etc., Am. Jour. Sci., vol. xl, 1890, p. 447.

Higher coast lines.—There were sheets of water preceding the Maumee episode, for across the higher lands of Michigan there are extensive belts of flat land or plains often covered in part with gravel floors, and in part with silt. They are the exact counterpart of the plains in front of the lower beaches, although more eroded by the streams cutting down to the lower levels. Thus extending from the vicinity of Kalamazoo there is an extensive plain, with a floor of well-rounded gravel, bounded on the south by ridges but with a generally open and descending country to the north. On this plain I have traveled for forty miles to eastward of Marshall, and could see in it no other history than that of the bottom of some bay in front of ridges of drift hills towards the south. The barometric height taken from the station at Kalamazoo gives the plain or terrace an elevation of 912 feet above the sea. Farther east the measurements reached 944 feet. In the valleys, there are lower river terraces probably corresponding to the Maumee Beach. The amount of warping in the region is very little. It has also been noted that there is scarcely any deformation south of Lake Erie until passing eastward of Madison, Ohio. It is well known that there are at least four troughs in Ohio connecting the Erie valley with that of the Ohio River, having summit floors at elevations of between 909 and 940 feet above the sea, composed of drift materials, and that there are terraces at the northern end of these valleys.* The terraces at the head of the Mahoning valley is a good example. It is probable that the gravel plains of Michigan and the terraces in Ohio, connected with these meridional troughs, are identical in age. But here is room for investigation. In Michigan there are other and higher gravel flats than those just referred to.

Professor Rominger records beach-like deposits at 1,682 feet above the sea on the highest lands near the northern part of the lower peninsula of Michigan.† Professor E. Desor noticed other similar deposits at considerable elevations in the northern peninsula of that State.‡ Mr. A. Murray long ago reported a series of beaches on the northern side of Lake Superior.§ Professor H. Y. Hind observed terraces at Great Dog Portage, north of the same lake at 1,435 feet.‖ Other beaches at 1,100 feet have been reported in Wisconsin. None of these have I seen, and do not know which of them, except those north of Superior, belong to true beaches, for I have everywhere had to distin-

* Geology of Ohio, vol. ii, p. 47.

† Geology of Michigan, vol. iii, p. 10.

‡ See Beaches, etc., between Lakes Mich. and Sup., by E. Desop in Foster and Whitney's Report, vol. ii.

§ Geology of Canada for 1863.

Report upon Assiniboine and Saskatchewan Expedition, 1859, p. 120.

guish between plain shore structures and those forms which go under the name of kames, osar, etc.

It is due, in part, to the delay in systematic investigation, that we owe our ignorance of the high-level shore-markings in New York. Terraces and delta deposits occur about Seneca and Keuka Lakes and elsewhere in New York. The gravel plain at Horseheads at the divide, south of Seneca Lake valley has an elevation of 900 feet. The valley is a mile or more wide. With free drainage towards the south. Is this shore deposit the equivalent of the Forest or some other beach? In a lateral valley, immediately to the east of Horseheads, there is a well marked terrace at an elevation of 1,200 feet. This terrace plain could not have been formed unless the waters filled the valleys at Horseheads, which is only three or four miles away, to a depth of 300 feet.

The terraces of the Genesee River, up to 1,500 feet above the sea, or 250 above the river, and the records north of the Adirondack Mountains tell the same story of water everywhere, at elevations indicating one vast sheet, extending over the lake basins, and only obstructed by the great islands of Ontario and Michigan, with beaches far higher than the now numerous valleys, radiating to the north, east, south and west. The margins by this shrinking Warren Water were constantly contracting, as shown by the beaches, but its full dimensions are not yet known.

Until these investigations are further extended, this chapter in the history of the lake regions cannot be completed. Its beginning was at the close of the drift episode of the Pleistocene period, and its dismemberment was the episode of the birth of the Algonquin and Lundy Gulfs, which afterwards became lakes. But whether this great sheet of water existed as an arm of the sea, or a glacial lake, may be questioned by the opposing schools. The absence of marine beaches seem to be an obstacle on one side. A sheet of water, at least 600 or 700 miles long and 400 miles wide, with several, or many outlets upon its southern side, appears still more unfavorable to the supposition of an ice dam to the east, of more than 2,000 feet in thickness, beneath which a river as great as the St. Lawrence was flowing, and continuing for the centuries which carved out the terraces and beaches. Indeed, some of the sea cliffs of the highlands of the Ontario peninsula, as well as terraces and beaches indicate a long wave action. The arguments set forth, against the glacial character of the Iroquois and Algonquin Beaches, obtain with greater force when applied to those of the Warren Water. But let the hypothesis of glacial dams be considered in a separate chapter.

CHAPTER VIII.

Post-Pleistocene Subsidence Versus Glacial Dams.*

(See map, fig. 15, page 73.)

General Continental Oscillations.

The growing interest in the evolution of the continent now calls for more accurate information than formerly, regarding the changes of level of land and sea in recent geological times. As these oscillations constituted some of the most important factors in the building of the Great Lakes, the study of their history has contributed to our knowledge of the changing relations of the continent and the sea.

From investigation of the submerged channels along the American coast, it has been shown that the continent was greatly elevated during some epoch or epochs intervening between the middle Miocene and the early Pleistocene periods. The elevation of the land was over 3,000 feet higher than now, and probably reached for a short time to over 5,000 feet.†

This elevated condition of the continent was followed by a depression of the land to far below the present altitude before the upward movement produced the now existing condition. There may have been more than one episode of elevation and depression; but the problem that we seek to solve is, *What was the maximum depression of the later Pleistocene times*, after the great beds of boulder clay were formed; for the great elevation was shortly before that period?

Most geologists are ready to accept the high continental elevation, but there are differences of opinion respecting the amount of the subsidence. Although many have their own views upon this subject, few serious attempts have been made to solve the problem uncolored by theory.

Evidence of Recent Regional Emergence.

We must seek for the evidence of the recent regional submergence in the remains of old shore-lines, such as beaches terraces and sea-

*Reprinted from Bull. Geol. Soc. Am., vol. [illegible], pp. 46[illegible]-47[illegible], 1890.

† "The High Continental Elevation preceding the Pleistocene Period," by J. W. Spencer; Bull. Geol. Soc. Am., vol. I, 1889, pp. 65-7[illegible].

cliffs, now elevated and more or less disturbed and obliterated. Isolated remnants of beaches are not accepted by all as proof of a recent elevation, although found at high altitudes; but the beaches often contain the direct proof of their own elevation.

No better example is found than the Iroquois beach of the Ontario basin (shown in the map on page 75). This elevated shore-line is one of the youngest and best preserved in the Great Lake region. It rests upon the youngest till deposits. Since its formation it has been warped toward the northeast, and thus at Fine, north of the Adirondack mountains, it has been lifted over 600 feet above its own elevation at the head of Lake Ontario.* By another series of deformed shore-lines† it has been found that the Iroquois beach, at the head of the lake, has been lifted its own height above the sea. Hence, here is measured proof that the northern side of the Adirondacks has been lately elevated 1,000 feet, or that it was recently 1,000 feet lower than now. The initial point of this movement was near the head of Lake Michigan. Its maximum deformation occurs in the Adirondacks, and amounts to seven feet per mile. Whether this rise continues to the Atlantic, or is transformed into a depression, or is faulted east of the mountains, remains to be determined. Only fragments need be looked for east of the region already explored, for the deserted shore has been traced into a region of broken mountains and wilderness.

Three hundred feet above the Iroquois plain, the Algonquin beach of the Huron basin is located.‡ In it there is a similar deformation to that recorded in the Iroquois shore, but the initial point of the warping is beyond Lake Michigan. With the deformation continuing toward the northeast, it would appear that the Laurentian mountains, north of the Great Lakes, were very much depressed during the Algonquin episode. The evidence of the formation of the Algonquin beach at sea-level has already been set forth §

While there is great deformation recorded in the higher beaches, the surveys of these more broken geological records do not enable us to trace the shore-lines down to sea-level, as in the case of the Iroquois, and to nearly as perfect an extent in the Algonquin beach. Consequently, it is necessary to rely more fully upon the perfection of the structure of the deserted shores, and upon their positions, which would

* "The Deformation of Iroquois Beach and Birth of Lake Ontario," by J. W. Spencer; Am. Jour. Sci., vol. xl, 1890, pp. 443-451.

† Ibid., p. 447.

‡ "Deformation of the Algonquin Beach and Birth of Lake Huron," by J. W. Spencer; Am. Jour. Sci. vol. xli, 1891, pp. 12-21.

§ Ibid., p. 21.

preclude their formation in confined lakes. Such conditions exist in Ontario, Michigan and Ohio, where extensive surveys have been made.

The lower of these shores, as the Ridgeway beach,* like those before named, were formed about bodies of water which opened only toward the north or east. But, ascending a little higher, the Maumee beach† occurs at altitudes which permitted its formation in water having free communication to the Ohio and Mississippi valleys by two depressions. Above this plain there are higher gravel terraces and plains in Michigan and elsewhere, notably those between Kalamazoo and Marshall, with an elevation of a little more than 900 feet above the sea. From them the country falls away by steps toward the lakes; but the sheet of water which they once bounded had at least five connections with the drainage of the Mississippi system. Other higher terraces about more insular points are found in the same region, and farther north, in Michigan, they are said to occur on the summit of the highest land east of Grand Traverse bay, at 1,682 feet above tide.

In Ontario there are well-marked sea-cliffs, carved out of the Niagara escarpment, as westward of Collingwood, especially at elevations of from 1,200 to 1,425 feet above tide. At various intervals between the plain of the Algonquin beach and the highest land of the peninsula (1,709 feet) there are also terrace and beach deposits moulded out of the drift. These remnants of shores are seen to within 20 feet of the highest point of land. The shore markings of these elevated lands are rendered more certain by the perfect water-worn stones, and the extent of the beach and terrace structure. The sea-cliffs are too deeply graven to represent evanescent coast lines. But all of these records are interrupted, owing to the topography of the country, erosion by atmospheric agencies, and the recent Pleistocene deformation of the region.

Some of the positions of the surveyed coast lines are shown in the map, page 75; but for the detailed list of localities reference should be made to a paper on "High level shores in the region of the Great Lakes and their deformation."‡

Again at Dog Lake, north of Lake Superior, Professor H. Y. Hind observed terraces at 1,425 feet above the sea.§

After allowing for all the measurable Pleistocene and recent deformation of the region, these elevated shores stand so high above every natural barrier, even far away toward the south as well as toward the

* "High Level Shores in the Region of the Great Lakes and their Deformation," by J. W. Spencer, Am. Journ. Sci., vol. xli, 1891, p. 207.

† Ibid., p. 208.

‡ Loc. cit.

§ Assiniboine and Saskatchewan Expedition, 1859, p. 120.

north, that their occurrence demands explanation by other than local causes.

The highlands of the Ontario peninsula do not form nilometers reaching more than 1,700 feet above the sea; but in Potter county, in western Pennsylvania, 100 miles south of Lake Ontario, they develop a water-shed, rising to 2,680 feet above tide, with the Genesee river flowing northward to Lake Ontario; the Alleghany to the Ohio river; and Pine creek to the Susquehanna. About the highest flattened knob, of only a few acres in extent, and rising to within 20 feet of its summit, there is a low ridge of small, well water-worn gravel, nearly free from sand. Mr. Carvill Lewis speaks of it as kame-like, but its structure and form are not different from that which may be a true beach. This is emphasized by the occurrence of a zone of boulders, forming a pavement a few feet below the gravel ridge — a feature so commonly developed in front of the deserted beaches of the lake region. This gravel ridge rests upon the highest point of, and at the very front of, the "terminal moraine" of Mr. Lewis, with the land declining to the north, as well as falling away to the south. These gravels form a sup[illegible]sting upon till charged with angular shingle of local Car[illegible]tone, and it is out of this material that the pebbles were [illegible].

There are similar superficial gravels on other, but of course, inferior knobs along the foremost portions of the "terminal moraine;" but the drainage from these ridges is toward the north, and Mr. Lewis emphasized the fact that there is no drift in the small streams flowing toward the south.* The theoretical importance of this observation will be noted later.

Besides these highest of all superficial gravels south of the Great Lakes, which I have examined, I have also visited the high terraces of the Genesee river, flowing northward from the deposits just described. Here several pauses in the receding waters are recorded. These are notable from an elevation of 1,900 feet downward. At this high altitude, the valley is nearly a mile wide and now 250 feet below the terrace. Our knowledge of these elevated and disconnected water deposits is yet very scanty, but certainly very suggestive when supplementing the surveys of the lower coast markings in the lake region.

A very interesting terrace remains in a valley three or four miles east of Horseheads, New York. The altitude of the terrace is 1,800 feet above tide, while the gravel-covered floor of the valley, at Horseheads, is only 900 feet. This last valley is over a mile wide, and it is

* "Terminal Moraine," by H. C. Lewis; Geol. Surv. of Pa., Rept. Z, 1884, p. 143.

that connecting the trough of Seneca lake with the Susquehanna valley.

Similar elevated terraces have been noted by Professor I. C. White along the upper Potomac valley facing the Atlantic, and along the adjacent tributaries of the Monongahela, which drain to the westward. These deposits he noted up to an elevation of 1,675 feet above the sea, and 175 feet above the valley, along a tributary creek above St. George, West Virginia.*

At Nachvak, in Labrador, Dr. Robert Bell found beaches of great distinctness at 1,500 feet above the sea. Gravel and shingle terraces were also found to an estimated height of 2,000 feet.†

It has already been noted that the differential rise of the Iroquois beach, north of the Adirondack mountains, amounts to seven feet per mile, and that it has there been lifted to a thousand feet. If this rise continues to the White mountains, then the equivalent of the Iroquois beach may be found among the terraces of the high valleys in that region. Its records may be preserved still further northeastward on the drift-covered sides of Mount Katahdin in Maine. Mount Desert, on the coast of Maine, rises to 1,500 feet,‡ and shows remnants of coast action to its summit; consequently it is too low to bear records of the Iroquois shore, unless the warping of the earth's crust becomes one of depression east of the Adirondacks.

In Ontario, some of the high shores, referred to above, occur at elevations of 1,000 feet above the Iroquois plain; therefore, their equivalents in the northern Adirondacks should be looked for at about 2,000 feet above tide. The beaches reported in Vermont by Professor Hitchcock at or below 2,300 feet, doubtless correspond to some high shore-lines of the Ontario peninsula. Upon the same basis these high beaches should be looked for at 3,000 feet in the White mountains, and at greater elevations on Mount Katahdin in Maine.

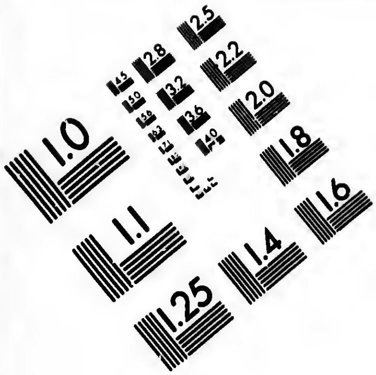
If we regard the gravels of the highlands of Pennsylvania as having been formed at sea-level, then it would be reasonable to look for their counterparts in New Hampshire, at elevations of over 4,000 feet on Mount Washington and to the summit of the drift (4,400 feet) on Mount Katahdin. These conjectural estimates, based upon a possible uniformity, may aid in the corelation of the topographic features of the mountain region of the east with the lake region.

---

*"Rounded Boulders at High Altitudes," by I. C. White: Am. Journ. Sci., vol. xxxiv, 1887, pp. 375-381.

†Rept. Geol. Surv. Can., 1885, DD, p. 8; and Bull. Geol. Soc. Am., vol. 1, 1889, p. 368.

‡"Geology of Mount Desert," by N. S. Shaler; 9th Ann. Rept. U. S. Geol. Surv., 1888, p. 993.



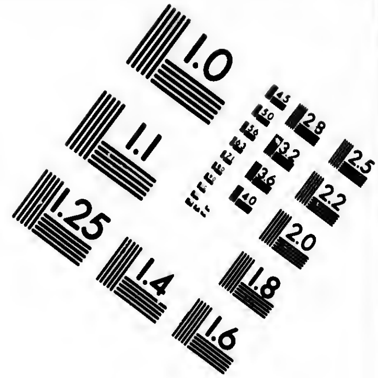
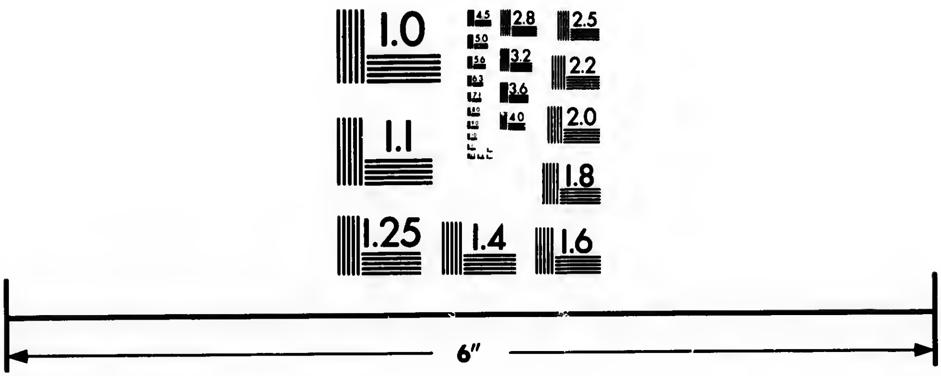
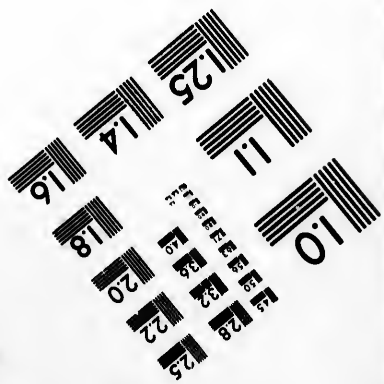


IMAGE EVALUATION
TEST TARGET (MT-3)





INTERPRETATIONS OF THE EVIDENCE.

So far as relates to the northeastern portion of the continent, our observations on Neptunian phenomena have now been epitomized. An explanation is necessary. That the pebbles of the beaches and the shore-lines were the results of wave or current action no one questions, but there are differences of opinion as to the conditions under which the waters moulded their coast-lines. Were these deserted shores constructed at sea-level, or were they moulded in glacial lakes? These are the theoretical questions before us.

The difficulties which the sea-level theory present to some minds may be stated as: (1) a great regional depression of the continent; (2) the absence of absolute continuity of the beaches; (3) the absence of marine organisms in the beaches; and (4) the personal equation of theoretical views. On the other hand, the theory of glacial dams presents such obstacles that their value will be considered at length.

The idea of the hydrostatic stability of the continent must not be too strongly relied upon, for the evidence adduced, which shows that the continent lately stood 3,000 or temporarily even 6,000 feet higher than now, appears conclusive. Such mobility of the earth's crust being established, there appears no reason why the terrestrial pendulum could not have moved equally in the opposite direction, and carried down the highlands of Pennsylvania to nearly 3,000 feet, or those of New England to twice this depth. The objections to such subsidence could only be based upon its magnitude, which observations must settle.

The absence of the continuity of the shore-markings is an objection only to a limited extent. Part of the reported absence arises from the imperfection in the explorations, owing to their changing character; to the local non-formation of beaches as described in a previous paper;* to the failure of identification of separated points, owing to subsequent terrestrial deformation; and to the interruptions occasioned by topographic features and subsequent obliterations by erosion. All of these difficulties are greatest in the higher regions, for there the beaches must be looked for among islands and detached mountain knobs.

The absence of marine remains seems perhaps the greatest obstacle to the acceptance of a sea-level formation of the beaches, as marine organisms are found only up to 520 feet.† But the Pleistocene gravels occur in Georgia and Alabama, in position facing the sea, at altitudes of 700 or 800 feet, and higher up the greater valleys at 1,500 feet,‡

* Ancient Shores, Boulder Pavements and High-Level Gravel Deposits in the Region of the Great Lakes, by J. W. Spencer; Bull. Geol. Soc. Am., vol. 1, 1889, p. 77.

† At Montreal.

‡ On the upper Etowah river of Georgia.

without containing any marine remains. Even where marine Pleistocene beaches occur on the coast of Norway there are very few localities where shells are found. How many of the older geological formations are unfossiliferous? How many of those ancient beach deposits, now represented by conglomerates, porous sandstones, and indeed many clays, are entirely barren? Under such conditions have we a right to pronounce judgment on the freshness of waters based on the absence of aqueous organic remains? This question will be referred to again in considering the glacial dam theory.

As to the personal equation, it ought not to pass beyond the limit of conservatism, but it is quite proper that it should be considered; for, as Professor Geikie has said, "when controversy ceases the interest in the investigation declines."

GLACIAL DAMS CONSIDERED.

Glacial lakes are of two kinds: those whose waters are retained by morainic barriers; and others sustained by ice barriers alone.

The former class is represented in several valleys in the Alps, where lateral glaciers enter and cross greater valleys; sometimes the glacier carries its lateral moraine across the valley and builds a more or less permanent earth dam. Such lakes remain long after the glacier has melted away, and even when drained show evidence of their origin. A consideration of this class of glacial lakes does not enter into the subject of this paper.

In Switzerland, Greenland and Alaska other glacial dams are now well known. These are retained by the ice alone. When glaciers, free from morainic materials, descend lateral valleys and across other valleys, they do not obstruct the rivers, for they continue to flow beneath the ice. However, there are many places where glacial lakes occur between the ice and the sides of the valleys; especially is this the case where two glaciers meet at the end of a mountain spur, like Lac Tacul in Switzerland. Small glacial lakes, like the Marjelen-see, sometimes occur where lateral valleys unite with the glacier-filled channels. All modern glacial lakes are of small size. One of the largest lakes described in Greenland is not over three or four miles long and a mile wide. Such lakes, when they exist above sea level, are evanescent. Mr. H. Topham described some glacial lakes of Alaska which discharge by a tunnel, eight miles long, under 500 feet of ice. Mr. I. C. Russell makes similar reports. The outflowing waters enlarge the tunnels, thereby draining the lakes; but the ice roofs fall in, and by the accumulation of ice blocks the tunnel becomes temporarily obstructed, causing the water of the lakes to rise. In the very nature of the case, large lakes could not be expected, for the conditions which would permit their formation would cause the glaciers to recede. Especially would this be the case if the glaciers were hundreds of feet above the sea, with rivers draining beneath or through them. It would be difficult to conceive how any water-level could be maintained long enough to permit the waves to carve out terraces and sea-cliffs. With glaciers coming down intc the sea, it is easy to understand how bays and inlets could be obstructed by the ice so as to allow the water to be freshened. In such lakes the water-level could be maintained long enough to leave inscriptions in the form of terraces and beaches.

Such is a brief account of the natural history of glacial dams. It has been said that the easiest explanation of the theory of our Great Lakes is by regarding them as formerly great glacial dams: so it was thought 10 years ago that the least troublesome hypothesis of the origin of the Great Lake basins was by their excavation by glaciers; but the writer, going into a field of invesigation almost sealed by pre-judgment, has shown that glaciers did not scoop out the basins, and has otherwise found satisfactory explanation of their origin* without invoking the necessity of ice being converted into rock-diggers. So, also, the evidence of glacial dams has not been found, so far as investigations have extended.

Let us examine how the glacial-dam theory applies to the shore-lines already described.

The physical features of the Ontario basin are the most favorable for the constructions of a great lake retained by glacial dams As proved by its deformation, the Iroquois beach was formed at sea-level. If this proof of the altitude of its birthplace did not exist, the evidence of its elevation would be obtained from a consideration of the ability of glaciers to close the St. Lawrence valley to the northeast. Such a barrier would have been from 60 to 100 miles wide, and from 800 to 1,300 feet deep (below surface of water), according to location. Yet the drainage of the then expanded lake, over 300 miles long (so far as serveyed) and 100 miles or more in width, was against, into, or under the supposed glaciers, except to a limited extent in its earliest stages, when a partial overflow was by the Mohawk valley. Had the lake been above sea-level, a river as large as the St. Lawrence would soon have eaten its way through the ice and lowered the lake, for in that direction alone it had to flow; consequently, it appears that the great

* "Origin of the Basins of the Great Lakes of America," by J. W. Spencer; Quart. Journ. Geol. Soc., vol. xlvi, 1890, p. 523.

cut terraces and beaches, requiring centuries or millenniums of time, could scarcely have been formed except at sea-level.

If the Algonquin beach of the upper lakes were formed in a glacial lake, then the ice barrier in the region of Lake Nipissing would have reached 600 or 700 feet beneath the surface of the water. The drainage must have been under the ice, and have amounted to a discharge equal to that of the modern Detroit river, as the discharge of Lake Superior, Lake Michigan and Lake Huron basins would have been thus borne seaward, descending 300 feet to the level of the Iroquois water. Under such conditions, the question may be asked, How could the lake surface be retained long enough at any level to carve out the deeply graven water lines and terrace plains of the Algonquin beach, in place of the discharging waters melting away the icy barriers, which were supposed to have been the means of retaining the lake 300 feet above the level of the Iroquois waters?

We now rise to the shores which bounded the Warren water. These I have explored from Lake Michigan to New York, and to the eastern portion of the Ontario peninsula. Under the glacial-dam theory, this sheet of water would need a barrier to the north as well as to the east. The drainage of the lake, at all stages, from the Ridgeway beach downward, was to the northeast, and beneath a greater hypothetical mass of ice than in the case of the Algonquin or Iroquois waters; but above the Ridgeway beach,* at the Maumee level,† there were outlets across Ohio and Illinois, if a lake it were. The difficulties are increasing.

The shore-markings occurring at Kalamazoo, at about 900 feet above tide, represent a sheet of water having at least five outlets across Ohio and Illinois. Again, the sea-cliffs of the Ontario peninsula, at from 1,200 to 1,425 feet and more, and the beaches now found up to 1,689 feet, would demand great dams toward the south and west as well as toward the north. But such dams could scarcely have existed with open waters carving out sea-cliffs and terraces on the high peninsula of Ontario, and also leaving records 200 miles southward. It should be noted that gravel deposits of the so-called kame and osar structures occur at all high levels; but of these I do not take cognizance.

The drainage of the high country, such as the Genesee valley, with terraces up to 1,900 feet or more, and of the "terminal moraine," up to 2,680 feet, was toward the north without obstruction.

* "High Level Shores in the Region of the Great Lakes and their Deformation," by J. W. Spencer: Am. Journ. Sci., vol. xli, 1891, p. 207.

† Ibid., p. 208.

Ascending now to Potter county, we find the gravel ridge at 2,660 feet, on the very edge of the highest knob of the "terminal moraine." This high point could not have stood out of the ice as a Greenland "nunatak," with a lake around it, for it is at the margin of the drift, and glaciers do not deposit their terminal detritus within the ice, but at their very margins. It seems impossible to conceive a glacial mass retaining a lake about this flattened knob, even if the country were submerged to almost sea-level. There are other similar deposits on adjacent summits. Again, had a glacier existed on the top or on the southern side of this "morainic" ridge, which is a water-shed, its melting ice must have carried great quantities of drift into the valleys toward the south, which neither Mr. Lewis nor I have seen. But the drainage was toward the north, into the hypothetical glacier, which, if it permitted sub-glaçial drainage, could scarcely have formed lakes.

CONCLUSIONS.

Under these conditions, fairly stated I think, whether is it easier to accept a great subsidence of the continent, to nearly 2,700 feet in western Pennsylvania, or account for the phenomena by glacial dams formed on land vastly lower toward the north? Indeed, the great deformation of the lake regions had scarcely begun, and, consequently, even the modern highlands north of the Great Lakes were then very much lower than now, when compared with the region to the south. I cannot hesitate forming a conclusion that the evidence is in favor of a late continental subsidence rather than in favor of glacial lakes hundreds of miles long and broad, like nothing ever seen, and which could not answer the requirements.

The difficulty in accepting the subsidence without the occurrence of marine shells has in part been pointed out. But their absence in the lower beaches may be accounted for, in part, by the sheets of water being more or less cut off from the sea and receiving great quanties of fresh water. This, however, will not explain their absence on the higher beaches. The varying climatic conditions of the water and the changes of level destroying the life, too rapid to allow of remigration, may in part account for the absence of organisms in the seashore lines.

The record of subsidence deciphered in the high-shore lines of the lake region is supported by the observations of Dr. G. M. Dawson, Mr. R. G. McConnell and others, on the monuments rising above the great plains of northwestern Canada, and on the mountains between there and the Pacific coast. Dr. Dawson* finds gravel terraces upon the high sides of the Rocky Mountains, facing the east, in position showing the origin not to have been river terraces.

From extensive observations Dr. Dawson concludes that the Pleistocene submergences amounted to 4,000 or 5,000 feet in the region of the international boundary (the 49th parallel), while in Alaska it did not exceed 2,500 or 3,000 feet. He also postulates two episodes of submergence, the latter being less extensive than the former. Further, he regards the elevation and subsidence of the great plains and western mountains as alternating, and that the drift material of the plains was deposited at sea-level.

Mr. R. G. McConnell informs us that on Cypress hills, with an altitude of 4,800 feet, the drift does not rise above 4,400 feet. One hundred and fifty miles northwestward, the drift is not found above 3,400 feet on Hand hills (Tyrrell); but south of Cypress hills, near the 49th parallel, the drift occurs up to 4,660 feet on Buttes (Dawson). From these observations Mr. McConnell shows a differential level of 7.2 feet per mile, the elevation being greater nearer the 49th parallel.

In the east, the history of the changes has not been fully deciphered. Erratics occur on top of Mount Washington to 6,300 feet, while on Mount Katahdin, in Maine, they occur only to 4,400 feet (Upham). Conforming with Dr. Dawson's views, as applied to the west, we have a greater rise in the White mountains than eastward. The altitude of beach formation on the highlands of Labrador (1,500 to 2,000 feet), shows the recent northern uplift to have been less than in New England.

Combining the movement of the east and the west, it would appear that the great Pleistocene uplift reached its maximum along a line between the Gulf of St. Lawrence and Vancouver island, rather than in higher latitudes. The youthfulness of the northern topographical features shows that the elevation of the lands in the higher latitudes, above the base-plane of river erosion, has taken place in recent geological times, for there is a lack of such great cañons in the country north of the great lake zone as occur in the region to the south of it.

If the subsidence of the northern portion of the continent appears to have been great, that of Barbadoes, toward the southeast, appears to have been greater; for Messrs. J. B. Harrington and A. J. Jukes-Browne† have pointed out that there are on the island oceanic deposits

---

* "Later Physiographical Geology of Rocky Mountain Region in Canada, with Special Reference to Changes in Elevation, and the History of the Glacial Period:" Trans. Roy. Soc. Can., vol. viii, sec. iv, 1890, pp. 3-74, pls. I-III.

†Geology of Barbadoes, 1890.

resting upon beds of sandstone and shales of probably Miocene age, and beneath coral formations of age not greater than the Pleistocene. These deposits indicate an origin of not less than a thousand fathoms, and, as Mr. Jukes-Browne points out, probably of vastly greater depth. This geologically recent subsidence was not likely synchronous with that to the north, but may have been one of those alternating conditions suggested by Dr. Dawson.

The fjords of the coast of Norway show that the Scandinavian peninsula lately stood 4,000 feet higher than now. The silt and terrace deposits at 3,000 feet* point to a subsidence of that region the same as similar deposits in the mountains of America.

The deep submerged channels south of Asia, like that of the Ganges, which is 8,570 feet deep, proves a recent submergence of that amount. But such deep channels are not known north of Asia; consequently the higher latitudes do not show a great amount of late depression. The Pliocene deposits in Sicily, at 3,000 feet, demonstrates a recent elevation.

Pliocene deposits in the southeast of England are now found at 600 feet above tide. Their counterparts at Utrecht have been shown by Mr. Clement Reid to be now submerged more than 1,143 feet †

The oft-quoted Moel Tryfean deposits, in northwestern Wales, show marine shells at 1,400 feet, with similar but unfossiliferous beds rising to nearly 2,000 feet. These deposits, which I have visited, I consider to have been formed where found; but they do not represent so late a subsidence as our deposits in the lake region, for they are not the superficial gravel, but are covered by a few feet of more recent till.

These few foreign examples just cited show that the continental movements, as set forth in this paper, are not peculiar to America; but they were not probably synchronous, although they have taken place in the most recent geological times.

This paper must, of necessity, be imperfect, as it is the first attempt to work out the detailed evidence of the recent terrestrial subsidence from records in ancient shore-lines of the Great Lake region, many of which have only recently been reported by the writer. All of the phenomena cited show that in recent geological times there have been gigantic movements causing the earth's crust to heave to and fro, producing conditions which have greatly modified the physical features, climatic conditions, and distribution of life.

---

*"High Level Terraces of Norway," J. R. Dakyns: Geol. Mag, sec. ii, vol. iv, 1877, p. 72.
†Brit. Admir. Chart, No. 70.

APPENDIX.—CHANNELS OVER DIVIDES NOT EVIDENCE PER SE OF GLACIAL LAKES.*

The locality of this paper was visited in company with Mr. G. K. Gilbert, and the descriptions given are only sufficient to allow a statement of my views, as I consider it a very important region.

The valley of Black river, New York, extends nearly 40 miles above Carthage, forming an embayment on the northern flanks of the Adirondack *massif.* Boonville is on the divide between the head of this valley and an eastern branch of the Mohawk river. The limestone floor of the divide is 1,141 feet above the sea. From it the valley rapidly widens, and at a point ten miles to the south it is two miles in width. At a short distance farther southward, the hills rapidly fell away, leaving a comparatively low country. A few miles westward, the parallel Iroquois beach records differential elevation of the land amounting to four feet or more per mile. In the great valley of the Black river, conspicuous terraces occur north of Boonville at 1,190, 1,170 and 1,130 feet. The terraces continue on the southern side of the divide, and at a point ten miles distant were noted at 1,095, 970, 940, 888 and 830 feet, with the floor of the valley 770 feet above tide. With the differential warping considered, the identity of the upper terraces is unquestionable. The summit of the divide is not covered with a gravel deposit; but a short distance southward gravel deposits were seen, though their altitude was not measured.

Let us now ask, What barrier retained the volume of water 325 feet above its floor in a valley one to two miles wide, with the opening country descending in the next ten miles another 325 feet? Here we have the action of the water in a great open embayment leaving records at an elevation of 650 feet without any barrier on the south, unless these waters were retained against the now high level banks, owing to a submergence of the region down to sea-level, as it can scarcely be supposed that a glacial dam could have occurred upon the southern side of the lake. The absence of the terrace deposits on the divide is easily explained by the action of tidal currents and need not be considered the proof of a glacial river flowing over the watershed into a great embayment which could not have retained the volume of water passing over the divide at hundreds of feet above the bottom of the valley without an obstruction or submergence to the south. The lower terraces are confined to the valleys and are not specially con-

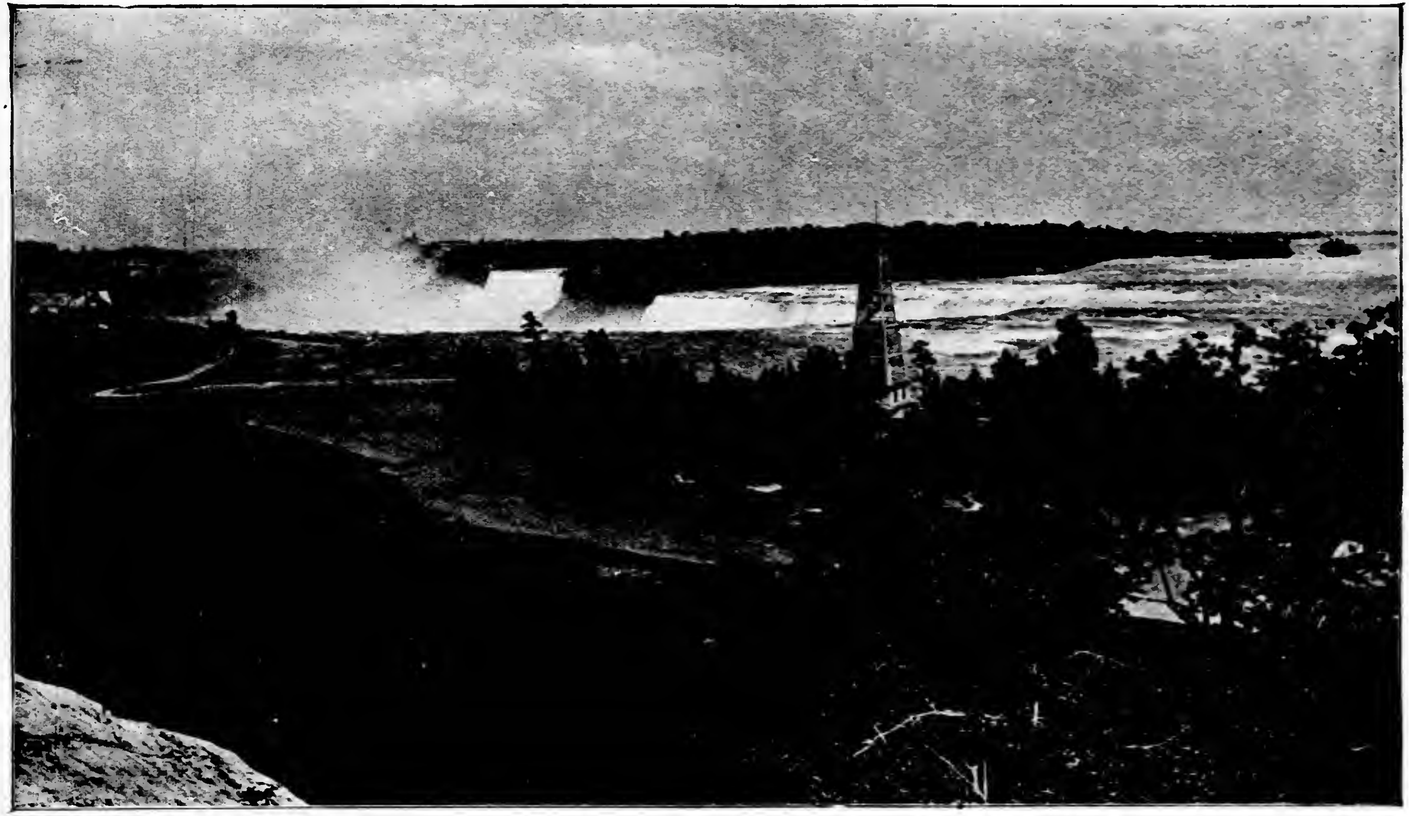
*Reprinted from Bull. Geol Soc, Am. vol. 23, p. 491-2, 1891.

sidered. Here, then, we find a col connected with terraces on the northern side, such as are often quoted as proof of glacial dams, but the terraces on the southern side disprove the efficiency of ice dams to account for this class of high level terraces.

Since the above was written the author has observed many other similar data, all showing the fallacy of constructing glacial dams upon the evidence of general flows over divides leading southward. Indeed, he has seen the same phenomena within the tropics on the Isthmus of Tehuantepec, where no glacial dams could have been situated.

n the
, but
ns to

other
upon
deed,
us of



VIEW FROM THE CANADA SIDE.

VIEW FROM THE CANADA SIDE.

CHAPTER IX.

Art. LXIII.—The History and Duration of Niagara Falls.*

Conjectures as to the Age of the Falls.

About the year 1760, Sir William Johnson took possession of Niagara Falls, and from that time its recession impressed itself upon the few observers, so that when Andrew Ellicott made the first survey of the chasm, shortly before 1790, he was informed that the cataract had receded twenty feet in thirty years; whereupon he concluded that its age was 55,440 years.** Bakewell's estimate, in 1830, reduced its duration to about 12,000 years.† According to Lyell, in 1841,‡ the Falls was about 35,000 years old, and this conjecture was generally accepted until a few years ago. The first steps taken towards the determination of the age of the falls were those to ascertain the rate of actual recession. In 1842, Prof. James Hall triangulated the cataract§; in 1875,‖ the Lake Survey; in 1886,¶ Prof. R. S. Woodward; and in 1890,§§ Mr. Aug. S. Kibbe repeated the measurements. In 1819,†† the International Commission surveyed the river, and showed that the apex of the cataract was very acute, yet it does not appear that the measurements could be compared with the later surveys made for the determination of the rate of recession. The four surveys naturally give data for superseding the earlier estimates, and if the mean rate of retreat of the Falls during 48 years be taken, its age would appear to be 9,000 years. The conjectures of the older geologists have been set aside by recent writers who have endeavored to reduce the age to 7,000 years by using the maximum rate of measured recession. Substituting a measured rate of retreat for one purely assumed was a step in the right direction, but without knowing it, the later writers were farther

* Reported from the Am. Jour. Sci., vol. xlviii, pp 455-472, 1894.
** "Journal of William Maclay," Appletons. 1890.
† Cited in "Travels in North America in 1841," by Sir Charles Lyell, vol. i, p 27.
‡ The same.
§ "Natural History of New York," Part IV, vol. iv., p 184.
‖ Lake Survey Chart.
¶ Report of the meeting of the Am. As. Ad. Sc. in Science, Sept., 1886.
§§ 7th Rept. Com. State Res. Niag., 1891.
†† Printed by the U. S. Lighthouse Board.

astray than the earlier, for they neglected to take into account the changing episodes of the river, which was not known to the earliest observers. Only one other geologist besides myself has called attention to the *varying* forces which have made the Niagara cañon,—and this is Mr. G. K. Gilbert,* by whom and the writer the principal phenomena affecting the history of the river have been discovered. The last question which had to be determined before a computation of the age of the falls could be undertaken was the approximate amount of work accomplished by the river during each of the episodes in its history. This I was able to estimate last fall.

Physical Features of the Niagara District.

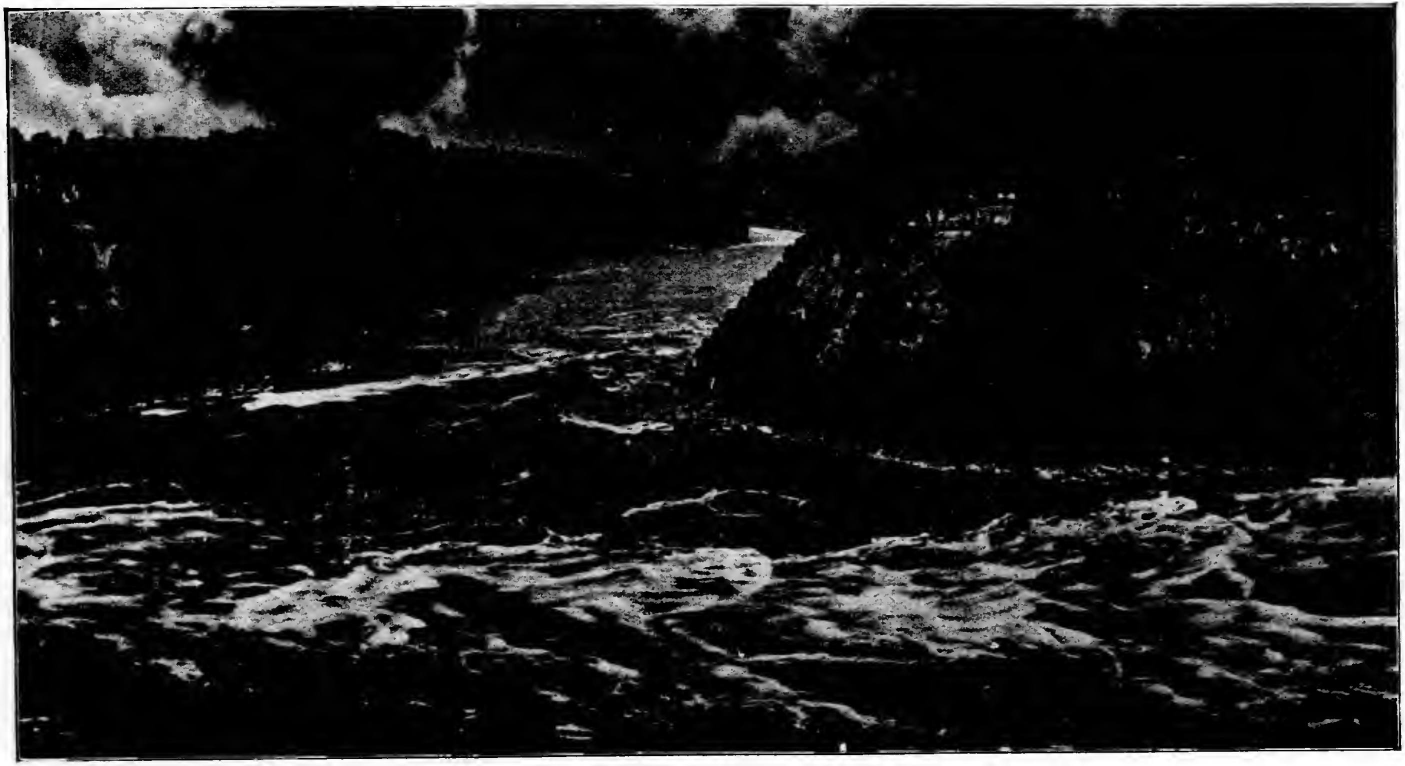
For distance of 19 miles from Lake Erie (573 feet above tide), the Niagara peninsula is a plain, with slight undulations, rising from 15 to 30 or 40 feet above the lake. But three features are notable: (*a*) a drift ridge trending westward from the falls and surmounted by a each (L, fig. 24) rising to 114 feet above the lake, with a knob 30 feetb higher, at Drummondville; (*b*) at the outlet of Lake Erie, the river cuts through an escarpment of Devonian limestone, which there rises to about 30 feet; and (*c*) at a point about a mile north of the site of the falls there is another limestone ridge here named William Johnson's ridge in honor of the first settler (*e*, *e*, fig. 17) with an elevation of 40 or 50 feet. Between these two rocky ridges is the Tonawanda basin. From the northern margin of the plain, the escarpment suddenly descends about 210 feet to a lower plain which extends eight miles to the shores of Lake Ontario (247 feet above the sea). Upon leaving Lake Erie the river channel is only a quarter of a mile wide but reaches a depth of 48 feet. After passing the Devonian escarpment, the river is broad, even a mile and a half above the fall, with a depth of from 1 to 16 feet. The cañon is about 36,000 feet long and varies from 900 to 1,400 feet in width (see fig. 17 and sections). After the river issues from the gorge its width is about a half a mile, and the depth reaches to 96 feet, or 94 feet below the surface of Lake Ontario. In the cañon, three-quarters of a mile below the site of the falls, the river has a depth of 189 feet, at a point where the surface is about 105 feet above the lower lake. That the upper part of the cañon are vertical should be emphasized.

*** Mr. Gilbert writes thus: "You are aware that I am everywhere quoted as estimating the age of the river (Niagara) as about the 7,000 years. It was partly to dispel this impression that I wrote. * * * In point of fact I have made no estimate and my opinion, so far as I have one, is that the age of the river is much greater than 7,000 years."**

count
rliest
atten-
— and
ncipal
vered.
ion of
mount
in its

le), the
n 15 to
le : (*a*)
d by a
0 feetb
e river
rises to
of the
John-
ation of
awanda
uddenly
s eight
Upon
ile wide
escarp-
all, with
000 feet
ections).
f a mile,
of Lake
te of the
surface is
the cañon

timating the
pression that
I have one, is



THE NIAGARA GORGE BELOW THE WHIRLPOOL.

Geology of the District.

The geology of the district is too well known to need description, but the measurements had not been made which could be used in determining the varying character of the work performed by the river; accordingly I made the following sections and those illustrated in figures 19, 22, 23, 24, 25, 26, 27.

The plain between the escarpment and Lake Ontario is underlaid by a great thickness of Medina shales, thinly covered with drift and lacustrine deposits. The flat country, between the head of the rapids above the falls of the Devonian escarpment near Lake Erie is underlaid by shaly rocks of Onondaga age. The southward dip of the strata from the end of the gorge to the Devil's hole (9,700 feet distant, at the mouth of Bloody run) is 40 feet; thence the whirlpool (8,500 feet) 26 feet; and from there to the falls (15,000 feet in a direct line) only 10 feet, or almost horizontal.

	At Falls.		Whirl pool.		Devil's Hole.		N. Cath. Col.		End of Gorge.	
	Feet thick.	Feet above Lake Ontario.	Feet thick.	Feet ab ve Lake Ontario.	Feet thick.	Feet above Lake Ontario.	Feet thick.	Feet above Lake Ontario.	Feet thick.	Feet above Lake Ontario.
Pleistocene in depressions and on ridges	160	410	40*	340	......	......	......	......	......	
Niagara limestone	55	280	65	300	†30	340	†35	340	†15	340
Crest of Falls	....	270	....	......	60	......	40	......	25	
Niagara shale	60	225	65	235	......	250	60	265	75	300
Clinton limestone	15–20	165	20	270	......	......	20	205	15	225
Bands of shale, limestone and sandstone at base,	20–15	......	....	15–20	......	......	20	......	20	
Surface of river	...	110	....	......	......	......	......	......	......	
Medina shale	25	......	25	......	......	......	......	......	20	
sandstone‡	5-10	100	8	105	......	......	......	......	5	170
shale	30	... ..	30	......	......	......	......	......	25	
sandstone	20	60	20	60	......	......	......	......	20	140
shale to lake level	40	......	40	......	......	......	......	......	120	

* Drift on we t side, rocks on east side of gorge. † The upper figures relate to rocks in river terrace; the lower in wall of go ge.
‡ Both the Medina sandstone and shales vary in thickness.

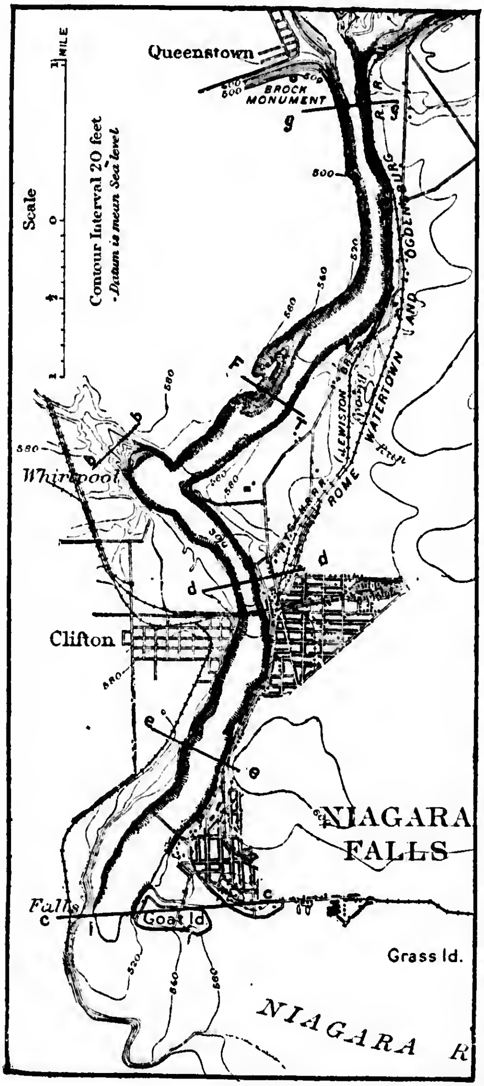


FIG. 17.— Map of Niagara Cañon (U. S. Lake and Topographic surveys) showing its variably width and the position of the cross sections.

Ancient Topography and Basement.

In the numerous writings upon the Niagara river one ancient topographic feature has been overlooked and another exaggerated into importance which it does not possess. The ancient drainage of the

Erie basin was not by way of the Niagara, but by a channel 40 miles to the west.* Even at the end of the Lake Erie the borings show old channels deeper than the floor of the river across the Devonian escarpments.† The feature overlooked is the Tonawanda valley, a mile and a half in width, extending from the rapids above the falls to the Johnson ridge. Its basement is 80 or 90 feet below the northern barrier of Johnson's ridge. The rocky sub-surface of Goat Island was part of the ancient floor (see fig. 27). This depression is part of the ancient Tonawanda basin, which is now filled with drift (see fig. 24). The gorge through Johnson's ridge is modern with vertical walls, but half a mile to the west it falls away and the wells reveal the continuation of the Tonawanda depression extending northward. It is again made known by a well half a mile west of the whirlpool (*w*, fig. 19), in the line of the extension of the St. David's valley. This forms an embayment one and half miles wide and only three-quarters of a mile deep in the face of the Niagara escarpment. The modern river is simply crossing a portion of the old Tonawanda basin in the vicinity of the falls, and consequently it has here much less rock to excavate than through and north of Johnson's ridge.

The other feature is the imaginary whirlpool — St. David's valley, supposed to have been the old course of the river. Above and below

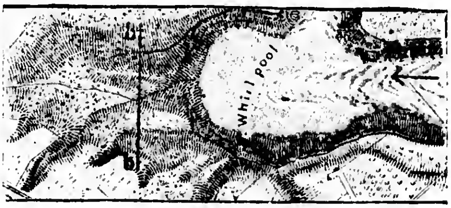


FIG. 18.—Map of the whirlpool; *bb*, position of section (in fig 17).

the whirlpool alike, the gorge is of recent date as may be seen by the vertical walls shown in the several sections. The whirlpool ravi e has sloping V-shaped boundaries in its higher portion, which is an antique structure. The depression is so obstructed with drift, that gives rise to landslides that the old topography is much obscured. Yet a little stream has removed the fallen earth and exposed a natural section of

* "Origin of the Basins of the Great Lakes," Q. J. G. S. Lond., vol. xlvi, p. 523, 1890, and "Notes on the Origin and History of the Great Lakes," Proc. A. A. A. S., vol. xxxvii, 1888.

† "The Life History of Niagara," by Julius Pohlman, Trans. Am. Inst. Min. Eng.

Clinton limestones, which cross the valley at an elevation of 115 feet above the surface of the whirlpool, or 160 feet above Lake Ontario, with Niagara shales showing for at least 20 feet higher. Thus the rocky barrier across the ravine is not less than 240 feet above the bottom of the cañon in the whirlpool. This barrier in the ravine is illustrated in fig. 19, which should be compared with figures 22 and 23, in order to appreciate the insignificance of the whirlpool ravine.*

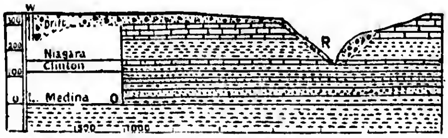


FIG. 19.—Section across the whirlpool ravine, located at *bb*, fig. 2; W. well; R, stream.

The form of the whirlpool cauldron requires explanation. At Mr. Shepherd's house, a short distance west of the whirlpool, there is a well 90 feet deep without reaching rock (*w*, fig. 19) and this shows the absence of Niagara limestones to a depth of more than 50 feet below the surface rocks of the western wall of the whirlpool. At that point the limestones rise 40 feet higher on the eastern side of the river than on the western, but the depression was leveled up with drift. Thus it appears that at this point the Niagara river took possession of the eastern side of a drift-filled valley (Tonawanda - St. David's), and the whirlpool ravine was a little tributary to it. When the falls had receded to the whirlpool and penetrated the rocky barrier, the currents were able to remove the filling of the buried ravine, and this gave rise to the form of the cauldron, which deepened its basin to lower levels by the currents of the river acting upon the underlying soft shales, with the landslides obscuring the older features. It is evident that there was no preglacial Niagara river.

The Niagara river crossed the broad shallow depression of the Tonawanda drainage, at the falls and that adjacent to the whirlpool on a basement of drift, but elsewhere generally on hard limestones. Out of both of these materials, terraces were carved thus marking the old river level, before it sunk within the chasm.

Discharge of the Niagara River.

The Corps of Engineers, U. S. A., made the measurements of the outflow of the Great Lakes between June 27th and September 17th,

* In Rept. of meeting of Am. As. Ad. Sc. in Science, Sept., 1886, it is noted that Prof. E. W. Claypole found rocks in the ravine, without giving any details in explanation. Since this paper has been in type, Prof. James Hall informed me that Prof. J. W. Powell and himself had also seen the occurrence of the rocks, but no notice has been printed. The error has been even recently repeated by a writer in "Nature."

1868.* That of Lake Huron was 216,435 cubic feet per second; and of Lake Erie for the first part of the season, 304,307 cubic feet, and 258,586 feet for the second part. From these figures I have taken the maximum proportional discharge (as the volume is variable) of Lake Erie, which is found to gather $\frac{3}{11}$ of the total drainage of the Niagara river, but the mean discharge is less than $\frac{3}{14}$. This is an important factor in the following computations.

Modern Recession of the Falls.

The four surveys illustrated in figure 18 show the modern recession of the horseshoe cataract. During 48 years 275,400 square feet fell away. The mean width of the adjacent portions of the gorge (as opposite Goat Island) is 1,350 feet. Thus the mean recession would be 4.175 feet a year. The American falls have undermined 32,900 square feet of rock, which gives a mean rate of 0.64 foot a year. But the rate is not uniform. In 1819, the crest of the Canadian fall was

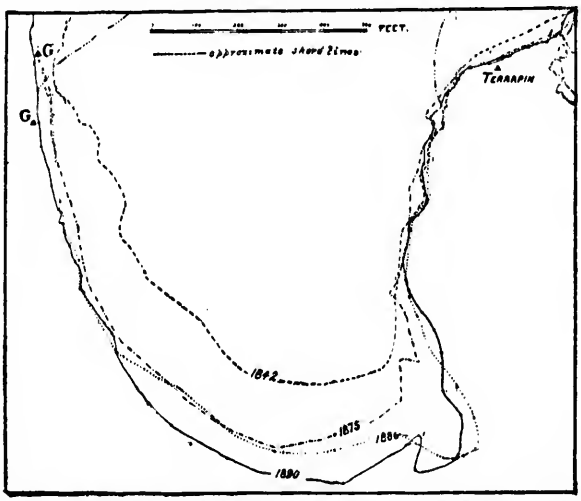


FIG. 20.—The four surveys of the Canadian Falls showing the retreat of the cataract (in which some inaccuracies are apparent). (Kibbe.)

very acute, it had become quite obtuse in 1842, acute in 1886, but it was broadening out again in 1890; thus there are cycles of slow and rapid retreat.

The measured recession has probably obtained since the cataract cut its way through Johnson's ridge, for beneath the Tonawanda basin the

*Report of Chief of Engineers for 1869, p. 582.

limestones have a thickness of only 45–55 feet, as the upper 90 feet had been removed in pre-Pleistocene times. The capping limestone in Johnson's ridge was 140 feet thick. To the north the thickness was reduced. Along those portions of the chasm where the limestone is heavier and the gorge narrower than in the pre-glacial depression, the stronger arches must have arrested the maximum rate of retreat, and on this account, I have reduced the measured mean rate of recession by an estimated amount of 10 per cent., or to 3.75 feet a year for the recession of the falls from the end of the cañon to Johnson's ridge, under conditions of the modern discharge and descent. The mean descent of the river was from the plain, now at 340 feet above Lake Ontario; but whilst passing the rapids of Johnson's ridge, 25 feet must be added to the declivity of the river. After the basin behind the river was reached, the water plain was reduced to about 320 feet, including 50 feet of descent above the falls in the form of rapids. The surface of the country has been deformed since the commencement of the cataract by a northward terrestrial uplift to the extent of 12 or 15 feet, divided throughout the length of the gorge, where, as seen in the cañon, the character of the different strata is remarkably uniform, except in the described depressions, across Johnson's ridge, and at the end of the chasm where the capping limestones were much thinner, but partly compensated for by the greater prominence of the hard Clinton and Medina layers.

The following computations are based upon the mean rate of recession, modified by the variations in the descent of the waters and their changing volumes, which have been discovered in the geological investigations of the Great Lakes.

Sketch of the Lake History and the Nativity of the Falls.

This outline is taken from the chapters on the Lake History noted at the foot of the page.* At the commencement of the Lacustrine epoch, Warren water gulf covered most of the Lake region, and Forest beach was its last strand. Afterwards the waters sank 150 feet, thereby dismembering Warren water gulf into Algonquin Gulf (confining it to the basins of Superior, Michigan and Huron) with an outlet

* "The Iroquois Beach, a chapter in the History of Lake Ontario," Trans. Roy. Soc Can. 1889, p. 133. "Deformation of the Iroquois Beach and Birth of Lake Ontario." Am. Jour. Sci., vol. xl, p. 443, 1890. "Deformation of Algonquin Beach and Birth of Lake Huron," Id. vol xli, p. 12, 1891. "High Level Beaches in the region of the Great Lakes and their Deformation." Id, p. 201. "Deformation of the Lundy Beach and the Birth of Lake Erie," Id, vol xlvii, p 207, 1894. All by J. W. Spencer. "The History of Niagara River," by G. K. Gilbert, Six. Rep. Com. State Res. Niag., 1891.

by way of the Ottawa valley, and Lundy gulf (occupying the Erie basin and) extending into the Ontario valley. These two bodies of water appear to have had a common level as if connected in some way across the Ontario basin, but their northeastern extensions are not known and involve unsettled questions that do not affect the history of Niagara. Again, the waters were lowered so that the Niagara River emptied the overflow of the Erie basin, without a fall into the Ontario valley. This condition did not last long, for the waters sank to a level (Iroquois beach) of 300 feet below the Lundy (and also Algonquin) plain, and the falls commenced their descent with the waters of the Erie basin alone. The subsidence was accompanied by slight pauses, but waters remained for a long time at the level of the Iroquois beach, which is now about 135 feet above Lake Ontario at the end of the gorge. Again the waters subsided to the level about 80 feet beneath the present level of the head of Lake Ontario, and thereby lengthened the river to 12 miles beyond the end of the chasm. At this time the descent of the river after passing the rapids at Johnson's ridge was 420 feet. By the continued northeastern terrestrial elevation the waters of the Huron basin were turned from the Ottawa drainage into the Erie basin, whose northeastern rim was elevated so as to flood the lake. Later, the waters at the head of Lake Ontario were raised 80 feet to the present level. This differential movement was at zero at the head of Lake Erie; 2.5 feet per mile in the Niagara district; 4 feet northeast of Lake Huron, and 5 feet per mile at the outlet of Lake Ontario.

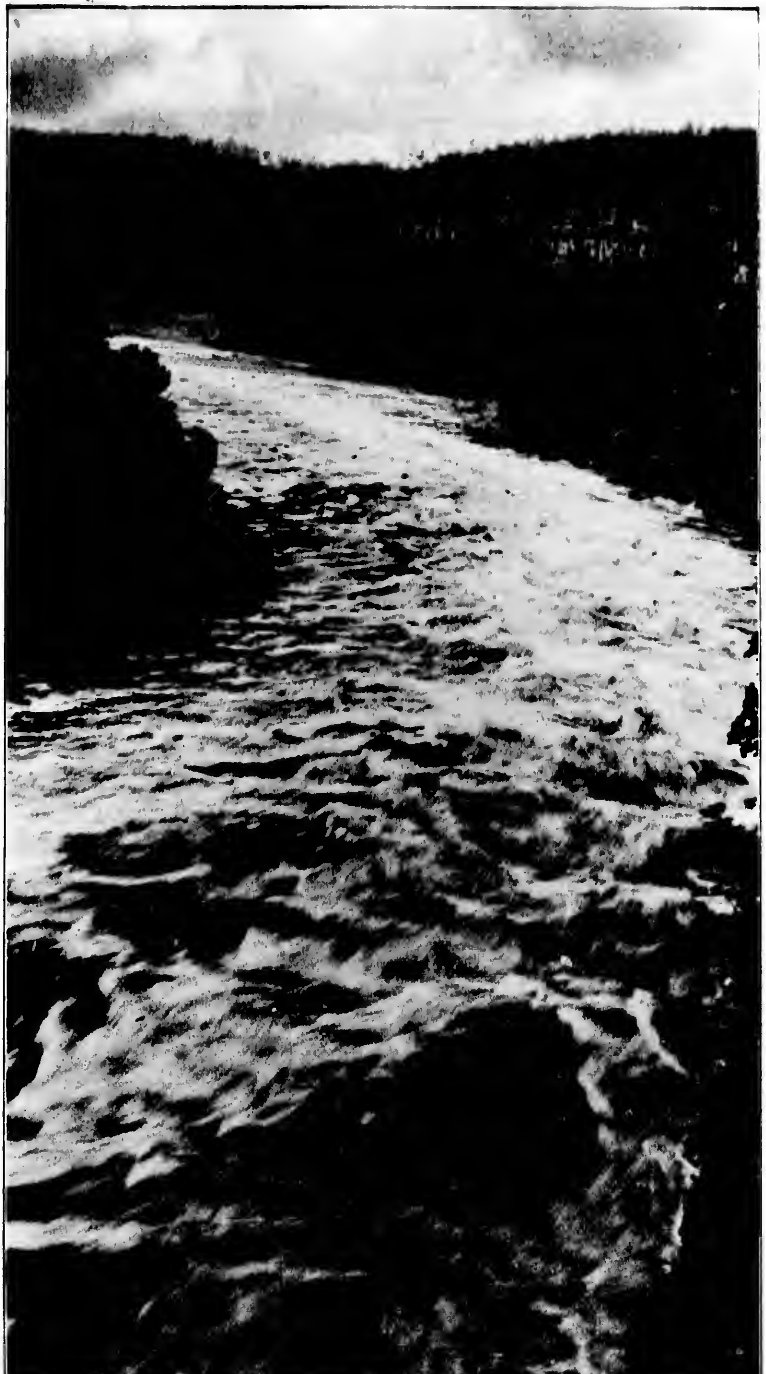
At the nativity of the Niagara River there was no fall. A little later in the Iroquois episode the falls were very much like the modern American cataract, both in height and volume, but afterwards it increased in magnitude and went through the changes noted later.

Laws of Erosion.

When erosion is considered from a theoretical point of view and the whole energy of the water is supposed to be expressed in the erosion, it varies as the mass of the water into the square of the velocity (wv^2). Hence for a given river increase of the amount of its water or increase of the velocity along its course should be expressed by greater erosion. But erosion is not the only expression of the theoretical value of the energy of the river. Again, it is well known that the more rapid the descent of the stream the more the erosive effects are expended on the floor of the channel, in deepening and forming the U-shaped valleys or gorges. On the other hand, the reduction in the slope causes

Erie
es of
way
not
ry of
River
tario
level
quin)
f the
auses,
each,
f the
neath
hened
ne the
as 420
waters
o the
e lake.
eet to
e head
north-
tario.
little
modern
rds it
er.

nd the
erosion,
(wv^2).
ncrease
erosion.
of the
pid the
ded on
ped val-
e causes



THE WHIRLPOOL RAPIDS.

the channel to become broader — a principle which has an important bearing in this study. While the observations are imperfect, owing to the variable conditions of erosion, still the attempt to ascertain the duration of the different episodes is the only natural sequence to the measurements of the modern recession of the falls, and it gives approximate results, for without considering the changing episodes the rate of recession is of no geological interest. But this study may lead to further detailed investigations.

Episodes of the River and the Duration of each — Age of the Falls.

First Episode.— From the history of the lakes and the river we learn that the early falls cascaded from the brow of the escarpment to the level of the Iroquois beach 200 feet below, (with the Erie drainage only $\frac{3}{11}$ of the total discharge of the upper lakes). There is no indication that the Erie rainfall was greater at that time than now. The length of the chasm excavated during the first episode is found in the

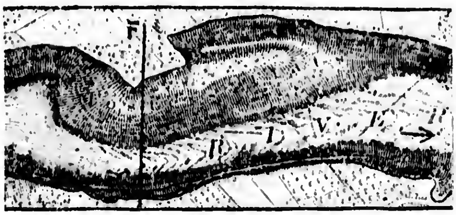


FIG. 21.— Map of the gorge at Foster's flats; F, location of the cross section fig. 20.

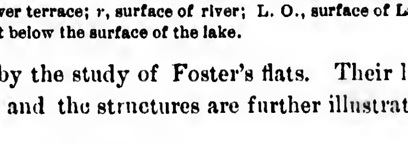


FIG. 22 — Section of the gorge at Foster's flats (FT, fig. 17). Platform (F) of the old river floor projecting into the cañon. Its section is shown in broken shading but with ravines descending from both sides of it. T, rock terrace surmounted by huge blocks of Niagara limestones; *b*, original river terrace; *r*, surface of river; L. O., surface of Lake Ontario. Bottom of river about 80 feet below the surface of the lake.

data furnished by the study of Foster's flats. Their location is shown at F, figure 17, and the structures are further illustrated in figures 21 and 22.

The terrace (T) represents the former level of the river (about 190 feet above Lake Ontario). It is the only feature of the kind in the cañon. It is about 50–60 feet above the Iroquois level to which the river descended. Thus the slope of the earlier and smaller streams was about half as great again as the modern river over the rapids at this locality. The youthful river was broad and shallow, like and of about the same magnitude as the modern American channel and falls, acting evenly over the whole breadth and receding at about the same rate. The remnant of the platform shows how far the fall had receded before the physical change which threw the current to the eastern side of the channel. This change could be effected by increasing the height of the falls which would favor the deepening of the chasm at the expense of the width, especially as the lower rocks are mostly shale. This change of breadth from a wide and shallow to a narrow and deep channel is shown along the lower part of the cañon and is illustrated by the contracted channel at the bottom of the cañon in a section just above the end of the gorge (fig. 23).

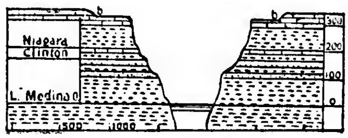


FIG. 23.—Section half a mile from the end of the cañon (*gg* fig. 17); *bb*, terraces of river at the original level; L, O., level of Lake Ontario; bottom of river about 80 feet below the surface of Lake Ontario.

As the changing conditions were gradual, I have placed the close of the first episode at the time when the falls had reached the foot of the terrace (B fig. 24), which is 11,000 feet from the end of the chasm. Varying the rate of recession for the different conditions of height and volume, acting under a general uniformity, the time needed to excavate the immature cañon as far as Foster's terrace is found to be 17,200 years.

Second Episode.—The subsiding of the waters at the end of the first episode, which concentrated the stream upon the side of the channel amounted to 220 feet, thus increasing the descent of the water to 420 feet, with the lake receding 12 miles, and adding this length of shaly rocks to be removed. The increased descent gave rise to new cascades over the hard Clinton limestones (*c* and *d*. fig. 24) and Medina sandstones (*h*, fig. 24) at the end of the cañon, after the shales between it and the lake had been somewhat reduced in height. A modern repitition of three such cascades over the same series of rocks may be seen along the Genesee River near Rochester. Under this condition the upper cascade receded by itself past Foster's terrace, a distance of 3,000 feet. Thus closed the first stage of the second episode. After passing Foster's flats, the chasm shows the effects of a greatly increased force, for the gorge is again widened with the terrace below washed away. As no change in the total height occurred about this time, the magnitude of the erosion indicates an increased discharge, which was produced by the turning of the waters of the Huron basin and adding them to the Niagara drainage. The effects of the greatly increased volume of the water were to widen the chasm and cut away part of Foster's platform, but leaving enough to tell the history. The upper falls were not joined by the more rapidly retreating lower cascades until after the whirlpool was passed, for the evidence of the upper water-level is left in the deposits of river gravels at an elevation of 190 feet on the northern side of the whirlpool ravine, which would not have been the case if the river were at a lower level after cascading over one united falls. Just above the whirlpool, the chasm becomes narrow, and here I close the second stage of this episode of three cascades. The length of this section of the gorge from (C to D fig. 24) is 7,000 feet. By considering the proportional amount of work accomplished during the elongation of the chasm, the deepening of the gorge left at the close of the first episode, and its extension 12 miles lakeward (the mean depth of shales removed from eight miles was 180 feet, and from

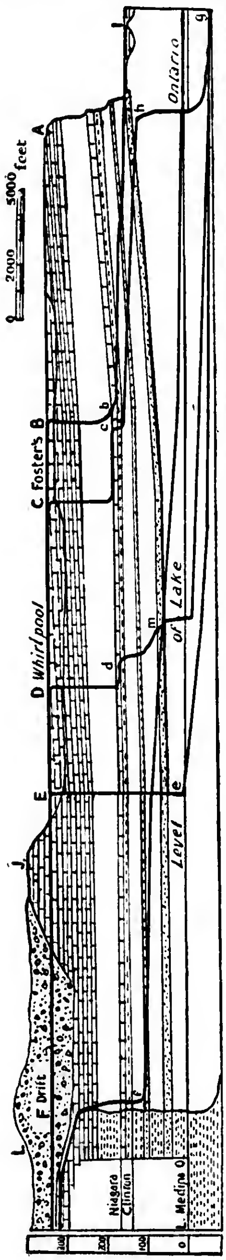


FIG. 24 — Longitudinal section showing the retreat of the falls and the geological structure. A, brow of escarpment and original site of falls; I, Iroquois beach and level of that water; B b I, chasm at the end of the first episode; C c h g, falls retreating in three cascades, but from h to g the slope was extended over a distance of 12 miles beyond the escarpment; D d m g, position of cataracts at the end of the second episode; E e g, development of gorge at the end of the third episode; F, present site of falls, and F m g, the modern cañon; g, level of the lowest stage of water in the river history; L, Lundy beach capping the drift; J, Johnson's ridge. Broken shading about whirlpool shows occurrence of drift on west bank only with rock on the eastern; block shading represents limestone; dotted, sandstone; broken lines and unshaded portion, shales. Bottom of river 80 feet below present surface of Lake Ontario, as shown in figure.

four miles, 60 feet), and applying the laws of erosion, I have found that the first stage required 6,000 years and the second 4,000 years; or the duration of the second episode was 10,000 years.*

Third Episode.—The narrowest portion of the gorge extends from the whirlpool for a distance of 4,000 feet as is shown in figure 25 and on the map in fig. 17. The various sections (figs. 22, 23, 25, 26, 27) should be compared.

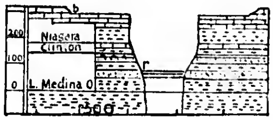


FIG. 25.—Section across the narrows just north of the railway bridges (*dd*, fig. 17) *b*, original bank of the river; *r*, surface of the river; L. O., level of lake; floor of cañon 80 feet below lake level.

This is at the site of the whirlpool rapids. My explanation of this narrow chasm, without any increased thickness of the limestone capping over the shaly bed is that the whole force of the falls descending 420 feet was concentrated in one cataract with a rapid of an additional height of 25 feet descending in front of Johnson's ridge. Thus the force engaged i undermining the limestones was exhausted in the recession of the falls by deepening the gorge in place of broadening it, a process more strongly brought out by contrast with the sections of the cañon, immediately above (fig. 26) and below (fig. 22) which are half as wide again. Such result is in accordance with the common, observations that increased declivity causes the channels to be deepened, and decreased slope accelerates the widening of the channel as is shown in the section near the end of the gorge (fig. 23). The computation of the time of the retreat of the falls across this section is a simple problem as the fall of water amounted to 420 feet in place of 320 of the present day, and the volume was the same. Under these conditions the duration of this episode was 800 years.

Fourth Episode.—This is characterized by the rising of the waters in the Ontario basin so as to bring the lake to the present level, 320 feet below the repaids above the falls. The commencement of the work of this epoch was taken where the cañon suddenly became broad

* One method considers only the recession of the upper one of the retreating falls (descending 150 feet) during the two stages of this episode. Owing to the prevalence of limestones in the upper section, the computation would appear to be an under estimate. Another process is based upon the excavation of the new portions of the chasm to the full depth of 420 feet, and adding to the components the time required to deepen the gorge of the first episode and extend the cañon to the lake—the amount of work being considered in terms compared with the full depth of excavation in the chasm.

at the head of the whirlpool rapids, a phenomena explained by the force of the river being vertically diminished and latterly increased—the converse to the conditions of those of the third episode. At first the rocks in Johnson's ridge offered great resistance

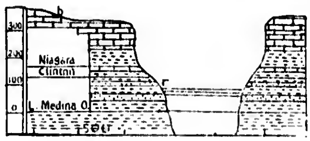


FIG. 26.—Section across the gorge at Johnson's ridge (*ee*, fig. 17); L. O. level of Lake Ontario; *r*, surface of river; *b*, original bank of river; bottom of river 80 feet below surface of the lake

on account of the increased thickness of limestones nevertheless the lateral erosion gained the ascendancy over the vertical. The section through Johnson's ridge is 5,500 feet long, and with the laws of erosion the time necessary for the falls to retreat through it would be about 1,500 years—thus would end the first stage of the last episode. The last stage is the modern, or that since the cataract reached the Tonawanda basin south of Johnson's ridge, whose rocky floor, generally

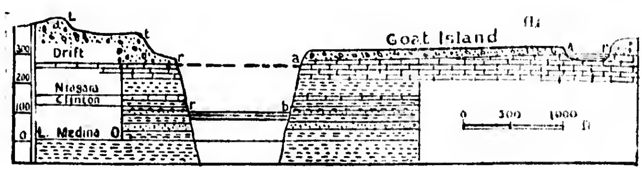


FIG. 27.—Section across gorge 1,000 feet north of the Horseshoe falls (*cc*, fig. 17) L, Lundy beach to the west; *t*, terrace with sandy face; *ra*, surface of river at crest of falls; *rs*, ditto below falls; A*r*, ditto of American falls; L. O., level of Lake Ontario. Bottom 80 feet below lake surface.

speaking, is about 80–90 feet lower than that on the ridge (see fig. 24); yet the cañon just north of the ridge is only 250 feet wider than through that barrier. The drift filling the basin offered but little resistance to the recession of the falls and accordingly the rate of retreat has been comparatively rapid along this section of the river, which is 6,000 feet long. Consequently its age is about 1,500 years. Thus the duration of the fourth epoch has been 3,000 years.

Age of Falls.—Allowing 1,000 years for the duration of the river before the advent of the falls,—for that its commencement was not characterized by a cascade is shown by the terraces on the edge of the escarpment and at the deserted mouth of the infant river,—and adding the duration of the four episodes, which have been calculated at 31,000 years, the age of Niagara River would be 32,000 years; and the date that the Huron drainage turned from the Ottawa valley to the Niagara was 7,800 years ago. In order to reduce the errors in reading the means of erosive effects, the component stages have been taken to as great a degree of accuracy as practicable. In the changes of level, the error would suggest itself to me as on the side of shortening the time; and there is no evidence that a much greater rate of recession than now has occurred other than that already made use of; also I have used the maximum discharge of Lake Erie. Consequently I am led to conclude that the present study has set forth the history and has compensated for possible over-estimates in degrees of hardness, and fairly represented the age of the falls, which is very near that of Lyell's conjecture. There is considerable cumulative evidence adduced from the history of the lakes to strengthen confidence in the methods pursued in this investigation. Let us see.

Confirmation of the Age of the Falls by the Phenomena of Terrestrial Movements.

In the deformatory elevation of the Niagara district, the Johnson ridge was raised 24 feet above the Chicago divide, between the Michigan and Mississippi waters, and did cause a rise of the waters in the lakes to the point of overflowing, but the ridge was incised by the retreating falls in time to prevent the change of the lake drainage. By the simplest case of division we have seen that Johnson's ridge was completely cut through only about 1,500 years ago. Allowing two or three feet of water to have been on the Chicago divide (covered with silt) and as much more for error, we find that the differential elevation of the Niagara district becomes a local absolute uplift of about 1.25 feet a century. The equivalent rate of elevation northeast of Lake Huron is 2 feet and at the outlet of Lake Ontario 2.5 feet a century. This average is that of episodes of activity and repose during 1,500 years. Applying the time ratio to the amounts of deformation we shall obtain the results given below in a form for comparison.

The rise of the Algonquin beach of the Huron basin, between the present outlet of the lake and the former outlet at Lake Nipissing, amounts to 660 feet,* about 560 † of which have been raised up since

* Elevation south of and adjacent to Lake Nipissing determined by Mr. F. B. Taylor.

† The waters of both Lundy and Algonquin lakes were lowered about 100 feet before the beginning of the Niagara river; this being apparent and local, produced by a pre-Iroquois uplift of about half a foot per mile, thus raising the northeastern extensions of the beaches.

the birth of Niagara Falls. Of this latter amount about 130 feet have been lifted since the waters were turned into the Niagara drainage. Again we get some proportions.

The ratios of the deformation of the Lundy and Iroquois beaches are about the same, and we have the Lundy beach differentially raised 160 feet in the Niagara district, and the Iroquois beach deformed to 370 feet near the outlet of Lake Ontario (compared with the level at the head of the lake) since the close of the Iroquois episode. And here there are data for comparison. These figures have been mostly taken from the papers already cited. Compiling the results derived from all these data, it appears that:

A. The time which has elapsed since the Iroquois episode, or the end of the first episode of the falls, is:

		Years.
	(1) From the computation given	13,800
	(2) From the date of deformation recorded in the Iroquois beach*	14,800
	(3) From the deformation recorded in the Lundy beach†,	12,800
	Mean result	13,800
B.	(1) Computed time since the Huron waters turned into the Niagara	7,800
	(2) From the proportional deformation of the Algonquin (N. E.) outlet compared with the computed age of the river‡	7,400
	(3) From the proportional deformation of the Algonquin uplift§	6,500
	Mean result	7,233
C.	(1) Computed age of Niagara river	32,000
	(2) From the rate of deformation of Algonquin beach since the commencement of Niagara river‖	28,000
	Mean result	30,000

These computations were originally made not to seek for favorable evidence but to discover discrepancies, for I did not expect that the data had been correlated with sufficient accuracy; but the several

* A differential rise of 370 feet at the outlet of Lake Ontario divided by 2.5 feet a century.

† A rise of 160 feet in the Niagara district divided by 1.25 feet a century.

‡ One hundred and thirty — five-hundred-sixtieths of 32,000 years.

§ Thirteen fifty-sixths of 28,000 (see next note)

‖ Rise of 660 feet in the Algonquin beach less 100 feet before the birth of the Niagara at the rate of 2 feet a century, results agreeing so closely in spite of the unavoidable inaccuracies, seem to me to confirm the general correctness of the determinations of the phenomena and the methods of compution.

Relationship of the Falls to Geological Time.

All attempts to reduce geological time to terms of years are most difficult, but the Niagara river seemed to be an easy chronometer to read, and yet we see that some utterances even this year are vastly farther from the mark than those made fifty years ago — the clock had not kept mean time throughout its existence. After this attempt at regulating the chronometer, investigators will doubtless carry the determinations to greater accuracy, but for the present I can offer this geological compensation. The Niagara seems a stepping stone back to the ice age. What is the connection between the river and the Pleistocene phenomena?

The Lake epoch is an after phase of the Glacial period, and Niagara came into existence long subsequent to the commencement of the lakes. If we take the differential elevation of the deserted beaches, and treat them as absolute uplifts in the Niagara district, with the mean rate of rise in the earlier portion of the lake epoch as in the later, then the appearance of Warren water in the Erie basin was about 60 per cent* longer ago than the age of Niagara river; or about 50,000 years ago. The earlier rate of deformation was not greater than that during the Niagara episode as shown by the deformation of the beaches, but it may have been slower, so that from 50,000 to 60,000 years ago Warren water covered more or less of the Erie basin. Before the birth of Niagara river, by several thousand years, there was open water extending from the Erie basin far into the Ontario and all the upper lakes were open water with a strait at Nipissing, but the northeastern limits are not known, and although they do not affect the age of Niagara, yet they leave an open question as to the end of the ice age, in case of those who do not regard the advent of the lakes as its termination. From these considerations it would appear that the close of the ice age may safely be placed at 50,000 years ago.

End of the Falls.

As has already been noted, the falls was in danger of being ended by the turning of the waters into the Mississippi, when the cut

*The beaches show an elevation in the Niagara district (accompanied by deformation) amounting to 940 feet above tide, of which 573 feet have been raised since the birth of the Niagara river.

through the Johnson ridge was effected. With the present rate of calculated terrestrial uplift in the Niagara district, and the rate of recession of the falls continued, or even doubled, before the cataract shall have reached the Devonian escarpment at Buffalo, that limestone barrier shall have been raised so high as to turn the waters of the upper lakes into the Mississippi drainage by way of Chicago. An elevation of 60 feet at the outlet of Lake Erie would bring the rocky floor of the channel as high as the Chicago divide, and an elevation of 70 feet would completely divert the drainage. This would require 5,000 or 6,000 years at the estimated rate of terrestrial elevation. It would be a repetition of the phenomena of the turning of the drainage of the upper lakes from the Ottawa valley into the Erie basin.

Conclusions.

The computation of the age of the Niagara river,— based upon the measured rate of recession during 48 years; upon the changing descent of the river from 200 to 420 feet and back to 320 feet; and upon the variable discharge of water from that of the Erie basin only, during three-fourths of the life of the river, to afterwards that of all the upper lakes,— leads to the conclusion that the Niagara Falls are 31,000 years old and the river of 32,000 years duration; also that the Huron drainage turned from the Ottawa river into Lake Erie less than 8,000 years ago. Lastly, if the rate of terrestrial deformation continues as it appears to have done, then in about 5,000 years the life of Niagara Falls will cease, by the turning of the waters into the Mississippi. These computations are confirmed by the rate and amount of differential elevation recorded in the deserted beaches. It is further roughly estimated that the lake epoch commenced 50,000 or 60,000 years ago, and there was open water long before the birth of Niagara in even the Ontario basin, and that under no circumstances could there have been any hydrostatic obstruction to the Ontario basin since before the birth of Niagara Falls.

Index to Duration of Niagara Falls and the History of the Great Lakes.