31. ORIGIN of the BASINS of the GREAT LAKES of AMERICA. By J. W
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CONTENTS.

1. Introduction.
2. Features of the Ontario Basin.
3. " " Erie Basin.
4. " " Huron Basin.
5. Features of Lake Michigan.
6. Buried Valleys revealed by Borings.
7. Glaciation of the Region.
8. Former High Continental Elevation of North America.
9. Deformation of Raised Shores and Beaches.
10. Conclusions from the Observations.

1. *Introduction.*

EVEN as recent as a decade ago very little was known as to the origin of the Great Lakes of North America. Whilst we find such generalized statements as "most lakes are due to terrestrial crust-movements," yet such crust-movements 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 the 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 basis 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. 524).

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

Map of the Drainage of the Ancient Laurentian Valley, now obstructed and forming the Great Lakes.

2. *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 thirty or forty miles. Into this plain, at a point about twenty 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 §.

3. *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.

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

* "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," &c.

‡ See British Admiralty Chart of Lake Ontario.

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

|| See U. S. Lake-Survey Chart of Lake Erie.

¶ Geology of Ohio.

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

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 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.

4. *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 ninety miles, there is a submerged escarpment rising to a height of from 300 to 450 feet, facing north-eastward. 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 south-eastward 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 1700 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‡.

5. *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 vertical submerged escarpments, one of which, upon the eastern side, has a height of 500 feet. Whilst 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 northerly trend; it is 612 feet deep. This and the lesser 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

* See Reports Geol. Canada, 1863-66.

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

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

basin, although not shown by the soundings ; for the Lake-Michigan valley is carved out of undisturbed and almost horizontal Palæozoic 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 form 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.

6. *Buried Valleys revealed by Borings.*

The deep wells revealed the existence of the buried channel down which the waters of the Erie Valley originally 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 or 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 twenty miles, is situated. But upon the northern side of Lake Simcoe there is another series of Drift ridges trending towards the north-east. 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 thirty 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 one continuous 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 *Eriean* 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 1000 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.

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

7. *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.

8. *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 depths 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 1200 and 1800 feet above its present altitude; and the whole continent in more recent times, but for a briefer period, at upwards of 3000 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.

9. *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 1700 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

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

† Appendix 13, Report of Chief of Engineers, U. S. A., 1875.

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 north-east; 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 investigations 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 mostly unpublished, but I will 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 towards the north, until at four miles east of Watertown it is 730 feet above the sea. Still further north-eastward, near Fine, on the borders of the Adirondack Wilderness, it reaches an elevation of 972 feet above the sea, beyond which I have made no instrumental measurements. 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 north-eastern end of the lake the uplift is found to have increased to five feet in a mile, and in the region of farthest observation to somewhat more, in a north-eastward direction. Thus in the deformed water-level I have already measured a barrier of about 609 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. Whilst 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-basin 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 occurred 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.

South-east of Georgian Bay the average measured warping is four

* 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.

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

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 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 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 buried 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.

10. *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 *Laurentian*) River and its tributaries, during a long period of continental elevation, until the streams had reached their base-lines 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, is measurable.

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 lake-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 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 the 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 1700 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 the 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 Manitoulin 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 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 some 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 connexion 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 on "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 that 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 south-east 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 Prof. 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 other 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.