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BOTH the interest and the importance of the subject make it worth while to follow out every clew that may lead to the approximate determination of the age of Niagara Falls. During this past season, in connection with some work done for the New York Central Railroad upon their branch line which runs along the eastern face of the gorge from Bloody Run to Lewiston, I fortunately came into possession of data from which an estimate of the age of the falls can be made entirely independent of those which have heretofore been current. The bearing and importance of the new data can best be seen after a brief *résumé* of the efforts heretofore made to solve this important problem.

In 1841 Sir Charles Lyell and the late Prof. James Hall visited the falls together; but, having no means of determining the rate of recession, except from the indefinite reports of residents and guides, they could place no great confidence in the "guess," made by Sir Charles Lyell, that it could not be more than one foot a year. As the length of the gorge from Lewiston up is about seven miles, the time required for its erosion at this rate would be thirty-five thousand years. The great authority and popularity of Lyell led the general public to put more confidence in this estimate than the distinguished authors themselves did. Mr. Bakewell, another eminent English geologist, at about the same time estimated the rate of the recession as threefold greater than Lyell and Hall had done, which would reduce the time to about eleven thousand years.

But, to prepare the way for a more definite settlement of the question, the New York Geological Survey, under Professor Hall's direction, had a careful trigonometric survey of the Horseshoe Fall made in 1842, erecting monuments at the points at which their angles were taken, so that, after a sufficient lapse of time, the actual rate

of recession could be more accurately determined. In 1886 Mr. Woodward, of the United States Geological Survey, made a new survey, and found that the actual amount of recession in the center

FIG. 1.—Looking north from below the Whirlpool, showing the electric road at the bottom of the east side of the gorge, and the steam road descending the face about halfway to the top.

of the Horseshoe Fall had proceeded at an average rate of about five feet per annum. The subject was thoroughly discussed by Drs. Pohlman and Gilbert, at the Buffalo meeting of the American Association in 1886, when it was proved, to the satisfaction of every one, that, if the supply of water had been constant throughout its history, the whole work of eroding the gorge from Lewiston to the Falls would have been accomplished, at the present rate of recession, in about seven thousand years.

But the question was immediately raised, Has the supply of water in Niagara River been constant? It was my privilege, in the autumn of 1892 (see Bulletin of the Geological Society of America, vol. iv, pp. 421–427), to bring forth the first positive evidence that the water pouring over Niagara had for a time been diverted, having been turned through Lake Nipissing down the valley of the Mattawa into the Ottawa River, following nearly the line of Champlain's old trail and of the present Canadian Pacific Railroad. The correctness of this inference has been abundantly confirmed by subsequent inves-

tigations of Mr. F. B. Taylor and Dr. Robert Bell.* The occasion of this diversion of the drainage of the Great Lakes from the Niagara through the Ottawa Valley was the well-known northerly subsidence of the land in Canada at the close of the Glacial period. When the ice melted off from the lower part of the Ottawa Valley the land stood five hundred feet lower than it does now, but the extent of this subsidence diminished both to the south and the west, making it difficult to estimate just how great it was at the Nipissing outlet. A subsidence of one hundred feet at that point, however, would now divert the waters into the Ottawa River. That it actually was so diverted is shown both by converging high-level shore lines at the head of the Mattawa Valley and by the immense delta deposits at its junction with the Ottawa, to which attention was first called in my paper referred to above.

FIG. 2.—View looking east across the gorge near the mouth, showing the railroads and the outcrops of Clinton and Niagara limestones above the steam road.

The indeterminate question which remained was, At what rate did this postglacial elevation of land which has brought it up to its present level proceed? Dr. Gilbert, Professor Spencer, and Mr. Taylor have brought forth a variety of facts which, according to

* See article by Mr. Taylor on The Scoured Bowlders of the Mattawa Valley, in the American Journal of Science, March, 1897, pp. 208–218.

their interpretation, show that this rate of elevation was so slow that from twenty thousand to thirty thousand years was required to restore to the Niagara River its present volume of water. Their arguments are based upon the varying width and depth of the Niagara gorge, proving, as they think, the presence of a smaller amount of water during the erosion of some portions. Dr. Gilbert has also brought forward some facts concerning the extent of supposed erosion produced by the diverted waters of Niagara when passing over an intermediate outlet between Lake Simcoe and Lake Nipissing. But the difficulty of obtaining any safe basis for calculation upon these speculative considerations has increased the desire to find a means of calculation which should be independent of the indeterminate problems involved. That I think I have found, and so have made a beginning in obtaining desired results. *The new evidence lies in the extent of the enlargement of the mouth of the Niagara gorge at Lewiston since the recession of the falls began.*

It is evident that the oldest part of the Niagara gorge is at its mouth, at Lewiston, where the escarpment suddenly breaks down to the level of Lake Ontario. The walls of the gorge rise here to a height of three hundred and forty feet above the level of the river. It is clear that from the moment the recession of the falls began at Lewiston the walls of the gorge on either side have been subject to the action of constant disintegrating agencies, tending to enlarge the mouth and make it V-shaped. What I did last summer was to measure the exact amount of this enlargement, and to obtain an approximate estimate of the rate at which it is going on.* As this enlargement proceeds wholly through the action of atmospheric agencies, the conditions are constant, and it is hoped that sufficiently definite results have been obtained to set some limits to the speculations which have been made upon more indefinite grounds.

The face on the east side of the gorge presents a series of alternate layers of hard and soft rocks, of which certain portions are very susceptible to the disintegrating agencies of the atmosphere. The summit consists of from twenty to thirty feet of compact Niagara limestone, which is underlaid by about seventy feet of Niagara shale; which in turn rests upon a compact stratum of Clinton limestone about twenty feet thick, which again is underlaid by a shaly deposit of seventy feet, resting upon a compact stratum of Medina sandstone twenty feet thick, below which a softer sandstone, that crumbles somewhat readily, extends to the level of the river.

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* For opportunity to do this work I am indebted to the interest of President S. R. Callaway, of the New York Central Railroad. The measurements were made by Mr. George S. Tibbits, engineer of the western division. The photographs were taken by Mr. C. F. Dutton, of Cleveland.

The present width of the river at the mouth of the gorge is seven hundred and seventy feet. It is scarcely possible that the original width of the gorge was here any less than this, for in the narrowest places above, even where the Niagara limestone is much thicker than at Lewiston, it is nowhere much less than six hundred feet in width. Nor is it probable that the river has to any considerable extent enlarged its channel at the mouth of the gorge at the water level. On the contrary, it is more probable that the mouth has been somewhat contracted, for the large masses of Niagara and Clinton limestone and Medina sandstone which have fallen down as the shales were undermined have accumulated at the base as a talus,

FIG. 3.—Looking up the gorge from near Lewiston, showing on the left the exposed situation of the eastern face of the gorge at the extreme angle, where the measurements were made.

which the present current of the river is too feeble to remove. This talus of great blocks of hard stone has effectually riprapped the banks, and really encroached to some extent upon the original channel.

We may therefore assume with confidence that the enlargement, under subaërial agencies, of the mouth of the gorge at the top of the escarpment has been no greater than the distance from the present water's edge to the present line of the escarpment at the summit of the Niagara limestone. This we found to be three hundred and eighty-eight feet—that is, the upper stratum of hard rock on the east side of the gorge had retreated that distance, through the action of atmospheric agencies, since the formation of the gorge first began. The accompanying photogravures and diagram will present the facts

at a glance. The total work of enlargement on the east side of the gorge has been the removal of an inverted triangular section of the rock strata three hundred and forty feet high and three hundred and eighty-eight feet base, which would be the same as a rectangular section of one hundred and ninety-four feet base. From this one can readily see that if the average erosion has been at the rate of one quarter of an inch per annum, the whole amount would have fallen down in less than ten thousand years; while if the time is lengthened, as some would have it, to forty thousand years, the rate would be reduced to one sixteenth of an inch per year.

Fortunately, the construction of the railroad along the face of the eastern wall of the gorge affords opportunity to study the rate of erosion during a definite period of time. The accompanying photogravures will illustrate to the eye facts which it is hard to make impressive by words alone. The course of the road is diagonally down the face of the gorge from its summit for a distance of about two miles, descending in that space about two hundred feet to the outcrop of hard quartzose Medina sandstone. The lower mile of this exposure presents the typical situation for making an estimate of the rate at which the face is crumbling away.

Beginning at what used to be known as the "Hermit's Cave," near the Catholic College grounds, where the Niagara shale is well exposed, and extending to the outer limit of the gorge, the height of the face above the railroad averages one hundred and fifty feet. Now, the crumbling away of the superincumbent cliffs gives continual trouble to the road. Three watchmen are constantly employed along this distance to remove the *débris* which falls down, and to give warning if more comes down than they can remove before trains are due. The seventy feet of Niagara shale, and the equal thickness of shaly Medina rock which underlies the Clinton limestone, are constantly falling off, even in fair weather, as any one can experience by walking along the bank; while after storms, and especially in the spring, when the frost is coming out, the disintegration proceeds at a much more rapid rate. Sometimes two or three days are required by the whole force of section hands to throw over the bank the result of a single fall of material.

At a rate of one quarter of an inch of waste each year the amount of *débris* accumulating for removal on the track along this distance would be only six hundred and ten cubic yards per annum—that is, if six hundred and ten cubic yards of material falls down from one mile of the face of the wall where it is a hundred and fifty feet high, the whole amount of enlargement of the mouth of the gorge would be accomplished in less than ten thousand years. Exact accounts have not been kept by the railroad; but even a hasty exami-

nation of the face of the wall makes it sure that the actual amount removed has been greatly in excess of six hundred yards annually. This estimate is based partly on the impression of the railroad officials as to the cost of removal, and partly on the impressions of the watchmen who spend their time in keeping guard and in the work of removing it.

FIG. 4.—Nearer view of the upper portion of the face near the mouth, showing the exposure of the situation at that point.

But that is not all. The accompanying photogravures indicate an actual amount of removal over a part of the area enormously in excess of the rate supposed. Fig. 5 shows a portion of the precipice, a hundred feet high, where the road first comes down to the level of the Clinton limestone, and where, consequently, the whole thickness of the Niagara shale is accessible to examination. Fortunately, Patrick MacNamara, the watchman at this station, was a workman on the road at the time of its construction in 1854, and has been connected with the road ever since, having been at his present post for twelve years. We have therefore his distinct remembrance, as well as the appearance of the bank, to inform us where the face of the original excavation then was. In the picture he is standing at the original face, while the other figure is nearly at the back of the space which has been left empty by the crumbling away of the shale. The horizontal distance is fully twenty feet, and the rocks overhang to that amount for the whole distance exposed in the photograph. All this amount of shale has fallen down in forty-four years, making a rate many times larger than the highest we have taken as the basis of our estimate. Of course, this rate for the crumbling away of the Niagara shale on its fresh exposure is much in excess of the average rate for a long period of time; but it is clear that the rate of erosion at the base of the Niagara limestone at the mouth of the gorge can never

have been sufficiently slow to reduce the total average much below the assumed rate of a quarter of an inch a year.

To impress the truth of this statement it is only necessary to follow the progress, in imagination, of the crumbling process which has

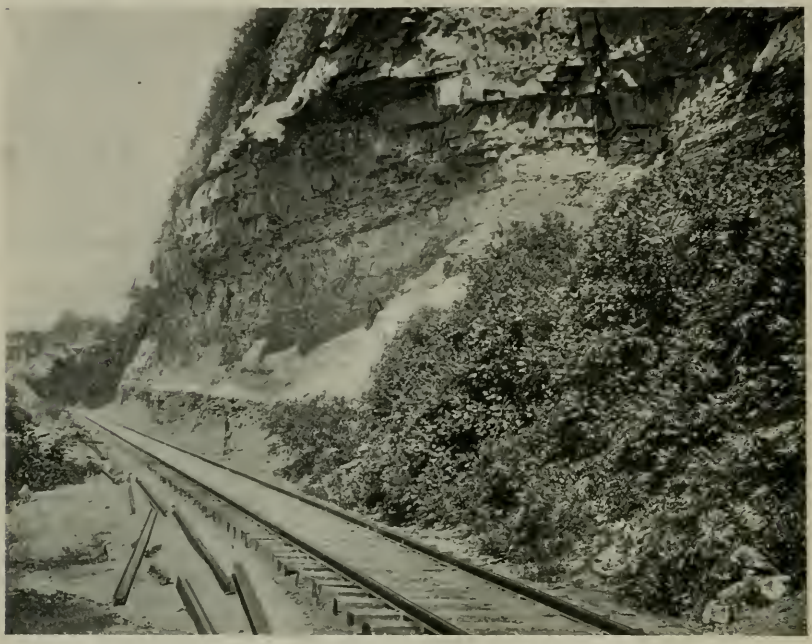

FIG. 5.—Showing extent of erosion at base of the Niagara shale since 1854. (See description in the text.)

brought the side of the gorge to its present condition. At first the face of the gorge was perpendicular, the plunging water making the gorge as wide at the bottom as at the top. At successive stages the strata of shale on the side would crumble away, as is shown in our photograph, and undermine the strata of hard rock. The large fragments would fall to the bottom, and, being too large to be carried away by the current, would form the talus to which we have already referred, which would grow in height with every successive century. The actual progress of the enlargement would thus be periodic, and not capable of measurement by decades; but after centuries the progress would be clearly marked, and especially whenever there was a falling away of the lower stratum of compact Medina sandstone, which is about two hundred feet below the top, would a new cycle of rapid disintegrations in the superincumbent strata follow.

An important point to be noticed, and which is evident from two of the reproduced photographs (Figs. 3 and 4), is that the talus has

never reached up so high as to check the disintegration at the mouth of the gorge of the Niagara shale and limestone which form the upper one hundred feet of the face, and which exhibit the maximum amount of enlargement which has taken place. The thickness of the Niagara limestone is here so small that it has not been so important an element in forming the talus as it has been farther up the stream, where it is two or three times as thick. Now, while our original supposition was that one quarter of an inch annually was eroded from the upper two hundred feet, this would involve the erosion of a half inch per annum over the top of the gorge to bring the calculation within the limit of ten thousand years. It certainly is difficult for one who examines the facts upon the ground to believe that the crumbling away of this exposed Niagara shale could have been at any less rate than that; so that the estimate of about ten thousand years for the date of that stage of the Glacial period in which Niagara River first began its work of erosion at Lewiston (an

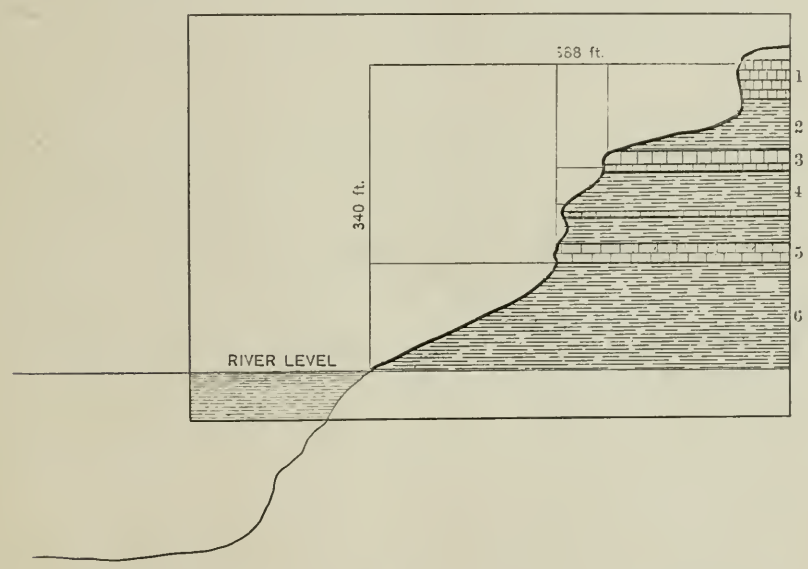

FIG. 6.—Section, drawn to equal vertical and horizontal scale, showing enlargement of Niagara gorge on the east side at its mouth at Lewiston: 1, Niagara limestone, 20 to 30 feet; 2, Niagara shale, 70 feet; 3, Clinton limestone, 20 to 30 feet; 4, Clinton and Medina shale, 70 feet; 5, Quartzose Medina sandstone, 20 to 30 feet: 6, softer Medina sandstone, 120 feet above water level.

estimate which is supported by a great variety of facts independent of those relating to the Niagara gorge) is strongly confirmed by this new line of evidence.

So far as I can see, the only question of serious doubt that can be

raised respecting this calculation will arise from the possible supposition that, when the eastern drainage over the Niagara channel began, the land stood at such a relatively lower level as would reduce the height of the fall to about half that of the present escarpment at that point; when it might be supposed that a protecting talus had accumulated which would interrupt the lateral erosion for the indefinite period when the drainage was being drawn around by way of the recently opened Lake Nipissing and Mattawa outlet. Then, upon the resumption of the present line of drainage, with the land standing at nearly its present level, the talus may have been undercut, and so fallen down to leave the upper strata exposed as at present. But there does not seem to be sufficient warrant for such a supposition to make it necessary seriously to entertain it, while the objections to it are significant and serious. First, the present narrowness of the river at the water level is such that it does not give much opportunity for enlargement after the first formation of the gorge; secondly, the Niagara limestone at the mouth of the gorge is so thin (stated by Hall to be twenty feet thick) that it would not form a protecting talus, even at half its present height.

P. S.—Since the above was written there has been reported in the papers an immense fall of rock from the east side of the gorge, near the head of the Whirlpool rapids. The estimate made of the amount is one hundred thousand tons. If that estimate is correct, it is a very impressive illustration of how the average fall of material from the side of the gorge is occasionally increased by a single instance. In making our calculations above, the total amount of material annually falling off from the portion of the side of the gorge under consideration amounted only to 1,237 tons, while the amount of material was 611 cubic yards. But the 100,000 tons which came off in a single slide a few weeks ago would be equal to twenty inches in thickness from the whole face of the cliff, where our estimate was only a quarter of an inch.

N. B.—In the diagram (Fig. 6) extend the Niagara shale (2) up to occupy lower two layers of (1), thus making Niagara limestone (1) half as thick as now.