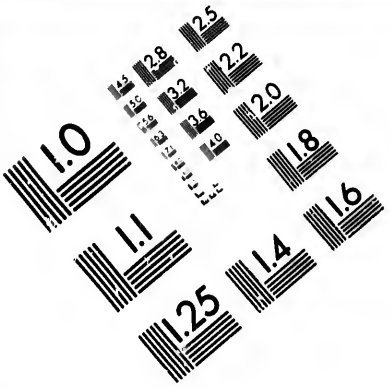

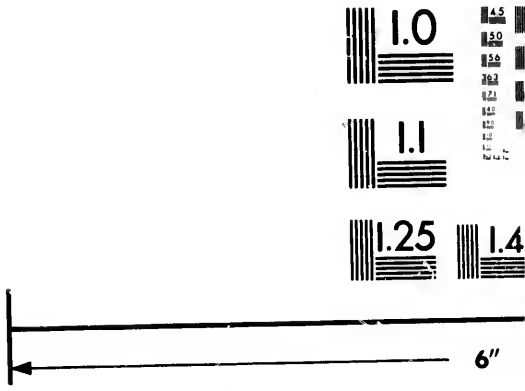

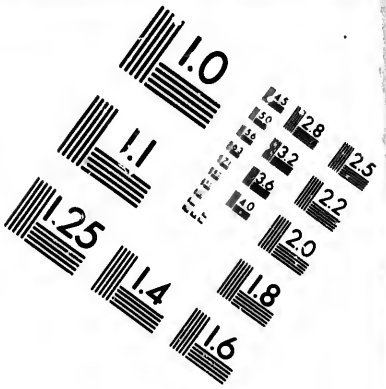

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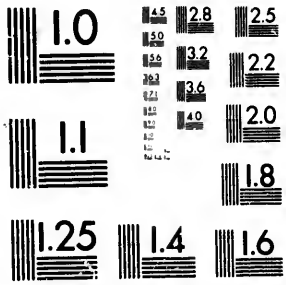

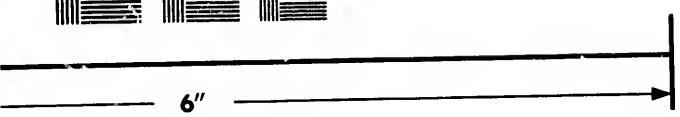

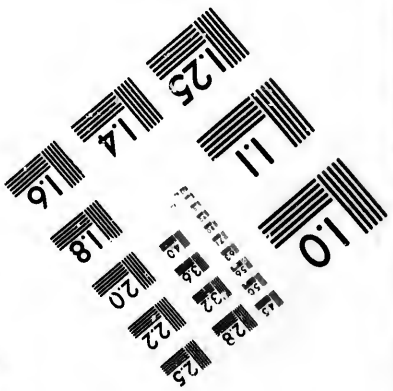

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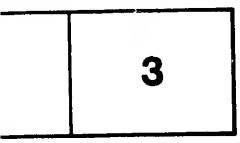
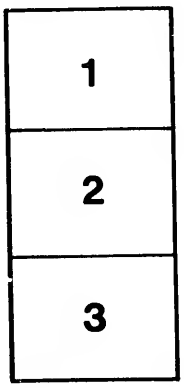
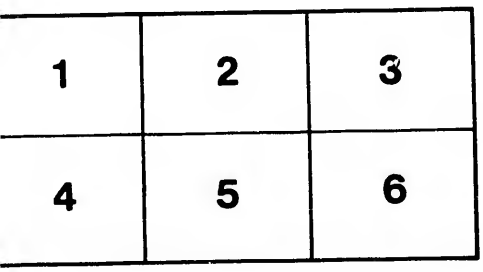






[*Reprinted from the* QUARTERLY JOURNAL OF SCIENCE, *April*, 1875.]

NIAGARA.

GLACIAL AND POST-GLACIAL PHENOMENA.

By THOMAS BELT, F.G.S.

THE glacial phenomena of the district of Niagara have been so often described, and the cause of, and the time occupied in, the excavation of the river gorge, so often discussed, that I did not expect, when, on Christmas-day, I made my first visit to the great falls, to have anything new to record, but went quite prepared to acquiesce in the conclusion that has been received for more than thirty years, that the whole of the gorge, from Queenstown to the falls, has been excavated since the glacial period. Since this theory was first advanced, many geologists have visited the district, and, so far as I can learn, no one has called in question this verdict; it has been accepted as an established fact, and various calculations of the time necessary to excavate the gorge have been made, throwing back the occurrence of the glacial period from 30,000 to 300,000 years ago.

It was with great surprise, therefore, that I found, that at first sight this conclusion was not evident, and that, on further examination, it was not tenable. I feel that in having to oppose the theory that the gorge of Niagara has been excavated since the glacial period, I shall be adding another scientific heresy to the many that are recorded against me; but the heresies of to-day are the truths of to-morrow, and I shall at least give my reasons for believing that my explanation of the problem ought to be classed in the latter, and not in the former category.

The question of the excavation of the gorge cannot be clearly understood without some knowledge of the glacial deposits, and I shall in the first place describe the glacial, and afterwards the post-glacial phenomena. So many authors have written on the subject, that I shall only mention those from whose works I have obtained information of

importance. Foremost in the list stand the names of Sir Charles Lyell and Professor James Hall, who visited the district together in 1841, and who afterwards published the conclusions, that they appear to have arrived at together. Sir Charles Lyell, in the "Proceedings of the Geological Society of London" for 1842 and 1843, and more fully in his "Travels in North America," where there is an excellent coloured bird's-eye view of the falls of Niagara and adjacent country, and also a geological map of the district, in which the reader who has not visited Niagara may correct the false impression he is likely to obtain, from the necessary foreshortening in the bird's-eye view, of the small distance between the falls and the whirlpool, which are, in reality, four miles apart. Professor James Hall published nearly identical opinions in the "Boston Journal of Natural History" for 1843-44, and more fully in the "Geology of New York," Part IV., in 1843. The latter work contains not only a bird's-eye view of the district, but an excellent map of the falls, constructed from a trigonometrical survey made in 1841, by Mr. Bakewell: afterwards in 1842, corrected by Professor Hall and two engineers. The whole of Professor Hall's observations on the glacial phenomena of the State of New York should be read by those interested in the study of the glacial period. They abound in original remarks, and in clear descriptions of the succession of the superficial deposits, and many of the conclusions at which this eminent state geologist arrived more than thirty years ago are only now receiving in England the attention they deserve. Professor Hall also describes other rivers running into Lake Ontario from the south, which, like Niagara, have had their pre-glacial channels filled up, and have since taken a more westerly course to the lake.

In 1859, Professor Ramsay published, in the "Quarterly Journal of the Geological Society," his observations on the glacial phenomena of Canada, made during a trip to that country in the preceding year. In this memoir he pointed out, I believe for the first time, that the river must have commenced to cut back the gorge at Queenstown, before the close of the glacial period.

To Dr. Newberry, the accomplished chief of the Geological Survey of Ohio, I am greatly indebted, not only for much personal kindness and assistance, but for an early copy of his "Surface Geology," to be published in the forthcoming volume on the "Geology of Ohio," from which I have obtained a vast amount of information respecting the glacial deposits of the district of the great lakes. A very large amount of

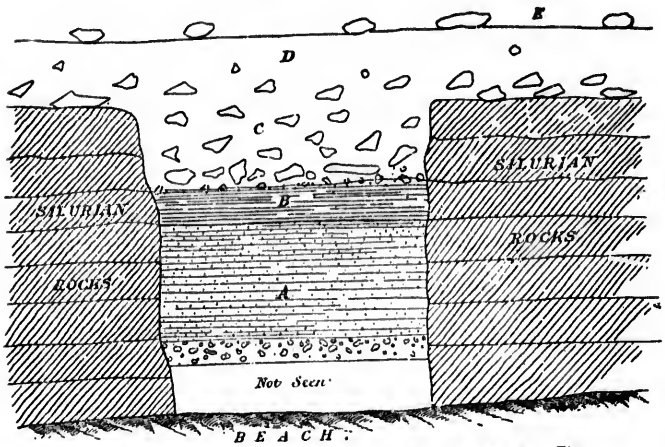
information is contained in the well-known works of Prof. Dana, not only in his admirable "Manual of Geology," but in various memoirs, amongst which I may especially mention his "Geology of the Newhaven Region," published in the "Transactions of the Connecticut Academy" in 1870. I may mention, that with the exception of Dr. Dawson, of Montreal, the whole of the most eminent of the geologists of eastern North America are now agreed that the principal glaciation of America was effected by land-ice, though there is abundant proofs, as I shall have occasion to show in this paper, that at a later stage, boulders were scattered over the country by floating icebergs. That later stage of floating ice was due, however, I contend, both in America and Europe, not to a submergence of the land below the ocean, but to the production of immense lakes of fresh water, by the damming up of the drainage of the continents by ice that flowed principally down the ocean depressions. In this conclusion, I have as yet no supporters amongst the geologists, either of America or Europe, if, indeed, I may not except Professor Hall, who informed me, in conversation, and authorised me to publish his opinion that the sea has never encroached on south-eastern New England since the deposition of the "*till*," and that the terraces of the Hudson and Connecticut were produced by the blockage of their waters by ice that flowed down the ocean bed, and of the presence of which we have proof in the immense moraines that compose the whole of Cape Cod.

Glacial Phenomena.

The rocks through which the gorge of Niagara is cut are limestones, sandstones, and shales. These rocks are all rounded and smoothed, and the limestones are frequently scratched and grooved. Besides the coarser ice marking, the rounded and smoothed surfaces of rock, when examined closely, exhibit innumerable fine scratches, which have been ascribed by Hall to small particles of sand imbedded in the ice that moulded the rocks, and he has shown the improbability that this moulding and fine scratching, which is universal over the whole northern part of the State of New York, wherever the rocks are of sufficient hardness to receive and retain striæ, could have been effected by icebergs. Lying on these glaciated rocks are superficial deposits of drift, containing beds of unstratified clay, with boulders, sands, and loam. These are spread over the whole district like a mantle, so that natural exposures of the bed rock are rare, excepting in the gorges cut by the river.

The cliffs bordering the gorge, from the falls to Queenstown, are everywhere capped by these deposits; one of the most interesting and instructive sections of which is exposed at the whirlpool, four miles below the falls, at the end of the filled-up pre-glacial gorge that runs down to St. David's. The following section exhibits the succession of deposits that fill the old gorge:—

Fig. 1.



Section through the old gorge at the whirlpool, along the line A B in Plan, Fig. 3.

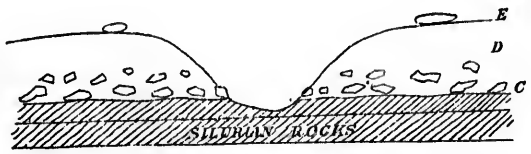
The lowest bed seen by me at the section is that marked A, which consists of clean yellow river sand, with occasional seams and rolled lumps of clay. Below these sands there were exposed, when Lyell described the beds,* strata of pebbles, cemented together by carbonate of lime, overlying laminated clays. I saw one large mass of the pebbly conglomerates lying on the beach, and have shown its position in the section underlying A, but I have not inserted the laminated beds mentioned by Lyell, as some that I saw low down in the gorge had evidently slipped down from A and B, the whole face of the unconsolidated materials filling the gorge, showing many slips produced by rain and frost.

The bed of laminated sands (A in section) graduates upwards into fine laminated silt (B in section), the powder of

* Travels in North America, vol. ii. p. 95.

which is almost impalpable when rubbed between the fingers. Higher up this silt is unlaminated, and contains a few small angular stones. It gradually changes upwards into C, which is a true "*till*," or "*grund morane*," containing large angular and subangular stones, many of great size, scratched and grooved. All the blocks imbedded in the clay are of the local limestones. A few rounded boulders, of northern origin, lie on the surface slope, but they have evidently rolled down from above. The higher part of C contains fewer and fewer stones, until it merges into D, which is composed of unstratified clay or "*till*," without stones. Of this there is from twenty to thirty feet in thickness, the upper part being more sandy than the lower, and sometimes obscurely stratified. On the surface are a few rounded boulders of granite or gneiss, all far travelled from the north, and it is noticeable, that whilst the angular blocks in the "till" are all of local origin, those lying on the surface are almost, if not quite, always of distant derivation, and are invariably rounded or subangular. Those seen on the surface, near the whirlpool, were all of granite or gneiss. The continuation of the till (C and D in section) is shown in some small valleys that run into the gorge at the whirlpool.

Fig 2.



Section of small valley running down to the gorge at the whirlpool. C, till with stones; D, till without stones; E, rounded boulders of northern origin on surface.

Here the till (C and D in section) lies upon the rounded and smoothed surface of the limestone. Some of the blocks of limestone at this point are of great size; one I measured was 9 feet by 6 feet, its thickness not seen, as it was half buried in the ground. On the opposite side of the river, and about a mile distant from it, I saw exactly the same succession of beds exposed in the cutting of the railway, half way between the railway bridge and Lewiston. The northern end of the old filled-up gorge at St. David's shows a similar succession of beds, with the addition, that on mounting the plateau from the lower one of the lake of Ontario, I found, exposed in

railway cuttings, that the till without stones was capped by stratified beds of clay and sand, with a few lines of small pebbles.

The above sections may be taken as typical ones of the superficial beds that mantle the whole of the northern part of the States of New York and Ohio, and much of Canada, and I proceed to show that they are exactly what would be produced by the accumulation of a great mass of ice in the north, that gradually progressed southward, and that afterwards melted back again as gradually as it had advanced.

Let us carry ourselves, in imagination, back to the preglacial times, when the old river ran through the filled-up gorge from the whirlpool to St. David's, and try to follow the successive steps by which it was filled up, and ultimately completely obliterated, or rather concealed. Let us bear in mind that the Niagara runs northward, in the direction from whence the ice came. Hall, Dana, Newberry, Lyell, and Ramsay, have all pointed out both from the scratchings of the rocks and from the transported blocks in the till, that the movement of the ice was from the north. It has also been clearly shown that the ice flowed up the St. Lawrence valley, from the north-east. It advanced up the slope of that great valley principally by the overflow of the higher parts of the ice over the lower. That there was some movement of the lower part of the ice from the pressure from the north is, however, sufficiently proved by the different formations that crop out from east to west, having furnished stones to the till that covers the rocks immediately to the south of them. Thus, according to Hall, huge blocks of Medina sandstone are moved southward unto the top of the Niagara limestone. In like manner, numerous masses of the Niagara limestone are drifted forward unto the Onondago salt group, and still further south, on the Chemung limestone, lie great numbers of immense blocks from the Onondago salt group to the north. The size of these fragments bears a proportion to the distance they have been transported from the parent block, the largest being nearest to it. This is characteristic only of the till, and not to the northern boulders that are strewn over the surface, and which have not been transported from their distant northern homes by land ice.

The immediate effect of the ice, as soon as it had dammed up the mouth of the valley of the St. Lawrence, must have been to form a great fresh water lake in front of it, on which it was constantly advancing. When, after filling the basin

of the Lake of Ontario, it had, in its progress south-westward, reached the base of the cliffs of the Queenstown escarpment, or had dammed back the water to that level, the commencement of the filling up of the old Niagara gorge was at hand, and from that time, during the advance of the ice and its subsequent retreat, the deposits of sand, till, and boulders shown in the sections were made. The first step was the partial arrest of the flow of the old river, causing it to deposit at a higher level than its original bed, first pebbles forming the conglomerate at the base of the section in fig. 1, and then the thick bed of river sand, when the current was still more impeded. The bed of fine silt (B in fig. 1) marks the time when the flow of water to the north-east was completely stopped. Dr. Newberry, several years ago, first drew attention to the fact, that at some time during the glacial period, all the great lakes of North America drained towards the Ohio and the Mississippi, and since then, several deep channels by which they did so have been described.

I did not see this fine bed of silt in any of the other sections I examined, and I think its preservation in the one at the whirlpool must have been entirely due to the protection the nearly perpendicular walls of the gorge afforded against the great pressure of the ice that passed over it. Its upper portion contains small angular stones, and it gradually merges into the unstratified till, containing large angular blocks.

It is probable that, during the advance of the ice, no till or *grund morane* was formed below it, but that the smoothing and scratching of the surfaces of the solid rocks were then effected, and that the till was deposited beneath the ice when it was melting back, and its pressure being gradually lessened. Mr. Bonney has objected to the theory of both the erosion of rock surfaces and the deposition of till having taken place below the ice.* But the two actions belong to different times; the one was accomplished during the advance, the other during the retreat of the ice. The effects are similar to those of a mountain torrent, which, when full, carries all before it, but which, when its waters lessen, deposits stones and mud in its course. During the advance of the ice, there could be little deposition below it, all the stones held at the bottom of the moving mass being probably ground to powder; but, as it melted back, the stones and clay held within it would be deposited at its foot.

* Nature, vol. x., p. 85.

Dana, in an excellent paper on the Glacial Era in New England, has ably argued this question, and has shown the enormous power that moving ice, 6000 feet thick, with a pressure of at least 300,000 pounds to the square foot, would have in abrading the rock surfaces below it, and carrying forward in its lower part the loose material it had broken off or caught up from the rocks below, and how the whole of this would be deposited at the melting of the ice.* It would greatly conduce to clear descriptions of glacial phenomena, if the old term "till" were confined to this deposit. It is the "Erie clay" of Dr. Newberry, the "Lower Boulder clay" of Wood, the "*grund morane*" and the "*moraine profonde*" of others. "Erie clay" is a local name, and includes stratified beds of a different origin. "Boulder clay" is often a misnomer, as frequently this clay contains no boulders. "*Grund morane*" and "*moraine profonde*" indicate a particular mode of origin, which, though probably correct, is still theoretical. "Till" is an old English word, long applied to this deposit, and may be used by every one, whatever theory of origin they may favour. I suggest, therefore, that it should be confined to designate the unstratified clay with angular blocks, generally of local origin, that lies at the bottom of all the glacial beds, and that the term "boulder clay" should be applied to the higher beds, which show the action of water as well as of ice. The term "drift" might be applied to any glacial deposit the nature and origin of which is doubtful, in the same way as the name "trap" is used for many igneous rocks of unascertained composition.

The preservation in the St. Lawrence valley, and in the Great Lake district, of beds of loose laminated sands and clays lying below the till is due, as has been shown by Dr. Newberry, to the fact, that the ice was rising against the slope of the land. It had, in consequence, little erosive power, but advanced principally by the slipping of the higher portions of the ice over the lower. When it topped the southern water-shed of the valley of the St. Lawrence, its action produced a different set of phenomena, for its motion was down the slope of the land, and its erosive power was vastly increased. With this subject I shall not here deal, nor shall I attempt to trace the limits of the ice in its greatest extension, as that would lead me into a dissertation on the whole of the glacial period in North America, far beyond the scope of this paper.

* American Journal of Science and Arts, vol. v., March, 1873.

As the ice melted back, it deposited the unstratified till under its receding foot, leaving a continuous mantle of it behind. Lying on the top of the till are seen scattered rounded boulders (E in section), often of great size, of granite, gneiss, and other crystalline rocks, that must have travelled from the Lawrentian hills in the far north. Amongst these, rocks of local origin are as scarce as in the till below those of distant derivation are rare. These foreign boulders are scattered over the surface, as if dropped by some agent that has left no other record of its movements. The rounded far-travelled blocks lie on soft unconsolidated beds that have not been disturbed. In some places, as on the top of a low hill on the Canadian side of the falls, I found great numbers of these blocks, and in some parts of northern New England and New York, great trains are found in lines along the sides of hills, as if stranded on a beach. They are found on the western prairies, according to Professor Hall, in long trains, "where, for many miles, the difference in elevation is not more than 50 feet; and here we observe long lines of boulders stretching away for miles beyond the reach of vision, as if once formerly a line of coast."* Speaking of the valley of the Hudson, Professor Hall says:—"In the vicinity of Albany and Troy, I have searched in vain for a boulder or pebble of granite, or of any rock older than the Potsdam sandstones in the deposits *below* the clay, while, in a period subsequent to the deposition of the clays and sands, boulders of granite are by no means rare."†

Only one satisfactory explanation has been given of the presence of these far-travelled blocks on the surface of the undisturbed loose beds of sand and clay, namely, that they have been dropped from floating ice, and most writers on the subject have concluded that they are proofs of the submergence of the land below the sea. There is certainly an area of land running from Lake Champlain northwards that has been elevated from below the level of the ocean since the glacial period, but there is no evidence whatever that the sea extended over the plateau of Lake Erie, and the entire absence of marine remains renders the supposition untenable. And if we follow the natural sequence of events that must have ensued during the retreat of the ice, we shall see that there is no occasion to call in the agency of the sea. For just as, during its advance, the ice from the north-east had blocked up the great valley of the St.

* Natural History of New York, part iv., p. 321.
† *Ibid.*, p 320.

Lawrence and changed it into an immense lake, so, during its retreat, it must have done the same. Probably it did so to a greater extent, not only because, in its retirement, it had left moraines and deposits of till, blocking up the deep channels draining into the Ohio and the Mississippi, but because, during the greatest accumulation of ice, the land northwards, and especially the area of the St. Lawrence, had been depressed, and an immense sheet of fresh water, dammed back by the lower part of the valley of the St. Lawrence, being still filled with ice, stretched south-westward and northward. On the northern shores of this great lake glaciers still came down from the Lawrentian hills, and gave birth to icebergs that floated southward, dropping boulders of granite, gneiss, and other crystalline rocks, on the bed of the lake, or stranding on its shores, and there depositing their freight. During this time were also formed many stratified beds of sand and gravel that lie above the till, and to it belong most of the deposits of the "terrace epoch" of Dana which were formed, not after, but during the glacial period.

Before leaving this branch of my subject, I must again advert, as I have done in previous papers, to the great importance of a proper appreciation of the effect of the stoppage of the drainage of the northern parts of the continents during the glacial period. It was not only a period of erosion and transportation of rocks, but of great fresh water deposits; and I fully believe that the fresh-water and inland sea beds that Professor Ramsay proves to have been deposited in old red sandstone and Permian times were due to former glacial periods, that of the Permian epoch being greater than the last one, and resulting in such a lowering of the level of the ocean, that there was great destruction of marine life by the increased salinity of the sea.

There are many proofs that the ice was thickest and highest during the glacial period in the bed of the Atlantic. That which advanced up the valley of the St. Lawrence came from the direction of Greenland, and the whole of the eastern coast of America, down as far south as New York, must have been blocked up by it. This is proved, not only by the many fresh-water beds and terraces due to the damming back of the rivers, but by the direction taken by the continental ice. Thus, over the higher summits of New England, the scratches point to the south-east and not to the east, as they would have done if the ice had been free to move directly towards the ocean. I think that this shows that the bed of the ocean was then occupied by ice,

and it could not fail to be so, for to the land it occupied the position of a great valley, down which the ice from the north would naturally flow. I do not think, however, that the time of the greatest extent of ice in the sea-bed was the same as that of the greatest thickness of ice on the land; for, as the margin of the ice of the ocean-bed moved southward, it would cut off the moisture-bearing currents travelling towards the land, and gather to itself the precipitation from them. Thus, I think it was that the ice on the land shrunk back, at the time of the greatest extent of that which occupied the bed of the Atlantic; and we have, both in America and Europe, a period of land-ice, followed by one of fresh-water deposits and fresh-water borne icebergs.

I endeavoured to show in my paper, published in this journal in October last, that the ice from Greenland also reached the western coast of Europe. It passed across Iceland, and overflowed Caithness. Ireland is so hugely glaciated, that we may conclude the northern ice invaded it also and, extreme as the view may seem, I can find no other satisfactory explanation of the fact, that the whole of the south of England is mantled by fresh-water glacial beds, than on the supposition that, at the height of the glacial period, the English Channel was blocked up to the south-west by ice that extended in an unbroken mass from Greenland. I sought in vain, before my last visit to North America, for a satisfactory solution of the presence of the fresh-water gravels and floated boulders of the south of England, and was driven to suppose that one or more barriers of land must have existed in the western part of the British Channel; but, after seeing how the ice in the bed of the Atlantic blocked up the water-shed of the eastern seaboard of North America, ten degrees of latitude further south, I have no difficulty in imagining that it may also have blocked up the English Channel, and caused the formation of the high and low-level gravels, the beds of the Rhine, and the floated boulders of Devonshire, Somersetshire, and Wales. I venture to predict, that evidence will yet be found of the encroachment of the edge of this ice from the north-west upon the Continent, probably upon the coast near Brest, and I also expect that traces will be discovered of the great flow of water that must have taken place, either round the south-eastern termination of the ice, or around the mountains of Britany, into the valley of the Loire.

Post-Glacial Phenomena.

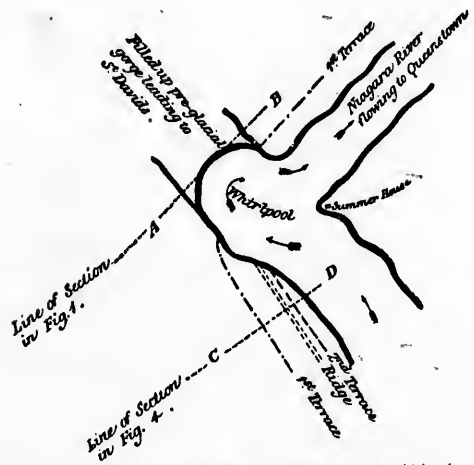
When the ice had retired so far back as to leave the channel to the St. Lawrence valley again open, the waters of Lake Ontario began to re-flow in that direction. From the whirlpool, northward, they did not run in their old channel, but took a more easterly course. This may have been because the lowest outlet through the moraines left by the ice was in that direction, as Dana has suggested; but I think it more likely that it was because the ice retired from the eastward first. If we look at a map of the southern side of Lake Ontario, we shall find that most of the rivers have been diverted in the lower part of their courses to the eastward, indicating that the cause was not one of accidental configuration of the ground, but some such general one as the early retirement of the icy barrier from the eastern part of the lake.

Wherever the river first commenced to flow, there it was likely to cut down through the rocks, for it would soon make for itself a channel through the loose drift lying on the surface; and between the banks of that channel it would be confined, and there only operate on the hard rocks below, just as, in copper engraving, the acid only acts on the plate in the lines cut through the soft wax covering it. To make clear the argument in the question we have to discuss, namely, how much of the gorge in which the river now runs has been excavated out of the solid rocks since the glacial period, I must, in the first place, direct attention to the sketch plan (Fig. 3) of the old and new gorges at the whirlpool, four miles below the falls. The sketch is founded principally on a small plan in Lyell's "Travels in North America," and partly from my own observations and sketches on the spot. I regret that I cannot give an accurate plan, and I could not learn that any complete survey has ever been made.

Standing at the summer-house, on the American side, at the point where the river takes a sudden bend to the eastward, I looked across the whirlpool to the old gorge opposite, and the question at once presented itself to my mind—from this point there are two channels downwards, one excavated before, the other after, the glacial period; to which does the one upwards to the falls belong? This question does not appear to have occurred to the authors of the theory, that the whole of the gorge through which the river now runs, from the falls to Queenstown is post-glacial. But why might not the old pre-glacial river have

excavated the gorge above the whirlpool, as well as the old one below it, and the present river have only cut back the gorge from Queenstown to the whirlpool, and, from that point upwards, have re-occupied and cleared out the old channel? On the face of it, the latter alternative seemed to me more likely, for the river above the whirlpool is running in a direct line for the old gorge, and is, moreover, about the same width as it is, the gorge to Queens own being narrower. I found, with surprise, that this important

Fig. 3.



Plan of the old and new gorges of Niagara river at the whirlpool.

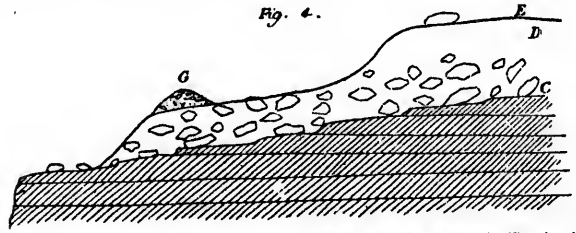
point had been overlooked, and that it had been assumed, without discussion, that the gorge above the whirlpool belonged to the new, and not to the old river.

I determined at once to devote the time I could spend at Niagara to the elucidation of this question, and soon found some data bearing on the subject. Lyell and Hall both noticed the terraces formed in the superficial deposits, when the river commenced to cut back the new gorge from Queenstown. These mark its course when it flowed along the top of the plateau, and it seemed to me unlikely, that if

the gorge above the whirlpool was pre-glacial, that the post-glacial river would have followed exactly the same line when it was bounded only by the superficial deposits that marked the older features of the country. I found that, above the whirlpool, the post-glacial river had run in different channels, having, apparently, often changed its course in the superficial deposits. Thus Lyell has described one of these deserted channels that ran from the muddy river to the whirlpool.* Another, I noticed, ran down from behind the town of Niagara-falls. In some places, the terraces and ridges that bounded the old river come down to, and are cut off by, the present gorge; at other places they retire back for at least 100 yards from it. They prove that, before the present river was confined in its rocky gorge, it often changed its channel, as rivers do now that run through superficial deposits over a nearly level plain.

On the Canadian side, a little above the whirlpool, two of these terraces come down to the gorge, and are cut off by it. Their direction is shown by dotted lines in the sketch plan of the river gorges at the whirlpool (fig. 3, p. 147), and the following figure is a section through them at the line C D, in plan.

Fig. 4.



Section through the line C D in Plan, Fig. 3, showing two terraces excavated in till and a river ridge capping the lower one. C, till with angular blocks; D, till without stones; E, rounded boulders of northern origin; G, river ridge.

There are here shown two river terraces, of which the highest and oldest has been formed by the washing off by the river of the clay without boulders (D), from that with boulder (C), leaving a level terrace, excepting where it is capped by the river ridge (G). The river at the whirlpool has cut back into the old gorge, clearing out the entrance to it and cutting off this terrace, but on the other side of the old gorge it re-appears and continues on, parallel to the course of the present river, and without any reference to

* Travels in North America, vol. i., p. 42.

the old blocked-up channel, across which it had evidently been at one time continuous.

This terrace must have been formed when the river was much wider than now, and flowing so slowly, that it had only power to cut through the unconsolidated sandy clay, without stones. The lower terrace marks a later stage, when, by the cutting back of the gorge, the river ran with a swifter current, at a lower level, and in a narrower channel, and cut through the lower hill to the solid rock below. It marks the last stage in the present river's course, before it occupied the gorge cut through the Silurian limestones. The ridge capping the bank of the old river-bed must have been heaped up during floods. It is well exposed, though in danger of total obliteration, as it is being carted away for gravel. The stones in it are all rounded, like true river gravel. Mixed through it, often filling the interstices between the stones, are multitudes of fresh-water shells belonging to the genera *Melania*, *Limnea*, *Unio*, and *Cyclas*. I was able to confirm the observation of Lyell, that the assemblage of species is the same as that now found in the river above the falls. Amongst the stones of the present beach above Goat Island, I found shells of the same species as I did in the old ridge above the whirlpool, and in not much better state of preservation; indeed, excepting that I had labelled the boxes containing the different sets, I could scarcely now tell which were the older of the two. This assemblage of dead shells in the gravel of the beach differs, both in the older and newer deposits, from that found living in the present river, in that many delicate shelled species are scarce, or not found at all, owing, no doubt, to only the more robust shells being preserved. Thus, thin-shelled species of *Physa* abound in the river, but I did not find any of their shells, either amongst the stones of the present or the old beach.

A little above the whirlpool, the gorge widens out abruptly, as shown in plan, and the terraces and ridge are cut off by it, so that they cap the gorge, and are exhibited in section almost as clearly as I have depicted them in fig. 4. The river ridge, composed entirely of loose gravel and sand, is seen running to the edge of the cliff. The widening of the gorge extends for some distance beyond it, cutting off the upper terrace in the same manner. At this spot the upper layers of limestone project beyond the lower beds, just as they do now at the table rock at the falls, forming an overhanging precipice, so that the widening of the gorge cannot have been caused by weathering. I cannot conceive how the present river could excavate the gorge beyond the loose

ridge of gravel, without washing both it and the terrace of unconsolidated till away; and it seems to me that we have here a proof, of what appeared before to be probable, that the river has at this point only re-opened the ancient gorge, the clay and stones that filled the widened part having been washed out by water from below, not from above, as would be necessary to excavate the gorge itself. I concluded, therefore, that the pre-glacial falls had been situated at least as high up as this point, and I thought that the narrowing of the gorge upwards, though it was still wider than that leading to Queenstown, might mark the commencement of the present river's work above the whirlpool.

On examining the gorge higher up, I however discovered that there were several places where it widened suddenly out, and at two of these I found similar proofs of the gorge not having been excavated by the present river. Thus, on the American side, between the railway and the suspension bridge, there are two or more widenings of the gorge, and I noticed a terrace of till at the upper one cut off by the setting back of the gorge. On the Canadian side, about a quarter of a mile below the suspension bridge, there is one of these sudden widenings or bulgings out of the gorge. Higher up a ridge of till, capped by river gravels containing fresh-water shells, marks a former channel of the river, and runs down about 50 yards from the gorge. This ridge does not wind round the widened part of the gorge, but runs down to it, and is abruptly cut off by it, similarly to the one above the whirlpool. Exactly the same argument may be used to prove that the present river has not cut out the gorge at this point, but only emptied it of the glacial clays and sands with which the old pre-glacial gorge was choked up. This example of a river ridge cut off by the re-excavation of an older gorge, is the nearest to the fall that I could find. From thence, upwards, the river terrace is back from the gorge, and uninterrupted by it.

The argument resolves itself into this form: above the whirlpool the gorge approaches both in direction and width nearer to the old one leading to St. David's than to the post-glacial one leading to Queenstown. That it is pre-glacial is strongly indicated by the fact of the post-glacial ridges being cut off by it in consequence of its re-excavation, whilst there has not been a single argument advanced in favour of the theory that it is post-glacial, which was simply founded on an assumption that does not bear investigation. The conclusion at which I arrive is, that the gorge was cut back from the whirlpool up to at least within three-quarters

Trigonometrical Survey of the Falls of Niagara.
(Reduced from Plan published in Geological Report of New York, 1843.)

of a mile from the falls before the glacial period. It may have existed to within a few yards of the falls, for anything that can be seen to the contrary, whilst, in favour of such a supposition, there may be advanced the great width of the gorge up to the commencement of the horse-shoe fall, the very small indentation that the American fall has made in the side of the gorge over which it leaps, and the appearance the plan of the falls presents, that the river is now cutting back a much narrower gorge, one as narrow as that leading to Queenstown from the whirlpool.

I hoped to have been able to find at Goat Island some evidence bearing on this question, as both Lyell and Hall have described river gravels capping the till there, and also indications of a pre-glacial channel excavated in the silurian rocks, but the whole of the island was covered with a glassy surface of ice produced by the frozen spray from the cataract, that made it most difficult to get about the sloping banks, and masked the beds I wished to examine. On the Canadian side there rises a high ridge of till, overlain by a thick bed of boulder clay, with large stones; and on the American side, there is what appears to be a continuation of this ridge, now cut through by the river. Around this ridge, on the American side, there are indications, as I have already mentioned, that the river once flowed. Goat Island seems to be a remnant of this ridge, and I imagine that it has been pierced, not from above, but from below, that it overlaid the pre-glacial gorge, and was undermined in the same way as the clay filling up the end of the old gorge has been at the whirlpool. This and other questions that arise I must leave to observers with more time at their disposal, and a more favourable season of the year to make their investigations than I enjoyed. The observations that I made are the result of three days' holiday from business, and I am sure, from what I saw, that three months close application would not exhaust the many points of interest that present themselves. The geologists of Canada and New York could not have a more interesting question to work at than this, and if they did no more than correctly and fully map out the gorge, the terraces, and the river ridges, they would confer a great benefit on geological science. The absence of such maps I found to be a great drawback to my investigations. The only part of the gorge that has been surveyed with minute accuracy is that at the falls. This was done by Professor Hall, assisted by competent engineers, in 1842, and permanent marks were at the same time fixed in the rocks. The first step of a new survey

should be a trigonometrical re-measurement of the rocks at the fall. This, compared with that made thirty-three years ago—one-third of a century—could not fail to afford data for calculating the present rate of retrocession, and would be a fitting compliment to the veteran geologist under whose auspices the first survey was made, and to whom the whole scientific world is a debtor for a lifetime spent in geological research.

Whenever that survey be made, I believe it will decide that the present river is cutting back the gorge much more slowly than Lyell estimated; that, instead of one foot yearly, the retrocession is not more than, if it is as much, as one foot in ten years, and that, allowing for the comparative softness of the rocks below the whirlpool, we shall have to put back the occurrence of the glacial period to at least 200,000 years ago, if we conclude that the whole of the gorge, from the falls to Queenstown, has been excavated since that time. But if the conclusion at which I have arrived is correct, that the gorge, from the whirlpool to the falls is pre-glacial, and that the present river has only cut through the softer beds between Queenstown and the whirlpool, and above the latter point merely cleared out the pre-glacial gorge in the harder rocks,—20,000 years, or even less, is amply sufficient for the work done, and the occurrence of the glacial epoch, as so measured, will be brought within the shorter period that, from other considerations, I have argued has elapsed since it was at its height.

Simply looked at from a geological point of view, the time occupied may not seem important, and it has been usual for geologists to ask for an unlimited duration, though, even from that standpoint, it is difficult to reconcile the small amount of denudation that glacial moraines exhibit with the remote antiquity that some physicists assign to them. In Ohio and Illinois, the mounds of the old Indians do not look more recent than the ridges and gravel hills of glacial origin, and in some parts cannot be distinguished from them until excavations are made into them. In England I know we have a school of geologists who have taught that the river valleys of the south of England have been excavated since the glacial period; but wherever we find undoubted glacial deposits, as in the north of England and in Scotland, we find them scarcely altered from the time when they were laid down.

But the student of the succession of changes in the organic world will have a serious difficulty removed, if it be proved that the glacial period occurred not more than twenty

thousand years ago. In the northern temperate zone, so far as we can learn, there has been little variation in the animal or vegetable world since the glacial period. In the tropics, the formation of specific differences has been probably more rapid, but in northern Europe, the species now living differ but little, if at all, from their pre-glacial ancestors. Some of the large mammalia have become extinct, but the fauna and flora are essentially the same as they were before the glacial periods—that is, though some species have died out, we have no proofs of any new ones having come in. There is not a single example of a distinct species having been formed since that time, though some varietal differences may be detected. Even man himself has, I believe, varied but little, physically, since pre-glacial times.

In the paper already referred to, published in No. 44 of this journal (Oct., 1873), I assumed that the arguments brought forward by distinguished geologists, to prove that the palæolithic implements and the mammalian remains found with them were post-glacial, were founded on a sound data. There were great difficulties to be surmounted if that conclusion was correct; but the published sections of the superficial beds, at Bedford and at Hoxne, seemed to admit of no other explanation. Since then I have been able to examine for myself some of the supposed post-glacial beds, and to devote more time to the study of the whole of the valley gravels in the south of England, at the bottom of which the palæolithic implements and mammalian remains are found. The conclusion at which I have arrived is, that so far as the British Isles is concerned, palæolithic man, the mammoth, the woolly rhinoceros, and the hippopotamus are entirely pre-glacial, and that the great and distinct break between the palæolithic and neolithic deposits in that area was caused by the culmination of the glacial period, when to the north of a line drawn irregularly from Lynn Regis, in Norfolk, through Birmingham westward, nearly the whole country was covered by land-ice, that destroyed the mammalian bones and the palæolithic implements, excepting where preserved in fissures and caverns, or in a few spots in the eastern counties, to which the ice did not reach; and when, to the south of that line, a great lake or sea of fresh water, dammed back by the ice that blocked up the German ocean to the north, and the British Channel to the west, covered the pre-glacial remains beneath a mantle of beach gravels as it rose and fell.

Dr. Falconer long ago argued that the older cave

mammalia were pre-glacial; Mr. Tiddiman has found a human bone beneath glacial *débris* in Yorkshire; in America Professor Whitney has announced the discovery of a pre-glacial human skull, and I hope soon to be able to lay before geologists the evidence I have collected, that I think proves that the tools of palæolithic man in the British Isles are all of pre-glacial age. Nearly all ethnologists are agreed that the representatives of palæolithic man are the Eskimos of the far north, and probably, in glacial times, they held much the same relation as they do now to more civilised communities, living further south in more congenial climes, and I have suggested that the records of a glacial civilisation still exist in the statues and cyclopian ruins of some Pacific Islands.*

If we have to go back 200,000 years to the glacial period, the small amount of change in the organic world, and the slow progress of civilisation northwards, from its southern home, are difficulties not easily surmounted by the evolutionist, for he has not unlimited time at his disposal. This world and its inhabitants do show signs of a beginning, and he will have to put that beginning back far beyond the time that physicists and astronomers will allow him, if 200,000 years scarcely takes us one step backward in the long succession of changes in the organic world, of which we have proofs in the strata of the earth's surface. These difficulties will be greatly lessened if the period of the glacial epoch has to be put back only 20,000 years; and, so far as the excavation of the gorge of Niagara affords a scale of measurement, there is no reason to ask for a longer time.

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