(Frontispiece.)

View of Canadian Falls. Low water, 1899; perimeter 2,950 feet, since shortened by 415 feet, owing to power diversion. (By permission of Baker Art Gallery, Columbus, Ohio).

CANADA
DEPARTMENT OF MINES, GEOLOGICAL SURVEY BRANCH
A. P. Low, B. Sc., F.R.G.S., Deputy Minister of Mines

THE

FALLS OF NIAGARA

THEIR EVOLUTION AND VARYING RELATIONS TO THE GREAT LAKES; CHARACTERISTICS OF THE POWER, AND THE EFFECTS OF ITS DIVERSION

BY

Joseph William Winthrop Spencer
M.A., PH. D. F.G.S.

1905-6

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1907

A. P. Low, B.Sc., F.R.G.S.,
Deputy Minister of Mines.

Sir,—I have the honour of transmitting, herewith, a monograph on the Geology and Physics of Niagara Falls, begun and extended under a commission from Dr. Robert Bell, Acting Deputy Head and Director of the Geological Survey, and later continued by yourself.

I have the honour to be,
Your obedient servant,
J. W. SPENCER.

December, 1907.

ROBERT BELL, I.S.O., M.D., D.Sc., F.R.S.,
Chief Geologist.

SIR,—I have had the honour of transmitting to you a report on and map of Recession-lines of Niagara Falls, for your Summary Report for 1905; also most of the maps and illustrations for the monograph which was begun in June, 1905, under commisson from you, as Acting Deputy Head and Director of the Geological Survey of Canada. The commission was further extended by you in consequence of unexpected discoveries of most important facts. The field work is completed, except an attempt to sound under the Falls themselves, and the general verification on the ground, which will be done after the draft of the report has been written; this last, I hope, will be ready next month.

I have the honour to be,
Your obedient servant,

J. W. SPENCER.

May, 1906.

PREFACE

Niagara and its history are so familiar, that most people naturally conclude that almost everything concerning the Falls has already been made known, so that additional work suggests little more than a re-description or essay writing. Among the various contributions to the literature, only a few, in number, bear upon the geological aspect, and fewer still have made additions to our knowledge of the subject. Yet such contributions, as will be seen from many necessary discoveries announced in this book, formed chapters too incomplete upon which to establish the science of the Falls. This statement applies not only to their geological, but also to their physical aspect. Thus, while the volume of the river had been measured for power purposes, some of the most important problems in its physics had not been elucidated by the engineer—not merely those bearing on the future of the Falls, but even that of the mean discharge given. The recession of the Falls through the different strata is the ordinary limit of research required of the geologist. But the changes, in the volume and currents of the river, in the height of the Falls, and in the effects of the buried valleys, determined by causes acting far from the great cataract, opened a new field of investigation, as did also the application of more precise methods of research than were formerly followed, so that the Falls of Niagara have given rise to a chapter in science, belonging entirely to themselves, which had not hitherto been understood, and which could not have been interpreted by any outside standard.

Four surveys of the crest-line of the receding Falls had been made, with considerable intervals between them. The last published one was made in 1890; but none had been undertaken by Canadian authorities. As the diversion of power at Niagara was attracting attention, and as such would change the recession, Dr. Robert Bell, Acting Deputy Minister and Director of the Geological Survey of Canada, saw the necessity for prompt action, as the operations in progress were tending to alter the natural conditions, so that the last opportunity was passing by. Moreover, observations made by the engineers of the power companies might be of value, which would be lost when these corps should be disbanded.

Under these conditions, and finding that I had already commenced such a work, on my own account, by a survey of the crest-line, in October, 1904, Dr. Bell commissioned me to prepare a 'complete monograph' upon the science of the Falls, as he had been aware of my previous contributions to this subject. These had already been published in a report of the Hon. Andrew H. Green,* who had been instrumental in having the Niagara Falls Park, on the New York side, established, after Lord Dufferin had proposed a similar Park on the Canadian side.

It was this Mr. Green who originated the Deep Waterways Commission, for the protection of the Falls. In this connection, it may be said that I represented Mr. Green in some of his negotiations with the late Secretary Hay, who also was much interested in Niagara Falls. Indeed, Mr. Green was especially desirous that I should make just such a survey as has now been carried out under Dr. Bell.

Upon Mr. Low succeeding to the directorate, he extended the commission to a date that I had supposed would be sufficient, which however proved not to be the case, so that the work was completed by myself *con amore,* and the Geological Survey has now the use of it under arrangements effected by Mr. Low.

The commission was commenced in June, 1905, and the field work was carried on until February, 1906. This was due to the mild winter, for even on January 25, 1906, the farmers

* Eleventh Rept. Com. State, Niag. Falls, 1895.

were ploughing. After having the report well advanced, its complex character demanded a revision in the field, to which I returned for several weeks, leaving it on October 26, 1906.

The new investigations under the survey were by:—(1) Soundings at all the changing points of the gorge, even under Niagara falls themselves, and in the Whirlpool; (2) Borings to ascertain the character of the buried channel beds, over which the river afterwards flowed; (3) Instrumental surveys of the old river banks and the position of the strata; (4) Investigations of lake fluctuations, based upon the daily records for fifty years, as to their bearing upon the stability of the earth's crust, the lowering of the lake outlets and of the lakes themselves, and as to new results of the discharges of the rivers—all of these modified by (5) Meteorological changes. The future effects on Niagara falls and upper lakes by the diversion of the water at the Falls have been ascertained. The recession of the Falls, from their birth to the present day, and for the future, has been determined, as well as their age. The existence of an ancient Erie outlet some miles to the west, not hitherto suspected, is a most important discovery in the history of the changes in the lake region. The International Boundary Line, showing the greater Falls to be in Canada, has been laid down on the map.

Besides the other scientific results, features bearing on International questions have arisen in connection with the effects of the draining of the Falls at the International Boundary, and the lowering of the lakes by power diversions, as also the ownership of the water rights of Niagara falls. Even the establishment of the Boundary Line at the falls comes to be a geological question, and not merely one of ordinary surveying.

It is only proper that the investigations should have been made under the Geological Survey of Canada, as most of the features revealing the history of Niagara falls lie in the Dominion. References and records have been added in the appendices to complete the work.

It would be unjust, here, not to pay tribute to the memory of the late Prof. J. P. Lesley, who first saw the value of my earliest observations bearing on Niagara falls, and through whose enthusiastic encouragement alone I was led to develop my researches along lines laid down and approved by him, thus forming a new chapter in the science, as he said, which has been the foundation of the present work.

The best collection of publications on Niagara falls is that of the Hon. Peter A. Porter, of Buffalo, who possesses many very old volumes. The bibliography has been omitted from this work, as much the greater part lies entirely outside of this subject, but it may be found in the rare publications of the Commissioners of the State Reservation of Niagara Falls, New York.

ACKNOWLEDGMENTS.

In all of this work I received much assistance. Capt. Carter of the *Maid of the Mist* placed his good ship at my disposal for sounding purposes. Mr. James Wilson, C.E., superintendent of Queen Victoria Park, gave me most valuable support throughout the whole period of the survey. Mr. W. T. Jennings and Mr. Geo. A. Rieker most kindly furnished me with their detailed surveys of the gorge. Messrs. Beverley Value and Jas. Goodwin, Messrs. Banker Payne and C. E. Mitchell, and Mr. A. H. Van Cleve, of the different power companies, greatly aided me. For most valuable information in connexion with borings I have to specially thank Mr. Jacob Schneider (who also assisted me in boring operations, as did Mr. C. C. Butler), and Messrs. D. A. Coste, F. W. James, W. J. Aikens, J. Hayden Smith, Geo. Lang, H. W. Hunter and others, of the gas well companies, to all of whom I desire to offer my warmest thanks. Mr. M. J. Butler, Deputy Minister of Railways and Canals, Mr. James White, of the Interior Department, Mr. J. L. Weller, of the Welland canal, Mr. Stewart, of the St. Lawrence

canals, Mr. Postlethwaite, of Toronto harbour, and others, kindly furnished me with lake fluctuation records. I must especially thank my assistants, Messrs. Robert Harvie and Claude E. Eldridge, for their great interest in the work and efficiency in the field. It is further due that acknowledgment should be expressed to my draughtsman, Mr. J. D. Cleary, and my clerical assistant and stenographer, Miss E. D. Liscom, for more than necessary aid that they rendered me. I desire to thank Mr. O. C. Sénécal, Chief Draughtsman of the department, for final additions to the maps, and for superintending the engravings, &c.

I especially desire to thank the United States Secretary of the Navy, and also Captain Z. L. Tanner, for kindly lending me, personally, apparatus for soundings in the rapids of Niagara Gorge.

Finally, I am particularly indebted to Mr. Wm. McMahon, Superintendent of the Bureau of Printing, for his interest in the work, and for the handsome presentation of this volume, and its expeditious appearance, after I was brought into direct contact with him, and for the assistance and courtesy of all the gentlemen of the Bureau with whom I have had associations.

ORIGIN OF THE NAME 'NIAGARA.'

The region was once occupied by a large tribe of Indians of which the name is not now known. In the early seventeenth century they were called 'the Neutrals' (as between the Hurons and the Iroquois), but about the middle of that century they were exterminated by the Iroquois after the defeat of the Hurons. Only one word of their language remains. It is Onghiara, the name of the falls and river below, which name was adopted by the Indians who afterwards peopled the district. The name became modified to Niagara with the accent on the penult (*Niagára*). and it was so pronounced at the beginning of the nineteenth century. (For a fuller account *see* p. 469).

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In the foregoing tables the researches include a vast number of data, many obtained instrumentally, which are either new or revised *de novo*, whereby the chain of evidence is completed in solving many difficult problems; therefore, scientifically, the author assumes responsibility for the statements, opinions and phraseology of this report. The absence of certain capitals, notably 'f' in Falls when referring to Niagara; the change of names as from St. David's, thus known in history, to St. David; the mixed form of numerals, when in series, etc., do not meet with the approval of the writer. Certain observations, set forth in some chapters elucidate subjects discussed in others, hence repetitions are unavoidable.

ERRATA.—Some errors have escaped observation, and others indicated were not corrected, but the significance has not been obscured. The sense is changed where the word 'Huron' occurs in the fourth line from foot of page 262, which should be *Erie*; so also 'to be' on sixth line from foot of page 396 should read *at not*.

ILLUSTRATIONS

CHAPTER I.

PARTIAL SUMMARY.

The International Boundary Line at Niagara falls was determined by the signed map of the Commission of that time (1819). At one point this line is found within 235 feet of Goat island, thus throwing the whole of the great crescent of the falls within Canadian territory, while only the turn beyond the crescent, trending to Goat island, belongs to New York. Here the cataract is now often reduced to mere strings of water. The withdrawal of the water for power purposes threatens to leave exposed a strip of rock belonging to Canada, now covered by the rapids, on the eastern side of the falls. The quantity of water falling over this end adjacent to Goat island is too small a factor in the whole volume to be considered. But the volume flowing down the American falls is approximately seven per cent of the whole. (*See* Chapters II. and III.) The proportion of the discharge at the rocky rim, which determines the flow of water down the Upper rapids, gives to Canada 75 to 80 per cent of the total discharge of the river. (*See* Chapter XXI.)

The recession of the falls between 1842 and 1905 was 285 feet at the centre of the apex, or a mean retreat for the full width of the gorge of 265 feet. Nearly seven and three-quarter acres of the rocky floor of the Upper rapids fell during that time. The retreat takes place by rapid central recession followed by a cessation of the same with a rapid lateral enlargement. Thus for twenty years there has been no apparently measurable central retreat. The mean recession has been found to be 4·2 feet per year, but during the last fifteen years this has been greatly reduced. The discovery of the position of Hennepin falls in 1678 shows that this rate has prevailed since then. The length of the Canadian falls was 2,950 feet in 1900, but from this 415 feet have been taken by the curtailment on the Canadian side. The recession of the American falls is only at the rate of 0·60 foot a year. (*See* Chapter III.) Its length including Luna island is about 1,000 feet.

The height of Niagara falls on the Canadian side is 158 feet, and 175 feet in the centre. The descent from the rim of Greens or First cascade to the edge is fifty-five feet, after the river has descended fourteen feet from Lake Erie. The height from the rim across the river to the cauldron below is 212 feet. This is the gross head of water in relationship to the horse-power of those companies that take the water from above the Upper rapids, while for those below it is only about 160 feet. This feature is most important when considered in its connexion with the effects on the falls, or the results that will arise from the diversion of water by the power companies, as well as the relative quantity of water used. For other features, and the slope of the river *see* Chapter IV. The total descent of the river from lake to lake is 326·58 feet (mean of fluctuations from 1891 to 1905).

The new sounding off the Goat island shelf at 192 feet reaches to ninety-two feet below the level of Lake Ontario. This depth is found near the head of the Whirlpool rapids, a mile and a-half below, but under the falls the depth is only seventy-two feet (to fallen rocks), with a shelf beyond at eighty-four feet or a little more. At the Cantilever bridge the depth is eighty-five feet, but the channel is refilled to a further depth of a hundred feet. At the Whirlpool, which is fifty-one feet below the head of the rapids, the depth before reaching the middle of the river was found to be 126 feet, or about fourteen feet less than in the river above. Below the Whirlpool it is considerably less, as also is the case below Foster flats. But near the end of the cañon a drowned cataract was brought to light where the river within the gorge rapidly deepens from fifty-three feet to nearly 150 feet below Lake Ontario level. The narrow channel as deep as 183 feet was also found a third of a mile beyond the mouth of the gorge, although it has generally been silted to a much less depth. (*See* Chapter v.)

The rock structure and the excavating power of Niagara falls are treated in Chapter VII., and the characteristics of the gorge in its relationship to the receding falls are described in the two following chapters; the original banks and bed of the Niagara river are described in Chapter IX.

The Whirlpool-St. David buried channel extends from the Whirlpool to the edge of the escarpment, about two and a half miles beyond, and was erroneously thought to be the ancient course of the Niagara river. The ancient cañon has now been explored by borings, the deepest of which reached to 269 feet, or to a level only a little above that of the Whirlpool. The operations were stopped at this point on account of the expense, which was growing very heavy, but in a general way we now know the effects of the buried valley on the river. To its great depth it gave rise to the Whirlpool, but not to the gorge above, as might have been the case. This was one of the most important points established by the present survey, as the effects it had produced in the recession of the falls had not been fully known. The head of the ancient stream, which at the Whirlpool began to form a gorge, was only a short distance south of the railway bridge—at Lyell ridge. The now buried channel never drained the Erie basin, nor that of any creek above the Upper rapids. But about the Whirlpool, it originated the valley later filled with drift, which was quickly re-excavated when the falls had receded as far as its outlet. Some curious features were observed in the borings, such as a breathing well at a depth of 226 feet, and the occurrence of a log of white spruce at a depth of 186 feet, buried there long ago in the Glacial period. *See* Chapters x. and xii.

The last-mentioned chapter treats of the Whirlpool rapids. In this locality the old river banks are well preserved, while the gorge itself is greatly contracted in breadth. Here, after the Glacial period, a small superficial valley diverted the Niagara river, after the falls had receded past the outlet of the Whirlpool, so that most of the water was concentrated and made a narrow cañon some 400 feet deep, which, upon the retreat of the falls above this point, has been refilled, thereby producing the Whirlpool rapids, which have been completed at a very recent date. The building of these rapids eventually lowered the height of the falls above. The widening of the gorge above this point is a very noticeable feature, but this is too technical for a short summary.

The curious basin at Niagara falls has affected the recession. Here the rock floor is about 110 feet lower than the rocky Lyell ridge, or about sixty feet lower than the river bed of pre-glacial times crossing that ridge. From the Lyell ridge southward, the rock valley, partly buried, deepens and widens to the falls. It long challenged explanation. By borings it has been found to be part of a valley heading in Lyell ridge and growing in the southward direction. At the falls it is over sixty feet below the level of Lake Erie, and it is traced by borings farther southwestward. (*See* Chapter xii.) Its explanation accordingly demanded the finding of a deep outlet from Erie basin. This was afterwards discovered by means of complete investigation of the visible and concealed features. It is described in Chapter xxxvii. The basin at the falls is now found to be part of a shallow valley extending a few miles to join the ancient outlet of the Erie basin, all the features of which are deeply covered by drift. This explains the occurrence of the Upper rapids, where now the Niagara river is descending over the left bank of the otherwise buried valley. It has a great deal to do with the recession of the falls. Here the river is turning its course nearly at right angles, now causing the falls in receding to climb, so to speak, the ancient lateral bank of a valley, so that the hard rock formations above are getting thicker, with the softer lower beds becoming more concealed, thus tending to reduce the rate of the recession. The investigation of the basin in the rocky floor brought to light the Falls-Chippawa valley. In the vicinity of the falls this is covered by a hundred feet or more of drift, which has been explored in many places by borings, so that the rocky floor beneath the mantle is everywhere found to be sinking towards the southwest. (*See* Chapter XIII.)

Foster flats begin at about two-thirds of a mile below the Whirlpool, and extend for a like distance. It is one of the wildest and most beautiful places in eastern America. Here is a series of terraces of the greatest importance in the investigations of the recession. These are floors of the Niagara river, showing that until the falls had reached this point, nearly three miles from the mouth of the gorge, there were two cataracts, one in advance of the other, each about 120 feet in height. Also it is found that the second one, which had been gaining on the upper, now became united with it. At this time the second channel was still high above the present bottom of the river. Lower down the gorge was the third cataract. It may be said that this cataract was at one time 300 feet high, and was lowered by the subsequent backing of the waters of Lake Ontario into the gorge. The lowest cataract remained until long after the united upper ones had passed this section of the cañon, but subsequently joined it, and made one Niagara falls from the time that they reached the Whirlpool. This complex history of Niagara river is largely recorded at Foster flats, which is a wonderful place. Until lately only the Erie waters emptied by the Niagara river. It was immediately after the falls had passed the head of Foster flats that the Huron drainage turned into the Erie basin, and henceforth the recession became very rapid. The features are described in Chapter XIV., and are referred to elsewhere.

The terraces at the mouth of the cañon, upon the flanks of the escarpment, furnish evidence of the lowering of the waters in the Ontario basin, and from these, along with the features at Smeaton ravine and at Foster flats, and the soundings in the river, the height of Niagara falls at different epochs in its early history is determined. (Chapter XV.)

The glacial features of the region are described in Chapter XVI.

The meteorological phenomena required investigation for several purposes, especially in relationship to the fluctuation of the lake levels, and to the discharge of the Erie basin compared with the whole volume of the Niagara river, for in some cases the rainfall appeared at variance with the stages of water in the lakes. In short, they were necessary elements in studying the problem of the lowering of the lakes. (Chapters XVII. to XIX.) After 1890 there was a diminution of the rainfall, but since 1900 the mean has slightly increased, and raised the lakes. But this is too complex for a brief summary here.

The fluctuations of the lake-levels have proved one of the most important studies. The levels are derived from the daily records kept at various stations since 1855 or 1860. The figures vary from year to year as well as from month to month, so that groups of years have to be taken for a fair average. Since 1890 all the lakes, except Superior, have been much lower than during the earlier years of observation. This has affected the calculation of the discharges. From these investigations, along with those of the meteorological conditions, it is found that the outlets of the lakes have been lowered (Chapters XVIII. and XIX.), but that the lowering has lately been slightly obscured owing to the recent increased rainfall. The most accurate statement of the elevation above the sea is the mean of the last fifteen years (1891 to 1905), and not that of the whole period of record of about half a century, although the mean annual fluctuations and discharges are transcribed without introducing the desirable corrections except where special use is made of them. The lowering of Lakes Erie and Ontario has been about one foot and of Lake Huron about a foot and two-thirds. Lake Superior has risen owing to increased rainfall. The lowering of the outlets is permanent, though increased rainfall may conceal the fact even more than now.

The lowering of the outlets affects the calculations of the discharge of the rivers, causing those before 1891 to be too great, and producing anomalous conditions that were not understood until the recent discovery of this feature, an allowance for which brings all the results into harmony. We may therefore take either the mean discharge for the fifteen years (1891-1905), or that of the whole period, if the correction be made. In the former case it reduces the discharge given by the U. S. Engineers by about 15,000 cubic feet per second for Niagara, that is from about 219,000 to 204,000 cubic feet per second. Other figures given, which require correction, are 222,000 and 215,000 cubic feet. A relatively greater correction is required for Lake Huron. It was necessary to determine the relative discharge of the Erie basin as compared with that of the four Upper lakes. The results derived from the rainfall of the basins, from their drainage areas, and the discharge of the fifteen years coincided very closely, but were entirely at variance with the previously given mean discharge, until allowance was made for the lowering of the outlets. Finally I found that the Erie discharge was fifteen per cent of the whole volume of the Niagara river. This factor was one very long sought for, on account of its bearing on the solution of the age of Niagara falls.

Another outcome of the investigations of the lake fluctuations is the establishment of the present stability of the earth's crust in the lake region during the last fifty years, where formerly it was supposed to be rising. (Chapter XXXI).

The discharge of the different rivers is given, and their relationship to the lake fluctuations, which are great. Thus on October 7, 1858, the corrected volume of Niagara was 292,000 cubic feet per second while on February 28, 1902, it fell to 158,500 cubic feet,—the mean of that month being 175,000 cubic feet. (Chapter XX.)

The mean discharge of 204,000 cubic feet gives a gross horse-power from above the Upper rapids of 4,900,000. It was reduced in February, 1902, to 4,200,000 horse-power, when low water prevailed, or for the lowest day to 3,800,000. But this does not represent the available force, as two of the power companies take the water from nearly fifty-five feet below the head. Again there are other great losses in the application so that the whole power cannot be used, and these will reduce the amount by 30 or 35 per cent. Accordingly the available low water discharge is reduced to 2,600,000 horse-power; for only this amount can be considered in the power question.

Seventy-five to eighty per cent of the power is on the Canadian side of the Boundary Line. But this is modified by the position from which it is taken. Thus the power taken above the First cascade affects alike both sides of the river, and also the flow of water over the falls, in so far as they are preserved or despoiled. The water taken below the rim affects the Canadian side almost exclusively, and since the encroachment here, the effect on the river occurs mostly where the water is the deepest, thus doing the least amount of harm. As much of the rim of Greens or First cascade is covered by only a thin sheet of water, the diversion of the present franchise power will greatly modify the eastern side of the falls. In fact, if the full amount be utilized it must drain not merely 800 feet on the eastern side of the Canadian falls, but some two hundred feet more on the western, so that the falls will be reduced from nearly 3,000 feet in width (in 1900) to 1,500 or 1,600 feet. It will further reduce the American falls from 1,000 feet (including Luna island) to a few disconnected streams. The full utilization is not in sight at the present moment, but that taken already has reduced the sheet of water on the Goat island shelf, so that in the near future it seems that the shrinkage of the water will leave only that portion of the greater falls which lies within the Canadian domain. This will complicate the question of the use of the water.

Another most important question that is arising from the diversion of the water above Greens or First cascade is the lowering of the Upper lakes. From 20 to 25 per cent of the discharge will be taken from the basin of the river above the First cascade—this will lower the river from 3·2 to 4 feet according to the stage of mean or low water, though at first the lowering of the river here will be partly lessened by the stronger current from above. The increased flow means eventually a lowering of the lakes, as the run-off will be in excess of the rain supply. This condition will continue until equilibrium is again established with the lakes at a lower level. The word lakes is used, for on the reduction of Lake Erie the same results will affect Lakes Huron and Michigan. Even with the lowering of the mean level of the lakes by two feet, and it may reach three or four feet, the effects on navigation in the harbours and canals are sure to be serious.

This feature has not hitherto been considered so far as I know, except to be discarded as unimportant, because the intake of the water is below the lake outlet. This ignorance has arisen from not investigating the science of Niagara. The diversion of even 125,000 horse-power above the rim will affect the Upper lakes more than the use of an extra 5,000 cubic feet at Chicago. But the increased velocity of the discharge in leaving Lake Erie will not merely lower the water of the lake to equilibrium, but it will produce an extra scour of the clayey and rocky bottom where the current runs five miles an hour, and thus permanently further reduce the level of the lake, as has occurred to the extent of one foot since 1890. (*See* Chapters XIX. to XXI.)

The raised and tilted shore lines, showing the recent movements in the earth's crust and former lake levels, are described in Chapters from XXII. onward. So far as Lake Erie was at first concerned in post-glacial times its area was only about one-sixth the present size, but upon the land rising faster at Niagara than farther westward the lake expanded. When the waters of Lake Ontario became lower the lake shore was about twelve miles from the mouth of the gorge, then the channel was excavated to a depth of about 180 feet below the present level. Later, by tilting, the Ontario waters backed up and drowned the lowest part of the Niagara, and reduced the aggregate height of the falls from 500 feet in all its parts to the present descent of the river of 326 feet.

The Huron drainage was towards the northeast, ultimately by Lake Nipissing, and the Ottawa. What is now Lake St. Clair became the headwaters of Lake Huron, draining northward, as is shown in the drowned channels in the bottom of that lake. But the tilting of the basin turned the waters into the Erie drainage, and augmented the Niagara from 15 to 100 per cent. As these were late changes, only about 3,500 years ago, the absence of warping during the last fifty years becomes the more striking. During the time when only the Erie waters flowed down the Niagara the St. Lawrence was small, as is proved by the recently observed smaller inner channel found there. In the process of the tilting which sent the Huron discharge southward some waters overflowed by way of Chicago into the Mississippi drainage, but the lowering of the Huron barrier to the south lately caused the entire diversion of that discharge to the Niagara.

Having investigated and analysed the components which have affected the recession of Niagara falls I have determined the changes in the volume of the discharge, in the height of the falls, the character of the original banks of the river and the variation of the features of the rocks and the rock surfaces, and the effective erosive power of the falls. Then, finding the character of the first and second cataracts, especially, I have been able to tell the story of the retreat of the Great Falls, and determine their approximate age.

At first the falls were only thirty-five feet high with a volume of 15 per cent of the present, falling directly into Lake Ontario. They receded for only a short distance before their height increased, but based upon proportional recession these conditions lasted 3,200 years. The falls were now separated into two cataracts, the second one growing in height, they receded to Foster flats, where their union occurred at a point extremely well marked. It was on the upper of these falls that I was enabled to make the determination of the time required for the recession. Had this evidence not been available the difficulties might have proved insurmountable. The time required for the recession of the double falls to Wilson point (in addition to the 3,200 years mentioned) is found to have been 31,600 years, and 700 years more to the head of Foster flats, the whole distance being nearly three miles. This was the length of the gorge excavated during the Erie Epoch. From now onward the recession was very rapid, modified at times, but in all requiring only about 3,500 years, so that the age of Niagara falls may be placed at about 39,000. Slight variations on one side or the other are probable, but under the conditions, all of which are now apparently known, the error in calculations will not exceed ten per cent.

An account of the pre-glacial topography is added, though it might have preceded the order of this work on the whole recession of the falls. During the present survey the buried channels explored have thrown so much light on Niagara that those bearing on the outlet of Lake Erie are of particular interest, and they form a distinct chapter that is added to the work, as also another describing the features by which the origin of the Great Lake basins has been found. The Falls-Chippawa valley demanded a search for what proved the discovery of the Erigan valley and cañon, a few miles to the west. The cañon was brought to light in the explorations of the 'Short hills,' where portions of it dissect the Niagara escarpment and are exposed in the deep ravines. Southward there is no suggestion of such an ancient outlet for the Erie basin on the surface of the flat country only a few feet above the level of Lake Erie. But the records of well borings all the way to the lakes were obtained, and they have great economic value in the question of supply of water, and obtaining natural gas. These problems require much further investigation, which the limit of the survey did not permit. However, a great buried valley was discovered, with details that could not have been expected. Thus, not merely was a channel found deep enough to drain the present Erie basin, but also several smaller tributaries of it. This completes the most important evidence in the study of the ancient Erie basin, which formerly received the drainage of even the Upper Ohio river. The history of these investigations required many years for elucidation and it embraces much of that bearing on the origin of the lake basins, which at last is pretty well known. *See* Chapters XXXV. to XXXVII.

CHAPTER II.

INTERNATIONAL BOUNDARY LINE AT NIAGARA FALLS

Boundary line located by the Commission of 1819.
Crescent of the Great falls on Canadian side of that line.
First Canadian Survey of Recession of the falls.
Deepest Inner Channel close to Goat Island shelf.

BOUNDARY LINE LOCATED BY THE COMMISSION OF 1819.

The use of the terms 'Canadian falls' and 'American falls' dates back to the settlement of the country, and the names were adopted by the writers since the earlier part of the nineteenth century, as by Bakewell, Hall and others, but they have had no more significance than as convenient designations of the two great cataracts. Indeed, the great natural phenomena should be quite independent of political limitations.

On almost every map on which this Boundary Line is indicated, even though in official publications, it has been erroneously placed. The map issued by the United States State Department for the use of the Lighthouse Board, which is a photographic copy of that of the Boundary Survey Commission, is an exception. The International Line on the recent map of the Interior Department of Canada is as correctly located as possible on one of such a small scale. Hitherto, the position of the Boundary has been of no importance as it was absolutely unapproachable and very few people knew or even cared where it was. Lately the question was raised in connexion with another survey of the falls (page 29), and accordingly it should be definitely understood. International questions may arise, as the river below the falls is navigable; and the withdrawal of the water from Goat island shelf, due to the power companies, will involve the necessity of the Boundary Line being well known.

An article has just appeared under the title of 'Niagara Falls Already Ruined,'* wherein the writer, Mr. Alton D. Adams, advocates the saving of the American falls by carrying the point of deepening the channel to the International Boundary. But to cover the cost he suggests the further abstraction of water from the Canadian falls to the extent of over one-third of the whole volume of the river. The scientific aspect of the proposition is germane to this paper—the fulfilling of it lies entirely within the jurisdiction of the State Department.

The Boundary Line was established by the International Commission in 1819.

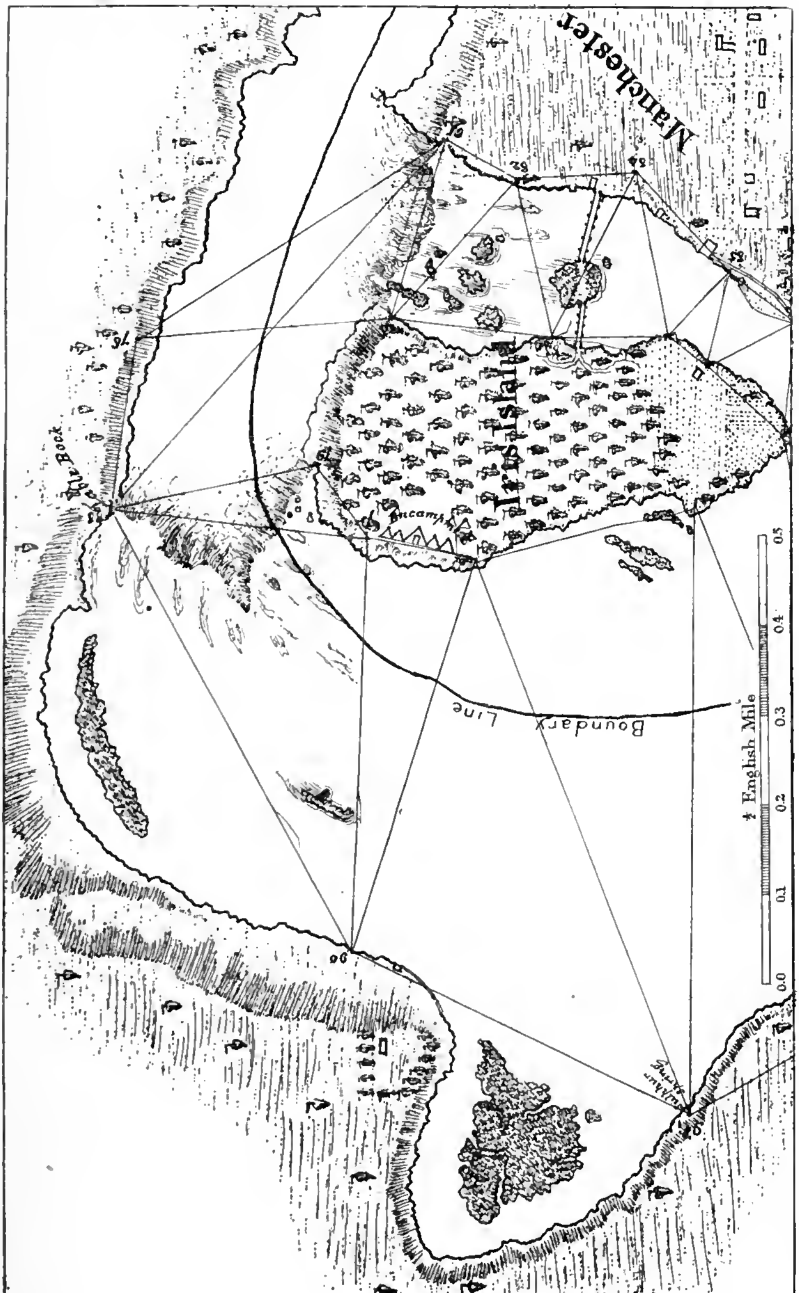
Under the Treaty of Ghent the Boundary Line is drawn through the middle of Lake Ontario 'until it strikes the communication by water between that lake and Lake Erie, thence along the middle of said communication into Lake Erie through the middle of said lake,' etc.; and the Treaty provided for a reference to commissioners to decide what islands should belong to each party. Their decision was to be final.

The commission adopted rules, one of which was to follow the deeper channel and to compensate for islands assigned to either party. It was for compensation, as it were, that the Boundary Line was located near Goat island and Grand island, giving only water equivalent to Canada. Unless other concessions were made it was no compensation to draw the Boundary Line near Goat island and Grand island, for the middle of the river (under Treaty) would have divided Grand island nearly equally, while a corner of Goat island and even more river would have fallen to Canada.

The Boundary map, here reproduced, is signed by Peter B. Porter and Anth. Barclay, commissioners, and William A.

* The Technical World Magazine, pp. 115-124, 1905.

PLATE 1.



International Boundary Map, adjacent to Niagara Falls (1819). Photographed from and on same scale as that of the original signed copy.

Bird and David Thompson, surveyors. It is dated 1819. The present copy is on the same scale as the original, the official copy in the State Department Library of Washington, to which access for making the photograph, was obtained through the kindness of Mr. William McNair, chief librarian.

The sketch of the crest of the falls in 1819 was only approximate, but the established position of the Boundary Line in its relationship to the shore of Goat island has been transscribed to the map of the recession (Plate II.) so that it will be understood in its bearing upon the present crest of the falls.

CRESCENT OF THE GREAT FALLS ON THE CANADIAN SIDE OF THE LINE.

At the end of Goat island shelf the Boundary Line is between 235 and 260 feet from the island. Opposite the apex of the falls it is about 300 feet from the Goat island shore, while the apex is 400 feet within the Canadian side of the line. After swinging round nearly parallel to the southwestern shore of Goat island it bends towards the New York side, above Goat island, and there passes onward between Navy island and Grand island. It hugs close the shore of Grand island, being only 200 feet away, with the Canadian bank from 1,200 to 2,300 feet beyond the Boundary Line. The placing of the Boundary Line gave the whole of the eastern channel, the American falls, and Goat island to the state of New York; but only from 235 to 300 feet of the river at the falls. This threw the crescent of the Canadian falls within the territorial boundary of Canada.

FIRST CANADIAN SURVEY OF RECESSION OF NIAGARA FALLS.

As the Boundary Line places the crest of the falls, where the recession is occurring most rapidly, entirely within Canadian jurisdiction, the preservation of Niagara falls becomes a special duty of the Canadian people. Four previous surveys have been made to ascertain the amount of recession of the falls, but the present survey made in October, 1904, and revised in August and November of 1905, is the first under Canadian authority. Even if the popular opinion, that the Boundary Line follows the deepest channel had here been correct, then below the falls that line would have been near Goat island as shown by the deep sounding of 192 feet (*see map*).

It was none too soon to make this survey, as the diversion of the water had already commenced, and will be greatly increased in the near future when there will be a marked difference in the natural changes of the cataract. The effects of the artificial changes are only now beginning to be appreciated. The Goat island shelf is already losing the water from its surface. (*See* Chapter XXI.)

Below the bank of Goat island, at the angle of the shelf, is a low flat bush-covered rock-surface, showing that the margin of the river was from thirty to fifty feet inside the present water edge. This would be mostly flooded were the river here two feet higher as it was formerly, for the inner was the true bank of the river. On the Canadian side, Table Rock has fallen away leaving only fragments of the terraces, as at T on map, plate II., and at some other points, to establish the old shore line, now further obliterated by the embankment curtailing falls. On the preliminary recession map the end of the Boundary Line is placed thirty feet too far west, but measuring to the natural bank it should still be thirty to fifty feet nearer Goat island, as shown on second edition of the Recession map, Plate II.

8

CHAPTER III.

NEW MEASUREMENTS OF THE RECESSION OF NIAGARA FALLS,

Surveys of the falls.
Montresor's Map of Niagara river (1764): Stegman's (1799); International Boundary map, 1819. Hall's (1842); U. S. Lake (1875); Woodward's (1886); Kibbe's (1890); Spencer's (1904-5).
Results of the Surveys of the Canadian falls.
Rate of Recession and change of Form.
Recession of American falls.
Slower retreat of the falls now and in the future.
Position of the falls at the time of Father Hennepin established.

SURVEYS OF THE FALLS.

Montresor's map.—On June 5, 1764, an order was given for the immediate survey of the Niagara river, by Capt. John Montresor, King George's Chief Engineer in America. In his diary* he wrote, 'Directed an astronomical survey with the plane table from Niagara to the fort at Little Niagara (that is Fort Schlosser), for the several works carried on here since my arrival.' This map is reproduced in Plate III. It should be noted that Fort Erie is not on the map, as it was not built until the end of the summer of that year. The map is from a photograph, of the original in the British Museum†, which was kindly furnished by Hon. Peter A. Porter, of Buffalo. This map, though inaccurate in detail, gives a fair representation of the river. It is especially interesting as showing the rounded apex of the falls as close upon the Canadian side, without the deep indentation, now due to the turn of the direction of the gorge.

* Reprinted in N. Y. Historical Society publication for 1881.
† The British Museum number on the map is CXXI., 73.

Stegman's map.—A map of the vicinity of Niagara falls, on the scale of three chains to the inch, was made by John Stegman*, and bears date of January 17, 1799. It was made by compass bearings and is, therefore, not as accurate as it should be. This is further apparent where the intervening shore lines were sketched in, but the measurements between salient points often correspond closely with more recent ones. The curvature of the Canadian falls is too broad. But there are other points on the map of value in studying the recession. See Map, much reduced in size, Plate IV.

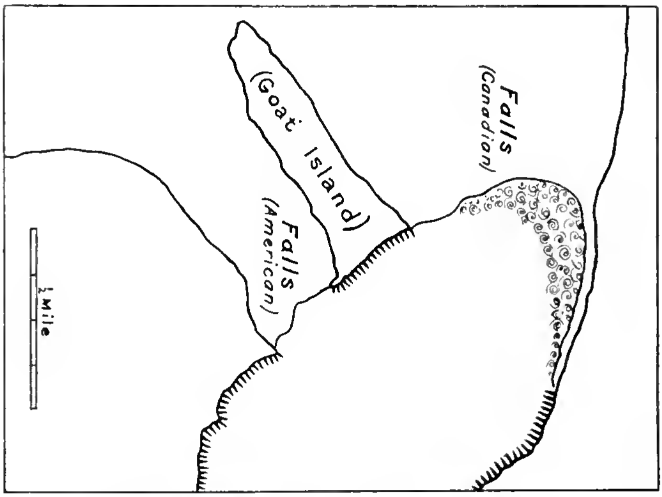


Fig. 1. Sketch Map of the Falls in 1764 (Montresor's).

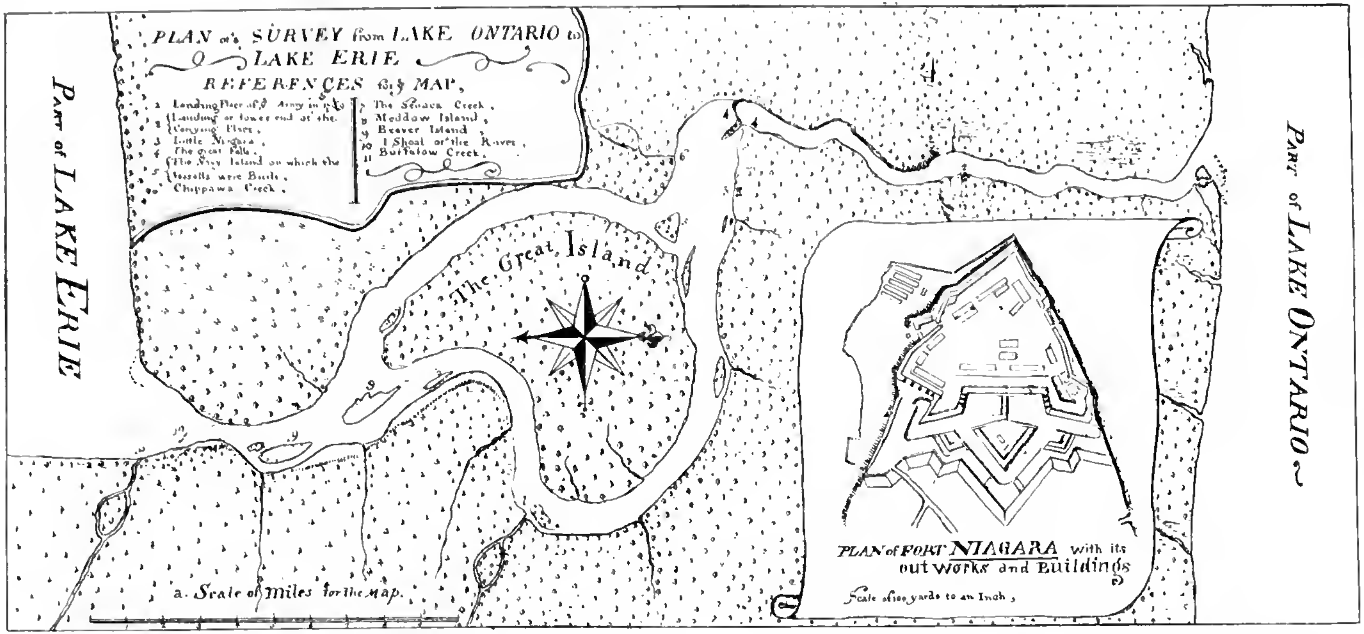
Ellicott's Survey, said to have been made about 1789, has not been found. However, his description of the falls† written in that year, is reprinted in Appendix I. Mr. Ellicott estimated the age of the falls at that early date as being about 55,440 years.‡

* 'Niagara Falls Park,' Court of Appeals for Ontario, Maps and Plans 'B' to Appeal Book, 1894. Only a few copies for use of court were printed. One may be seen in library at Osgoode Hall, another in the Public Library, Toronto; and the author possesses a copy. In this volume are also maps by Chewett, and others.

† 'Massachusetts Magazine,' July, 1790, pp. 387-8.

‡ 'Journal' of William Maclay, Appleton's, 1890.

PLATE III.



Montresor's Map of Niagara river,—1764. (Surveyed early in summer of the year. Little Fort Niagara was built in July, 1764, and Fort Erie still later in same year, but this last name is not on map completed earlier. In transcription an error on map occurs for date of landing of army, which should be 1759, not 1769).

International Boundary Survey map of 1819.—On this map the crest line of the falls was sketched in, and has been transferred to map Plate II. Difficulty was found in locating the position of both ends of the crest line, but Stegman's map was of much aid in this matter.

Other early maps.—Chewett's survey of 1831, that of Messrs. Burwell, Keating and Hawkin of 1834, and others, add to our knowledge of the early determinations of the features of the falls*.

In Stegman's map the falls are a flattened crescent. In 1819 there was a very sharp apex, in contrast with the flattened form in the survey made by Prof. James Hall.†

Hall's, U.S. Lake, Woodward's, Kibbe's and Spencer's surveys.

The first trigonometrical survey of Niagara falls, made for establishing a basis of the measurement of recession, was that of Hall in 1842. The second measurement was made by the United States Lake Survey in 1875‡. At this time another notch was beginning to form on one side of the centre, but the principal recession was at the head and towards the western side. The third survey was that of Prof. R. S. Woodward in 1886. During the last interval the recession was small where before it had been greatest. But there was an enormous enlargement of the apex which had appeared in 1875. It was now somewhat similar to the form of 1819. The survey of August S. Kibbe†† in 1890 was the most detailed. The growth of the apex of 1886 had been suspended. The great recession was on its western side as in 1875, but the apex had assumed a much more acute form. The next survey was begun in October, 1904, by myself, aided by Mr. James Goodwin, C.E., and Messrs.

* See foot note, page 20.

† 'Natural History' of New York, Vol. 4, 1842 (on reduced scale).

‡ Lake Survey chart of Niagara Falls, scale 1 to 10,000, 1875.

†† Seventh Report Com. State Res., Niagara, N.Y., 1891.

PLATE III (a)

NIAGARA FALLS. *From drawing by Pieric, 1768.*

PLATE IV.

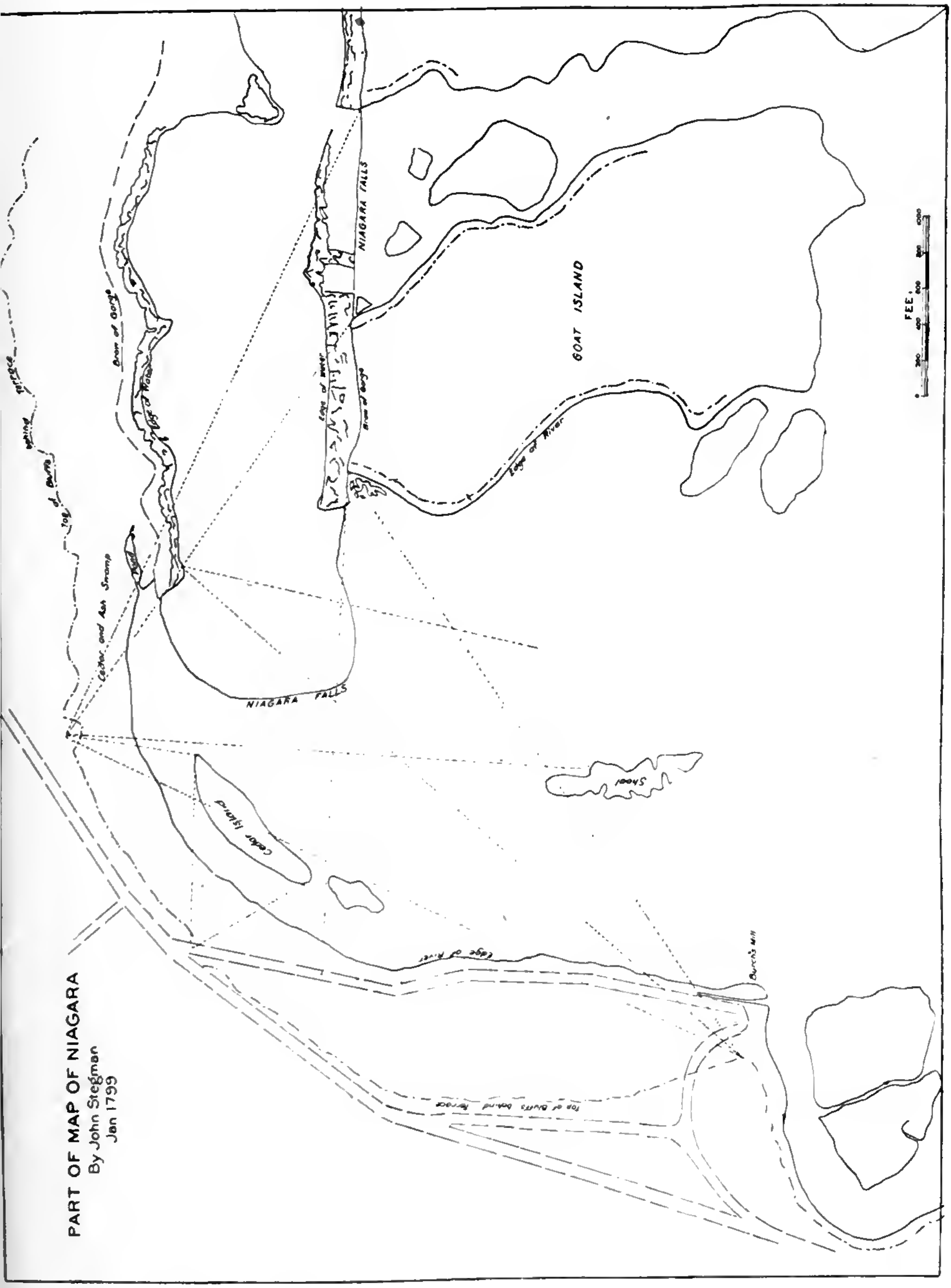
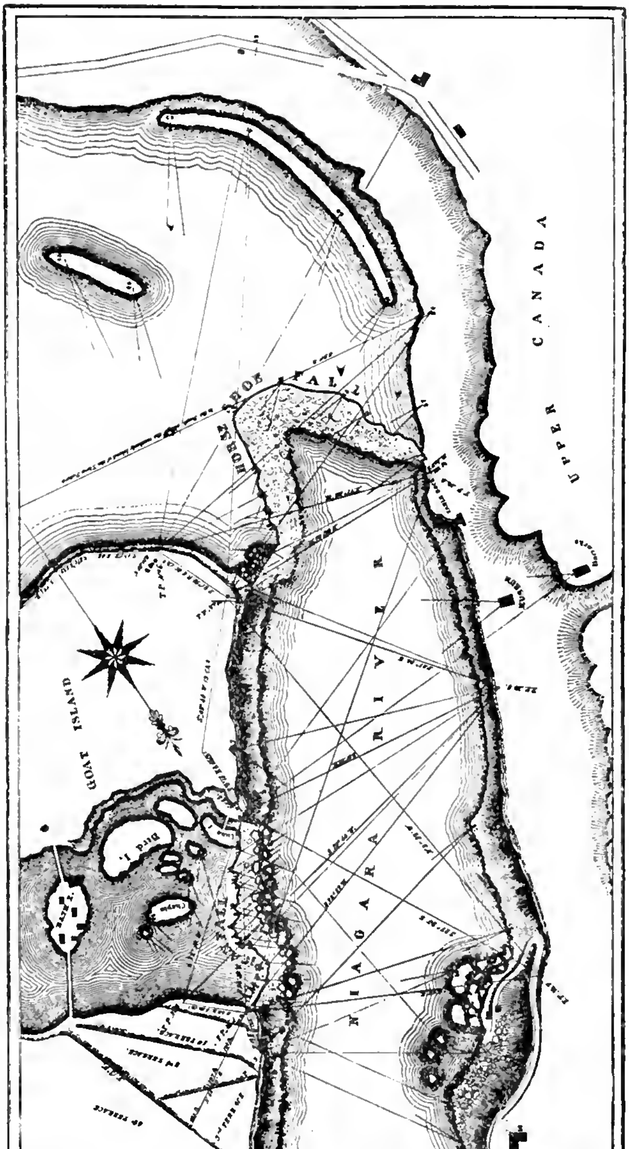

PART OF MAP OF NIAGARA
By John Stegman
Jan 1799
NIAGARA FALLS
NIAGARA FALLS
GOAT ISLAND
Cedar Island
Shoal
Edge of River
Edge of River
Brow of Gorge
Edge of Water
Cedar and Ash Swamp
Top of Bluffs behind Terrace
Burch's Mill

Plate V.



First Trigonometrical Map of Niagara falls, by Professor James Hall, 1842. (Reduced scale).

Hoyle and McPherson, Engineers of the Electrical Development Company. In August and again in November, 1905, I re-surveyed the crest-line with my own assistants; but in December a remarkable rock-fall occurred which is added in a sketch line on the map. It is also shown on Plate VII.,* which gives the effect of the water diverted from Goat island shelf. In Appendix II., reference data of the survey will be found.

These are the five surveys which mark the four periods of measured recession. The fact that another survey has been made requires some mention. After my survey was first made in October, 1904, and I had been requested to contribute the results to the Commission of the N. Y. Reservation at Niagara falls (which I could not do), I found on my return to complete the investigations of the falls in June, 1905, that the United States Geological Survey had sent out a surveyor to duplicate my survey, which was then purely a scientific question. The gentleman in charge had the opportunity of seeing my survey of October, 1904, and later I saw the result of his. Some discrepancies appeared, which led me to make the re-survey in November, 1905, which confirmed my previous observations as does also the photograph of the crest-line shown in Plate VI. However, this is an unimportant detail, as in a very few years all will be changed.

From being a scientific question only, where my survey had the priority, it became an International one when the surveyor located the International Line very much nearer the Canadian side than where it had been established by the Boundary Commission in 1819. The apex of the falls is now situated about 400 feet west of the Boundary Line, thus placing the crescent within the Canadian territory. Apart from any boundary question, a survey of the falls can only be made from the Canadian side. My two surveys of August and November, 1905, constitute them the last actually made, while that of October,

* Photographed Dec. 9, 1905.

1904, gives it priority after that of Kibbe. It was shown in the first edition of the Recession map, to accompany Summary Report of the Geological Survey of Canada for 1905, no important change having occurred in the meanwhile.

RESULTS OF SURVEYS OF THE CANADIAN FALLS.

Most writers have taken the total area of recession and divided it by the entire length of the crest line, namely:—2,215 feet in 1842, 2,950 feet in 1880, 2,535 feet in 1905.

This later shortening of the falls is due to diversion for power thus restricting the width of the river by filling in the bank so that the crest line has been reduced 415 feet. Calculations based upon the perimeter show the enlargement of the cauldron, but to measure the retreat of the cataract the area which has fallen away should be divided by the width of the cataract which has produced the gorge.

Just north of Table Rock House is a fragment of a terrace (T on map Plate II.) which marks the former bank of the river. Between the original shore of the river here, and the end of the Canadian falls at Goat island, is a natural cross-section which has escaped subsequent changes from the widening of the gorge by frost action, and undermining of the cliff. Thus the true width of the river is shown to be nearly 1,200 feet across, not including the recently uncovered rock flat at the edge of Goat island. From a point 600 to 700 feet below Table Rock House, where a fragment of the old rocky bank can be found, the full width of the gorge reaching across the same Goat island shelf is also found to be 1,200 feet. Accordingly this figure will be adopted as the mean breadth of the chasm which is due to the recession of the cataract.

RATE OF RECESSION AND CHANGE OF FORM.

The recession of the Canadian falls from 1890 to 1905 I have found to be 39,832 square feet, or nearly one acre. This represents a recession of 32·2 feet as above defined in fifteen

Plate VI.

View of Crest-line of Niagara Falls, Sept., 1906, from temporary mound near shaft of Electric Development Company.

View of Goat Island shelf, Dec. 9, 1905, showing (a) shrinkage of water, and (b) the recently exposed shelf beside the apex breaking the descent of the cataract.

NIAGARA FALLS.

From engraving of painting by Van der Lyn, 1804.

years, or annually 2·2 feet. In the meantime there has been practically no medial recession; but the remnants of the former western border of the apex have disappeared. The beginning of the new apex is suggested by a short new channel in the upper beds of rock down which the water shoots before breaking over the falls. This is illustrated in Plate VI. A second channel is also beginning to appear, but not sufficiently to affect the outline of the crest in a pronounced manner. Since the above was observed the rocks have fallen away, so that by October, 1906, a widening was in progress reducing the width of even the little V-shaped trench.

Adjacent to the apex, upon its eastern side, the manner of recession has recently taken upon itself the wedging-off of upper layers of limestone. This occurred after the instrumental measurements of November, 1905, but prior to December 9, 1905. Accordingly the cataract strikes a projecting shelf and rebounds to the abyss below. This is shown in Plate VII. The manner of rebounding was anticipated at one point in the shelf where the waters had been noticed to strike a ledge forty or fifty feet below. In October, 1906, the projecting shelf appeared to have a length of 200 feet or more. These changes seem to have affected the bursts of spray rising out of the cauldron. The elevation of the spray is scarcely greater, if as great, as the level of the wall top, while formerly the explosions were more frequent, sending up columns to a great height. Plate VII. also shows the reduced volume of water on the Goat island shelf, occasioned by the diversion of part of the water, which at the time the picture was taken was equivalent to the lowering of Lake Erie by three-quarters of a foot.

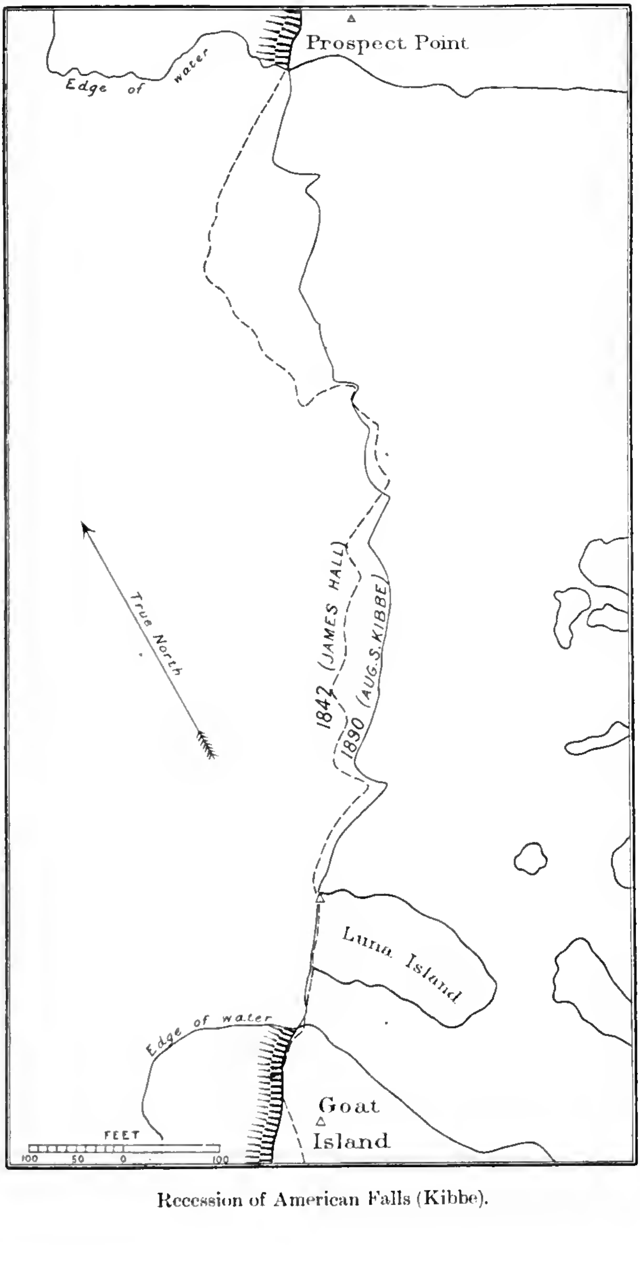
Between 1875 and 1890, 97,735 feet fell away, making an average recession of 81·44 feet, or 5·42 feet per annum. The greatest fall occurred in January, 1889, and another in 1882. Attention should be called to the fact that during this time a great apex which was beginning in 1875 was completed in 1886; after which there was a rapid widening of the chasm. Indeed, since the date just mentioned, there has been no recession of the apex, the work being expended in broadening and straightening the crest line. Going back from 1875 to 1842, 180,000 square feet above the point of Table Rock House collapsed. During that period the most notable rock-falls occurred at Table Rock in 1846, and in 1850. The area here given represents a mean recession of 150 feet, or an annual retreat of 4·54 feet.

Owing to the deep incision of the crescent, shown by the survey of 1819, the recession of Niagara falls after this date must have been very rapid as a consequence of the double face of the great natural quarry. This is shown by the representation of the form of the crest of 1819 on map (Plate II.), though it can only be considered as approximate. However, this form was soon afterward changed by the great fall of rock in 1823, which carried away a large mass of Table Rock then extending northward of that shown by Hall in 1842, though it left the platform in front of Table Rock House projecting fifty-eight feet until the rock fall of 1850. Before 1823 Table Rock extended some 600 or 800 feet to north of Table Rock House, or beyond the location of the Hennepin channel, though here it may have been as wide as it was known elsewhere.

The survey of 1819 shows a form more favourable for rapid recession than during the succeeding periods, on account of the deep indentations of the crest line, like that which appeared in 1886, and is now beginning to repeat itself in the V-shaped apex mentioned. The representations of the surveys of 1764, 1799 and 1831, while not to be relied upon, show the crest lines to have been flattened.

Between 1842 and 1904-05 there has been a disappearance of 317,642 square feet, or nearly seven and three-quarter acres, representing a total recession of 265 feet and a maximum of 285 feet, not taking into account the small superficial channel

PLATE VIII.



Recession of American Falls (Kibbe).

now appearing; but this total medial recession was reached in forty-four years without any addition in the subsequent nineteen years, during which time the work of the falls has been that of rounding the irregularities of the crest line. This represent a mean annual recession of 4·2 feet.

RECESSION OF THE AMERICAN FALLS.

The recession of Niagara Falls is almost wholly determined by the Canadian falls, as they had already receded about 2,400 feet since they parted company with the American falls at the foot of Goat island, some 600 years ago. During all this time the American falls do not seem to have retreated more than 110 feet, if so much, in excess of the unknown widening of the gorge from frost action. In 1819 the International Boundary surveys represented the incision in the crest line almost as deep as we see it to-day. On account of the inferior recession of the American cataract as compared with the Canadian one, and on account of the small amount of recession shown between the surveys of Prof. Hall in 1842 and Mr. Kibbe in 1890, a re-survey was unnecessary. (Mr. Kibbe's survey is given in Plate VIII.

The total breadth of this cataract in a straight line from Prospect point to Luna island is 855 feet, and from Luna island to Goat island is sixty feet. The amount which Mr. Kibbe found fallen between 1842 and 1890 was only 26,600 square feet, which is an average recession of twenty-nine feet in forty-eight years, or 0·60 of a foot per annum. A curious phenomenon is seen here (*See* Kibbe's map), in that the wall of the gorge appears to have receded faster than the shelf beneath the northern side of the American channel, which shelf protrudes as shown on map in Plate VIII., and in profile on Plate XV.

This at first suggests that frost action beneath the falls is very small, while at a point exposed to spray it becomes

View of both Falls of Niagara, from upper arch bridge.

exaggerated. But there seems another reason. In 1721, Charlevoix visited Niagara falls, and specially mentions several points as then jutting out. The projecting shelf may be the remains of the floor of the falls before the separation of the Canadian cataract.

SLOWER RETREAT OF THE FALLS NOW AND IN THE FUTURE.

From the measurements obtained it is seen that there has been reduction in the recession of Niagara falls during the last fifteen years, giving rise to problems which require investigation. The rock structure is variable. The channels in the river had not hitherto been studied. The discharge of the river has been reduced, to some extent artificially, and to a small extent by meteorological conditions; there has also been lowering of the lakes by scouring of the beds of their outlets. The course of the river is changing in relationship to the underlying rock formation.

The measurement of the recession of the falls is the first step in the research. The diversion of the water for power purposes already shows a pronounced lowering on the Upper rapids. The great reduction in the rate of the recession during the last fifteen years now seems to be due more to the changing course of the receding channel and character of underlying beds, than to other causes. In the immediate future there will be a large quantity of power brought into operation, and should the full capacity of the franchise be utilized the retardation of the recession from this cause must be very great. To generations 600 or 1,000 years hence this retardation may be of advantage, provided any of Niagara falls be left. On the other hand their grandeur will become a matter of history only, while at the present day they are seen by 600,000 to 1,000,000 people every year.

From the scientific point of view it will not be possible in future to determine the rate of recession in its bearing on the past age of the gorge; for a large volume of water will be so diverted from the falls as to greatly check the retreat. The present time affords the last opportunity of making the measurement of Niagara falls in even their approximately natural condition.

POSITION OF THE FALLS AT THE TIME OF FATHER HENNEPIN ESTABLISHED.

Father Hennepin first saw Niagara falls in 1678. He mentioned and illustrated a cross cascade (*See* Plate XLIII., Appendix 1), on the western side of the great cataract, without the separating rock appearing at the surface of the water. Could such a condition have obtained, and if so, where? After I had recorded a remnant of the lower margin of the river remaining just north of Table Rock House, Mr. James Wilson, who has rendered me invaluable aid throughout this work, called my attention to a depression since filled in north of Table Rock House, beyond which no lateral falls could have existed. He had the profiles made before the changes in the Park. While some of these features could still be found, the identification of the position of the falls is due jointly to his observations and my own researches.

Near Table Rock House is a slight elevation of six or seven feet above the lowest marginal bed of the river shown in the terrace T, on Map II. It is also well shown in the view, Plate X. (on opposite page). From the old profile it was found that north of this ridge at Table Rock House the low depression, already mentioned, begins to rise at a point 450 feet north of that building. About 250 feet beyond this a steeper old bank is found from fifteen to twenty feet above the floor of Hennepin channel. This point at 450 feet was the beginning of the inner edge of the old channel, the course of which was nearly parallel with the clay banks behind; consequently the present brow of the gorge follows a line at a very acute angle to the

PLATE X.

View showing ridge to right of Table Rock House and depression beyond, representing an oblique section of the channel of the Cross Falls, shown by Hennepin in 1678. (Behind the Ontario Company's Power House in gorge just below the falls.)

course of the deserted channel. That this channel did exist there is proof in the map of Stegman, made in 1799 (Plate IV.). He shows a pond 400 feet long and nowhere more than forty or fifty feet wide, connecting at its southern end with the river, but blocked at its northern extremity. This depression has a position identical with the drained one of later date. As it is known that 100 feet of the Table Rock cliff have fallen away since the time of Hall's survey, the channel just mentioned should be projected somewhat farther as on the map. Here then are the remains of a channel behind a low elevation of rock which must have produced a cross fall when the great cataract was passing this point. Thus the position of the falls at the time of Hennepin in 1678 has been closely located. Allowing for the fallen shelves of Table Rock, and carrying the crest line of the great falls outward in a curve similar to that of Hall's time, it crosses to the northern face of Goat island shelf at the same distance in front of the present falls as would be found by extending them down the gorge 950 feet in accordance with the measured rate of recession.

Had there been no measurements for determining the rate of recession, Hennepin's cross-fall carefully worked out would have furnished means for ascertaining the rate during the last 227 years (to 1905) carrying back the date 164 years before that of Hall, when no other white man than Hennepin had left a description of the 'Moccasin falls' of the Indians, of the time of Champlain.

Then there was no Goat island shelf, but the Canadian falls had the form of semi-circle without the re-entrant curve by which the sheet of water has been since lengthened to 2,950 feet in 1900, before the curtailment of 415 feet by commercial men. Accordingly the Canadian falls at this late date were much grander than in the time of Hennepin, when their diameter was only 1,200 feet, with a perimeter of 1,500 to 1,800 feet. The form was then a flattened curve with probably a slight indentation corresponding to the deep sounding at the angle of Goat island shelf.

The insular rise north of Table Rock House with the depression beyond and behind the power-house may be seen in Plate x.

NOTE 1.—Plate IIIa (page 23) is reproduced from a drawing made in 1768, by Lt. Wm. Pierie, Royal Artillery. The illustration was kindly furnished by Hon. Peter A. Porter, of Buffalo, N.Y. Next to that of Hennepin (1678) shown in Plate XLIII., this is the oldest picture of the Falls of Niagara known to me. At first glance the picture appears very much distorted, with Goat island far too small and out of proportion. However, when taken along with Kalm's description in 1750 (See Ap. 1), the picture becomes a valuable record of the recession of the falls. It shows that the eastern limb of the crescent, covered with water, reached nearly across the face of the island; also that the same rocky shelf extended much further across the gorge than now, and that the re-entrant angle of the falls was then relatively small.

NOTE 2.—Plate VIIa, page 33, is reduced to one-fifth of its full size, from an engraving of a painting by John Van der Lyn, 1804. The engraving is dedicated to the Society of Fine Arts of New York. The picture shows Table Rock, since fallen, and also the greater breadth of Goat island shelf than now. (By kindness of W. K. Vanderbilt, jr., Esq.)

CHAPTER IV.

HEIGHT OF THE FALLS AND SLOPE OF NIAGARA RIVER.

Descent of the Upper rapids.
Height of the falls.
Descent of Whirlpool rapids, Cascade at outlet of Whirlpool, and of Rapids at Foster flats.
Table of slope of Niagara river.

DESCENT OF THE UPPER RAPIDS.

The descent of the river from Lake Erie to the rapids, where a ridge extends across the river producing the First cascade, is nearly fourteen feet. From this determining barrier the Upper rapids descend in different cascades fifty-five feet to the present edge of the water, as now diverted on the Canadian side; but the descent of the rapids to the apex is considerably less, as it is situated several hundred feet farther up the side of the lately buried pre-glacial channel. This is an additional cause for the thinness of the sheet of water there. The depth of water is greatest along that part of the crest extending from the Canadian edge to the present apex. This is due to the transverse ancient Falls-Chippawa trough crossing the direction of the rapids. From Greens or First cascade the rapids extend about 2,500 feet to the apex of the falls, but the distance is much greater toward the western edge, owing to the curvature of the river and the crescent shape of the cataract.

THE HEIGHT OF THE FALLS.

The height of the falls on the Canadian side at ordinary stages is 158 feet, but on the side adjacent to Goat island it is two feet more. These heights are to the level of the river at the power-house a thousand feet to the north, where the river is a mass of surging foam. Unquestionably the water must pile up somewhat immediately at the foot of the falls so as to reduce slightly the height given. It would be difficult to determine this exactly, for at the end of the tunnel of the Electrical Development Company under the falls, some 600 feet from the edge of the river, one sees the impetuous irresistible torrent boiling and churning the ever-changing surface of the water.

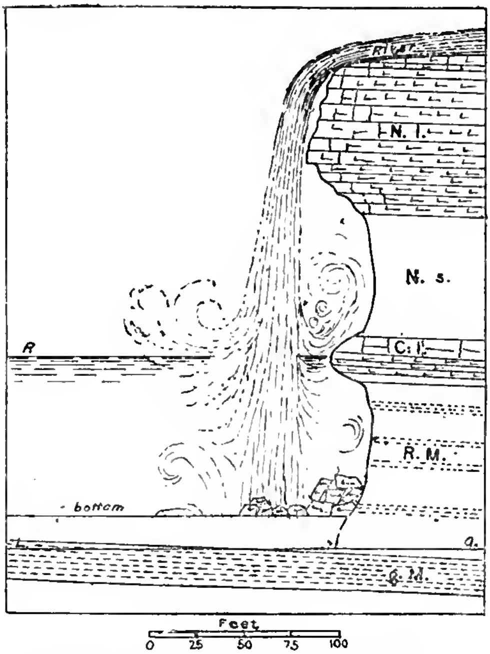


Fig. 2. Profile section of Canadian falls (horizontal and vertical scales the same) R., surface of river; L. O., surface of Lake Ontario; N. l., Niagara limestones; N. s., Niagara shale; C. l., Clinton limestone; R. M., Red Medina shale and sandstone; g. M., Gray Medina sandstones; M. s., Medina shale.

At the apex the falls descend 175 feet. This superior height is due to its being farther up the rising bed of the channel and nearer its middle. There is then, in the middle, both an increased height of the cataract and a greater volume of water, which facilitate the recession here until retarded by its protruding ledges.

Below the foaming cauldron, the surface of the river forms a stretch of comparatively smooth water, so that it is navigable for a mile and a half, to near Cantilever bridge, with a descent of a foot and a half or less. I have seen this section of the river, during the season of 1905, twelve feet above ordinary stages, when the Canadian edge of the river above the falls had risen three feet.

Turning now to the New York channel, there is a barrier in the upper part of the river similar to that described above the Canadian falls. This is situated a little below the head of Goat island, and is also the First cascade of the eastern channel. The descent of this Upper rapid is forty-five feet. The American falls at its northern edge descends 167·5 feet, while upon the margin, adjacent to Luna island, it is 169 feet. Luna island produces a third but intermediate cataract of small size, from which, before taking the final leap, the waters bound from one ledge to another.

DESCENT OF WHIRLPOOL RAPIDS, OF CASCADE AT OUTLET OF WHIRLPOOL, AND OF RAPIDS AT FOSTER FLATS.

Below the head of the Whirlpool rapids the river descends fifty-one and a half feet to the Whirlpool, and again seven feet to another smoother stretch above Foster flats. Twenty feet more of violent rapids reduce the river to the level as at the foot of Foster flats, and sixteen feet more of descent to the mouth of the gorge. These features are more fully shown in the accompanying table of the slope of the river, and also in the longitudinal section, figure 3.

The level of the river in the gorge is constantly changing, and this differing at various points. It may vary from a few inches to two or three feet—these pulsations occur irregularly, varying from a fraction of a minute to a few minutes apart.

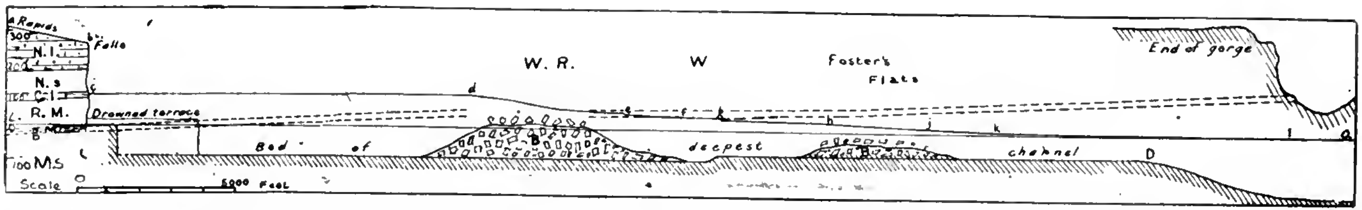


Fig. 3. Longitudinal section of the gorge showing the slope and bottom of river. Vertical distortion ten times. W., position of Whirlpool; W. R., Whirlpool rapids; L. O., level of Lake Ontario; a b c d e f g h i k l represent slope of river cutting plane of Medina gray band just above Whirlpool; D., position of drowned falls or great rapids; N. l., Niagara limestone; N. s., Niagara shale; C. l., Clinton limestone; R. M., Red Medina shale and sandstone; g. M gray Medina band; M. s. Medina shale; depth of river below Whirlpool less than above. Channels at Whirlpool and Foster rapids obstructed with blocks.

TABLE OF SLOPE OF NIAGARA RIVER.

——	Above Sea.	Above Lake Ontario.	Fall.
	Ft.	Ft.	Ft.
Lake Erie—			
At Pt. Colborne, 1860-1905	572·35	326·58	
" 1891-1905	571·65		
" 1904 (Jan.-Nov.)	572·28		
At Cleveland, 1855-1905	572·67		
" 1904 (Jan.-Nov.)	572·51		
Niagara river—			
At Bridgeburg ... Low	566·49		
" ... High	568·74		
" 1871-1895 ... Mean	567·46		
Tonawanda, N.Y., 1871-1895	564·76		
Schlosser, N.Y. ... Low	561·69		
" ... High	566·19		
" 1871-1895	562		
Chippawa, 1904 (Jan.-Nov.)	561·18*	315	
At Mean Lake level	562·50		
Head of Rapids—			
Forebay Ontario Power Company, 1904 (Jan.-Nov.)	558·75	313·7	
Rock floor at intake	552	306	
At elbow of loop behind Dufferin island	532		
Top Canadian falls, central apex, opposite Monument of Survey, T. P. 6	521±	275	
Edge of river opposite T. P. 6	520·5	274	
Edge of falls at Goat island	505·5	259	
Edge of falls on Canadian side, ordinary stage (new shore line)	504·3	258	
Edge on Canadian side, very high water	507·3		
Bench Marks, Table-Rock House	511·13	265	
Descent of Upper rapids, Canadian side from Ont. Co. forebay			55
River surface below falls at end of Electrical Development tunnel	346±	100±	
River surface 1,000 feet farther down (Ontario Power Company)	346±	100±	
River surface ... Very high	358	112	
Descent of Canadian falls, centre			175
" " western side			158
" " eastern side			160
Top of American falls, northern side	512·5	266·5	
" " southern side, at Luna island	511	265	
Descent of Upper rapids, New York channel, from level of Ont. Co. forebay at western end of Green cascade			50
Descent of American falls			167·5
River surface at Cantilever bridge, head of Whirlpool rapids	345	98·5	
River surface under Grand Trunk Railway bridge	343	96·5	
River surface eddy at foot of Whirlpool rapids proper	301	54·5	
River surface at Whirlpool	293	47	
Descent of Whirlpool rapids			51·5

* This datum appears too high.

TABLE OF SLOPE OF NIAGARA RIVER—*Continued.*

——	Above Sea.	Above Lake Ontario.	Fall.
	Ft.	Ft.	Ft.
Basin between Whirlpool and Foster flats.....	286	40	
Foot of Foster flats, in eddy...	265	19	
Cable crossing (Ontario Power Company) ..	256	10	
Mouth of gorge..................	249	3	
River at Queenston ....Low..	246·20	0·20	
" .... High.	250·71	4·7	
" 1875–1895.... . ....Mean.	247·93†	2·0	
Lake Ontario—			
At Toronto, 1855–1905.......... .. .. "	245·86		
" 1891–1905.... .... "	245·07		
Descent from Lake Erie to Lake Ontario (1891–1905)	.. ..	.,.	326·58

† Mean of 1891-1905 would be lower.

The lake levels are reduced from the mean monthly tables in the Lake Survey reports, and unpublished records of Welland canal and Toronto harbour. The datum at Niagara falls, the profile of the Niagara Falls Park and River railway, the section at the Michigan Central Railway bridge, Mr. Jennings' measurement of the rapids, levels determined by the power companies, new levels concerning the falls taken by myself, wherein the first attempt at measuring the height of their centre appears, and Mr. White's 'Altitudes in Canada' for other points of the slope of the river, have furnished the above information, which is the most precise obtainable. For convenience, unless otherwise specified, throughout this work Lake Erie will be considered as 326 feet above Lake Ontario; and Lake Ontario as 246 feet above the sea, as the elevation of 245 feet applies only since 1890.

Attention should be called to the fact that the Canadian edge of the falls has been artificially carried back about 415 feet. This should have slightly increased the height, but as the water was diverted to a deeper part of the channel the descent was not materially changed.

CHAPTER V.

NEW SOUNDINGS IN THE GORGE OF NIAGARA RIVER.

Former soundings in the river.
Position of the new soundings.
Soundings under the Canadian falls (1906, first attempted).
Soundings from the Canadian falls to near the Cantilever bridge.
Soundings and borings at Cantilever bridge.
Whirlpool rapids.
Soundings in the Whirlpool.
Soundings below the Whirlpool outlet.
Soundings below Foster flats, and just inside of gorge.
Soundings in the river beyond end of gorge.
Soundings above the Upper rapids.
Depth of water on the Upper rapids.

FORMER SOUNDINGS IN THE RIVER.

Soundings of the depth of the river had been made where navigation demanded. Thus they were taken in the river from Lake Erie to as near the rapids above the falls as the boats dare go without risk. Soundings were also made in the river below the mouth of the gorge as far up as the landing stages of Queenston and Lewiston. Since before 1750 the early settlers of the country used small boats to cross the river below the line of the American falls, as is done now by the *Maid of the Mist.* In this region soundings were also made by the United States Lake Survey, and published in 1875. Another line of soundings was made at the Michigan Central Railway bridge in 1899. These have been published by Mr. P. W. Curry* from the data furnished by the engineers of the railway. No other soundings have ever been published. The present data at the bridge were kindly furnished me by Mr. H. Ibsen, bridge engineer, of the Michigan Central railway.

The current at the Michigan Central bridge is very strong, and rendered the sounding of the depths a difficult undertaking.

* Trans. Can. Inst., Toronto, vol. VII., p. 7, 1901

It was, however, accomplished by using weights of 600 pounds made in the form of a tad-pole,† supported on an axis, so as to offer the least resistance to the current. A large sized telegraph wire was used. Three out of four of the sinkers were eventually lost. The soundings could not disclose the character of the gorge, as beneath the bottom of the river, the channel was refilled with fallen blocks.

The statement was made that no other soundings had been published, but it is said that a Mr. Nissen, in a boat called *The Fool-Killer,* made soundings in the Whirlpool and elsewhere which were not published. Soundings, however, taken in swift currents by ordinary methods are very unreliable.

POSITION OF THE NEW SOUNDINGS.

In my investigations, the question arose as to what was the character of the channel beneath the surface. Without a knowledge of the changing features I could not determine what work the river had done at the various points. No one knew the depth of the river in front of the American falls, or at any point above in the direction of the Canadian falls. All guesses as to the depth beneath the Canadian falls proved most erroneous, based as they were upon deep soundings (previous to my work), below the line of the American falls, two-thirds of a mile away, which were taken to indicate the depth of the river throughout its course, interrupted, however, by the Whirlpool rapids.

The Whirlpool is situated along the course of an ancient buried channel. Its depth was a mystery. Just beyond the outlet of the Whirlpool the channel is modern. What had been accomplished by the ancient stream, and what by the modern river? Here was another point where a knowledge of the depth of the river was necessary. Borings at the Michigan Central Railway bridge give proof as to the character of the old valley,

† See also Rept. of Chief of Engineers, U.S.A., pt. VIII., 1900.

though more or less filled as before mentioned, and the soundings at the bridge supplied information from which to draw conclusions as to the depth of the Whirlpool rapids.

Farther down the river below the Whirlpool are Foster flats. Here there had been great changes in the river. The soundings below the mouth of the Whirlpool would show what the falls had done after they had passed Foster flats, and before reaching the Whirlpool gorge. The rapids in the narrows opposite Foster flats could only be regarded as a repetition of the Whirlpool rapids on a modified scale—occupying a channel partly refilled by the extraordinary mass of fallen rock which occurs at this point. It was necessary to know the character of the channel below the flats inside the gorge and near its end, as well as just beyond.

The soundings of 1905 brought to light for the first time the nature of the floor of the gorge, leaving us still ignorant of the depth of the river under the Great Falls. To make any soundings here seemed at first impossible. Captain Carter of the *Maid of the Mist* and Mr. Wilson, with others, were ready to assist. Finally the soundings were successfully made in September, 1906, completely changing prevailing views of the recession.

Other methods than those used elsewhere had to be adopted for sounding under the falls. A buoy about 3·5 feet long pointed below and loaded at the end with twenty-seven pounds of lead, (the whole weighing fifty pounds) was made. About six inches of it floated above the surface of the water. A rod on top carried a red flag. The lower end was covered with a lead shoe to record the scratches when bottom should be struck. Within this buoy were two Tanner-Blish sounding tubes doubly protected from the jarring blows. The buoy was taken out in a tug from Fort Day through the kindness of Mr. Champagne, and placed overboard by my assistant, Mr. Walker. Different points chosen for sending off the buoy were determined by the distance from an anchored buoy. The course of the sounding buoy was observed by others. It struck the rapids of the First cascade at different trials in fifteen to twenty minutes. Another fifteen to twenty minutes carried it down the Upper rapids over the falls and some distance below, even as far as Carter cove, where it was picked up by the steamer.

SOUNDINGS UNDER THE FALLS FIRST ATTEMPTED.

As shown on the large map and in a section (figure 5), the depth of the river is eighty-four feet at a point about a thousand feet from the falls. This point is near the middle of the gorge, with a deeper channel reaching to 192 feet nearer the eastern side. As the shelf was found for some distance down the river it was thought to extend to the falls themselves, as also the deeper inner channel. The opinion as to the shelf was found to be correct, but not that as to the deeper channel. Near the centre of the apex, where the volume of water is largest, soundings under the falls reached depths of sixty-nine and seventy-two feet. From the markings on the lead shoe of the buoy it was found that the sixty-nine foot sounding struck hard rock of a boulder or fallen block, while the seventy-two foot sounding scraped on such a surface as would be shown in striking shales. On the eastern edge of the apex the buoy struck rock with such force as to damage the end, showing that soundings could not be made there, as the water was checked by ledges breaking its descent. The width between the rock wall mentioned and the point of the seventy-two foot sounding is too narrow to permit of a deep channel corresponding to that of 192 feet extending to the present site of the great channel.

The effective depth below the falls, being somewhat less than that on the shelf (which has a general depth of 80 to 100 feet extending as far as Carter cove) may be due to the boulders or fallen blocks, or the floor may rise upwards as in the case of the cove behind the Wilson ridge at Foster flats. These variations of the depth have changed our idea of the mode of recession, and of the history of the channel itself.

SOUNDINGS FROM THE CANADIAN FALLS TO NEAR CANTILEVER BRIDGE.

The soundings in this section of the gorge were made from the *Maid of the Mist,* and extended from a point in the foam as near the cataract as it was safe for the vessel to navigate, for a distance of a mile and a half, to a point near the Cantilever bridge above the Whirlpool rapids.

The soundings on the chart show extremely variable depths. This is due to a narrow and very deep channel penetrating the general floor, which floor near the falls is from 80 to 100 feet below the surface. Still there are points on it where reefs occur much nearer the surface of the water. An extensive one is found opposite the American falls, where at extremely low water great boulders may be seen near the surface. The current here is rapid, and on account of the danger in sailing over rocks a detailed exploration was not undertaken. On my large chart or map this reef is shown to extend about one-third of the way across the river, but it is supposed to reach farther than this distance from the Canadian side. Additional information is thrown upon this subject by my assistant, Mr. Claude E. Eldridge, in his sketch map of the ice-jam of March, 1906 (figure 4). In this figure, a stranded ice mass is seen about two-thirds away from the Canadian shore, nearly opposite Luna island. It is at present supposed that the floor rises so near the surface that at this point one of the great rock blocks protrudes to hold the ice. Indeed, near this point, I found a depth of only fifty-seven feet, and I have seen fallen blocks in one case standing fifty feet high, where the mass was lying on its edge. This observation is of importance as showing that the deep channel, which trenches the floor under the Goat island shelf, is very narrow. A cross section from the Goat

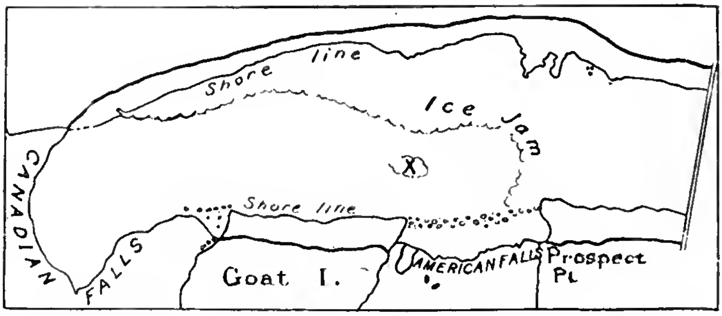


Fig. 4. Sketch of Ice-jam, March, 1906, showing stranded mass at x (C. E. Eldridge.)

island shelf is shown in figure 5. The deep channel is further illustrated in figure 6, which is a section between Carter cove and the shore below Prospect point.

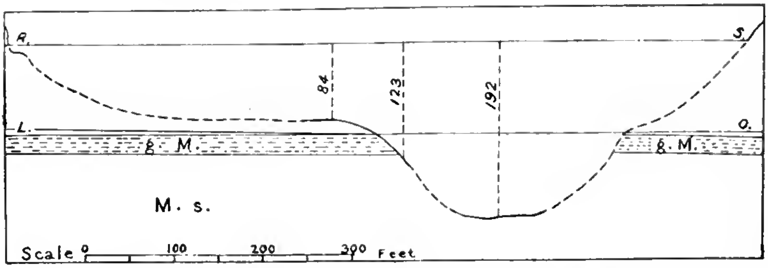


Fig. 5. Section from near Table Rock House to the Goat Island shelf. Horizontal and vertical scale the same. R. S., river surface; L. O., level of Lake Ontario; g. M., band of Medina gray sandstone; M. s., Medina shale. This legend applies to the following sections and so need not to be repeated.

The soundings above Carter cove shown in figure 6, are sufficiently far apart to leave room for a narrow channel, which

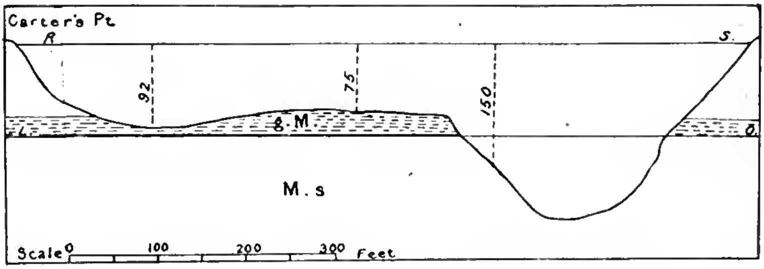


Fig. 6. Section from Carter cove to shore below Prospect point.

must exist on account of the 192-foot soundings above, and because the soundings in front of the American falls are deeper than on the shelf beyond. Until the later soundings I regarded the shelf opposite the American falls, terminating rather abruptly, as a site of a drowned falls with its floor trenched upon the eastern side by a deeper channel. Just below Carter cove (Plate XXXVIII. B, Chapter XXXIV.), the broad channel of the river is very deep, without the occurrence of the shelf as is shown in figure 7, a section at the Upper Arch bridge.

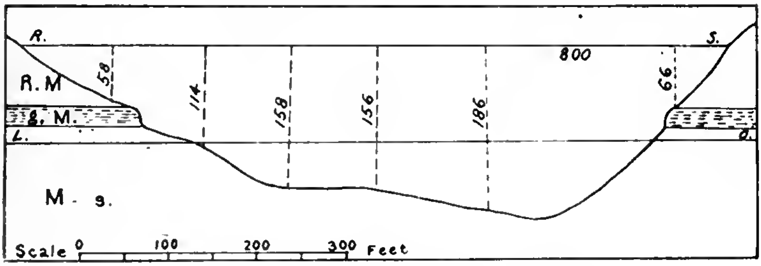


Fig. 7. Section at the Upper Arch bridge.

The discovery of the reduced depth of the river under the falls, showing its effective excavating power, confirmed the idea that in this vicinity the height of the falls had been greater but is now reduced by the backing water in the gorge.

SOUNDINGS AND BORINGS AT CANTILEVER BRIDGE.

At the east pier of the bridge, the Michigan Central railway bored with a diamond drill in 1899, to determine the character of the foundation. This is located in the upper end of the Narrows of the gorge of the Whirlpool rapids, and for the first time disclosed its character, showing a succession of clay, and boulders, mostly limestone, extending to a depth of 185 feet below the surface of the river, which is here about ninety-seven feet above Lake Ontario. (*See* Chapter XII., on Whirlpool Rapids section.) Thus it is seen that deep channel in the rocks, extending from the falls through the wider portion of the cañon, still continues at the same depth of about eighty-seven feet below lake level into the Narrows of the Whirpool rapids. The first geological uses of this section were made by Mr. P. W. Currie, who published it in the 'Transactions of the Canadian Institute.'

As may be seen in cross-section, figure 8, this buried channel is refilled so that the present greatest depth of the river is eighty-six feet.

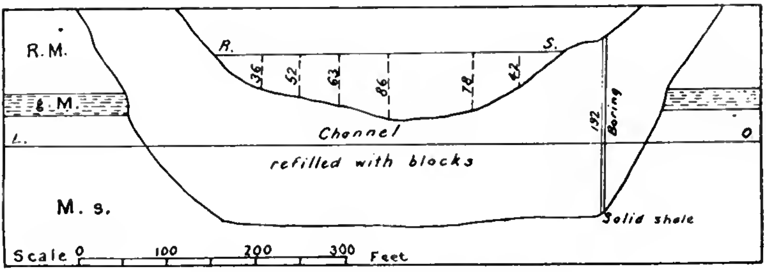


Fig. 8. Section of river at Cantilever bridge.

THE WHIRLPOOL RAPIDS.

From this point on the velocity of the current becomes greatly accelerated, as between here and the Whirlpool the descent is over fifty-one feet. While the water shoots with a smooth surface under the railway bridges, it soon becomes tempestuous in the rapids. Adjacent to them are some unusually large masses, one of which is 120 feet long, and more than 60 feet wide, and 10 feet thick. Such have fallen recently, as is shown by the entire absence of an incipient cañon where Muddy creek tumbles over the soft rock on the western side of the Narrows. It is with such blocks that the bottom of the channel is refilled, some reaching near the surface, producing boiling breakers. No ordinary rock-mass could resist these wild currents, broken and interrupted by all manner of secondary currents, and succession of tossing billows rushing down at the rate of from twenty to thirty miles an hour. Even this velocity is indeterminable on account of the constant changes, and we know nothing about the under currents. The sounding lead might be lowered into the river from a cable, but there is every probability that it would be caught in some crevice among the rocks. No useful information would be derived from ascertaining the actual depth, as the borings at the Cantilever bridge show that the channel in the rock formations had been excavated to its full depth, before the fallen blocks had obstructed the passage of the river. The maximum depth in the rapids is very much less than eighty-six feet.

In spite of their wild character some daring spirits have navigated these rapids in barrels and specially constructed boats. In one case a boat was made with water-tight compartments and a keel of iron weighing 1,600 pounds. The navigator was strapped into it in a manner that enabled him to release himself. On one of his two voyages the boat upset in spite of the heavy keel, when the man was under water for over a minute, after which the boat righted itself and he escaped. On the other voyage his boat shot nearer the Canadian bank and did not upturn. A further illustration of the caprices of the current occurred lately. Five small, flat-bottomed boats, belonging to the *Maid of the Mist,* were cut loose at the landing of that steamer by some miscreant and turned adrift. All of these went through the rapids into the Whirlpool where they were recovered. One of them was upset, two more were filled with water, while two others containing the oars went through in an almost dry condition. The first steamer, *Maid of the Mist,* shot these rapids under a full head of steam and escaped.

SOUNDINGS IN THE WHIRLPOOL.

There has been much speculation and interest as to the depth of the Whirlpool. Mr. Nissen made some soundings in it from his boat, but these are not known. He could not directly cross its course. For those who are not familiar with the Whirlpool let it be said that the waters come into it, crosses its outlet, circle round, and finally pass out almost entirely as under-currents. Thus any floating object carried into it may remain swirling round for days or even weeks. Where the upper current comes in contact with the lower, great timbers may be seen pitching down endwise, being dragged into the lower current, but most of these soon come to the surface again. There is always much material in the Whirlpool constantly floating round its course, advancing or retreating from the shore with the intermittent surging.

During the last season the quantity of logs was greatly increased by the removal of the temporary dams of the power companies, who dislodged their timbers by dynamite, thus sending them into the river. These caused the greatest difficulty in making the soundings. While a boat could sail round in the safer waters it could not cross the centre of the pool, where the currents meet, lest it be drawn endwise into the boiling vortices.

The surface of the Whirlpool is forty-seven feet above Lake Ontario. In my paper on the 'Duration of Niagara Falls,' I had made sections of the river channel, of which the Whirlpool is an arm, assuming the depth as substantially the same as the deepest soundings above. From one of these soundings I concluded that the river and Whirlpool reached a depth of from 90 to 100 feet below the level of Lake Ontario, which would indicate channel 136 to 146 feet deep. I have heard it estimated at 300 feet, but the great current is an under-tow, so that its depth was not determinable, except by measurement with specially devised appliances.

My method of sounding here at the Whirlpool, as at other points, was by swinging a cable across a stretch of water of 1,150 feet. This distance was considerably increased as it was necessary to carry the cable to a height of sixty or eighty feet above the water in order to allow for curvature, and to prevent its falling into the water lest it be caught by the drifting wood. This cable of seven strands is the same as that used on the navigational sounding instruments of Commander Tanner. It is supposed to stand a strain of 600 pounds, although at one time it was subjected to a strain of 900 pounds without breaking. But at different times it was broken. It was suspended at the two ends on movable drums, with a pulley wheel clamped to it, which was shifted to any desired point over the river. Through this wheel a second cable was operated, having at one end the sounding lead, and at the drum a recording meter. By this means the position, and by the use of hydrostatic tubes, the depth to which the sounding lead reached could be measured.

Two 'leads' were used, one of which was twelve and a half and the other thirty pounds in weight. They were made of lead with a form offering least resistance possible, yet these were beaten about and hurled against the rocks by the current as if struck with a sledge hammer. The depths were accurately determined by the Tanner-Blish tube of small bore, with rings closely ground on the inside. These tubes are twenty-four inches long with a rubber cap on their upper end. With the closed end above, one was placed in a brass tube upon supporting springs so as to relieve the jar, and this again was inserted in the sounding leads. Protected from the currents these little tubes quietly recorded the depth of the water; for the pressure compressed the air into a smaller space, and the rising water wet the inside of the tube. So far as moistened, the ground rings, which appear white when dry, become transparent and sharply mark the height to which the water has ascended. By measuring this on the proper scale the depth in fathoms is immediately read off. In a very few cases the roughness of the current dashing the leads against the rocks rendered the readings not quite certain. In such cases the readings were rejected.

When the friction brake of the drum was released, the weight was allowed to sink as rapidly as possible in order to reach bottom along the shortest line, as otherwise the current carried it down. In some cases this line when measured did not materially exceed the depth recorded in the gauges. Sometimes the lead was carried far out of position, but in every case

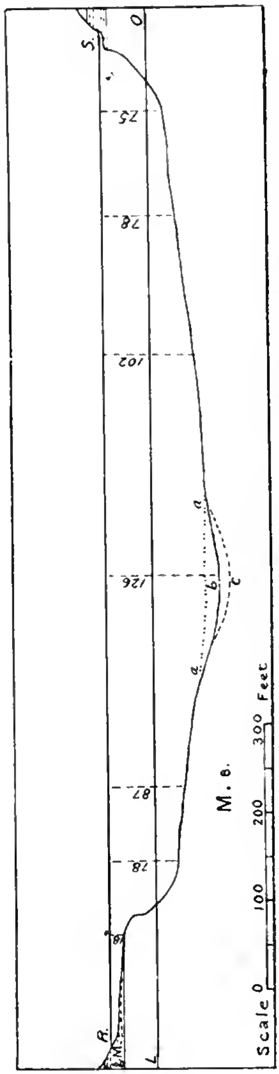


Fig. 9. Section across Whirlpool from Thompson point to Colt ravine. a—a, depth of Whirlpool along section line; b, depth 200 feet riverward; c, supposed depth of river channel on east side of Whirlpool.

the sudden striking of the bottom and releasing of tension on the cable was instantly felt at the drum, and the slack of the wire began to uncoil. Accordingly there was no doubt when the bottom was touched. In this way I made a line of soundings between Thompson point, at the outlet of the Whirlpool, and the little gorge of Colt ravine, in directions at right angles to the axis of the Whirlpool. This line is on the edge of the Whirlpool proper, where it joins the true river. (*See* the large map. The section is illustrated in figure 9 (p. 64).

Nine soundings were made along this line, besides scattered ones. Close under Thompson point a depth of seventy-five feet was obtained. This increased to 102 feet at a point about 500 feet from shore. On the western side of the Whirlpool there is a shelf submerged to a depth of only eighteen feet at a point about 150 feet from the shore. Just beyond there is a sudden deepening to seventy-eight and eighty-seven feet. In sounding under Thompson point the inward currents were moderately strong, but at the point where the depth was 102 feet there was a neutral zone, so that the sounding cable paid out only three feet more than the hydrostatic depth. Between this sounding and one of eighty-seven feet upon the other side a very remarkable result was obtained. Long after the drum was expected to have ceased uncoiling the weight and cable still continued to run out. At the surface the current did not greatly deflect the cable, but it was caught by an under current which carried it some 200 feet (beyond the point where it entered the water), into the channel of the river proper—that is to say, in the course of the river as if there had been no Whirlpool. The whole feature, however, is, generally speaking, regarded as the Whirlpool. It is an important distinction in the study of the mechanics of the river.

On account of the vortices in the currents, and the difficulty of swinging the cable, it had seemed impracticable to determine the depth at this point. The current favoured the sounding here, which reached a depth of 126 feet, indicating that the channel was deeper than the Whirlpool proper, and that the lead had reached a point seventy-nine feet below the level of Lake

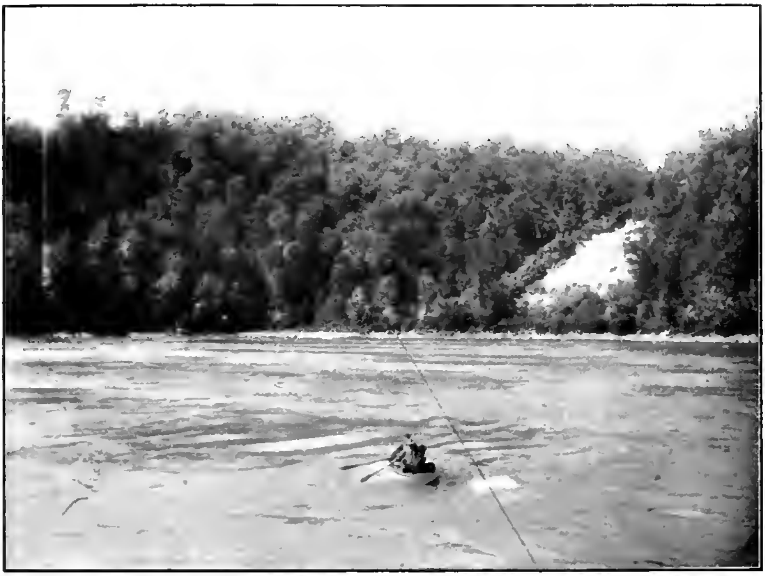
Ontario. This is a depth of only eight to fifteen feet less than that of the river above Whirlpool rapids, or that of the refilled Whirlpool rapid channel revealed at Cantilever bridge. Yet the lead had not been drawn into the deepest portion of the channel.

Putting all these things together it now appears for the first time that the forces, which excavated the Whirlpool rapids section, acted to the same depth as in the gorge above, and in the Whirlpool below the rapids. Learning, by several failures, how to sound the Whirlpool, I now think it possible to make soundings in the outer channel, but for the discovery of an additional ten feet or more in depth the result would not be commensurate with a very high cost. In the last mentioned sounding the lead was peculiarly checked by battering against numerous small points, as if it struck a ragged edge of the Medina shale, and not scraped bright by occasional heavy blows on hard limestone as had occurred elsewhere; so that it is probable that the pre-glacial channel does not exceed a depth of more than fifty feet below lake level, if so much.

Before leaving the Whirlpool it may be said that the suspension cable was carried round the pool in a boat, illustrated in Plate XI. A. Some additional soundings were also taken, which are shown on the chart, reaching from twenty-four to ninety feet in depth.

SOUNDINGS BELOW THE OUTLET OF THE WHIRLPOOL.

Below the Whirlpool outlet is a descent of about seven feet, where the waters again become smoother before passing on to the rapids at Foster flats. From a point on the Gorge Railway track I attempted to send a cable across the river in a boat, as shown in Plate XI. B, opposite this page. Attached at one end to the boat the cable was paid out from the shore; the boat reached the opposite side and was caught by an assistant, but before it could be landed the current swept it down so that



View of end of the Whirlpool, with boat carrying the cable across for sounding purposes.

View of Boat crossing the rapids, just below outlet of Whirlpool, and carrying a cable across river for sounding purposes.

the cable had to be cut in order to save the men, who were carried past the vortex of a small whirlpool to where there was imminent danger. A second attempt was made by having a long rope lying in the boat to which the cable was attached so that it paid out from both ends. But the rope proved of no advantage as it was rapidly carried down the river, and in a mysterious way some 700 or 800 feet of cable were cut out and disappeared in the river.

The river at this point had probably never been crossed before. It appeared safer to attempt the crossing from the New York to the Canadian side, but such did not prove the case. It is much better to navigate in the opposite direction, so as not to be carried down into the rapids below. A third time, on the initiative of my assistant, as the boat was on the other side from me, they attached the rope and brought it across to the New York side where the men were quickly landed and the rope made fast to a pole; when almost immediately thereafter, on the current tightening it up, it snapped like a thread. The river is 640 feet wide here, and including the time of pulling up against the side current and landing, it took just a minute and a half to make the trip. Failing to get the cable across, and before making a fourth attempt, the men who had learned the art of navigating these currents agreed to make the soundings from the boat, on which a third man now embarked. The soundings were made from each side of the river, the men going as far as they dared go, and then returning for me to make the readings. In this way I succeeded in obtaining eight soundings in this section, and in crossing at last, the lead was dropped in the middle and dragged so as to get the maximum depth, which was ninety-nine feet. At this point the river is thirty-nine to forty feet above Lake Ontario, so that the deepest part of the river is sixty feet below the level of Lake Ontario. Thus the river here is shallower than in the main channel above the mouth of the Whirlpool. On the New

York side there is a shallower shelf extending some distance from shore.

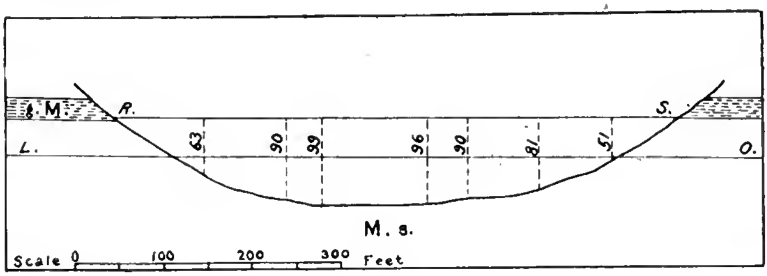


Fig. 10. Section of the river, quarter of mile below Whirlpool outlet and above Foster flats.

I must here pay tribute to the bravery and skill of James Scott and Alexander Leger in the navigation of this hitherto unexplored part of the river, for without them it would probably have still remained unknown. Fred. Scott was the third man.

SOUNDINGS BELOW FOSTER FLATS, AND JUST INSIDE THE GORGE.

It was necessary to ascertain the character of the river below Foster flats. The Ontario Power Company had succeeded in getting a cable across the river swung from the top of the gorge. This was kindly placed at my disposal by Mr. Banker Payne, the general manager. Here the river has lost much of its depth, being only sixty-three feet. This is at a level ten feet above the lake; thus making the soundings

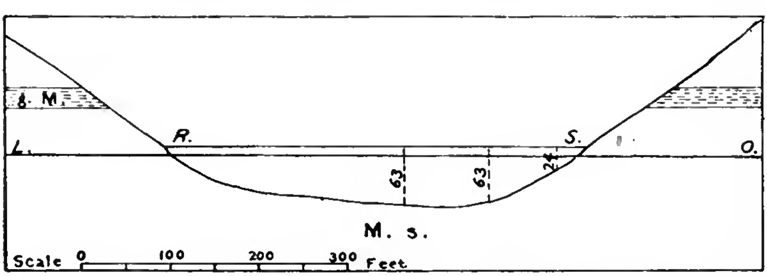


Fig. 11. Section of river below Foster flats and a mile and a-quarter within gorge.

reach to the depth of about fifty-three feet below the surface of Lake Ontario. We find the depth a little less here than in the reach between Foster flats and the outlet of the Whirlpool. But at this point, which is a mile and a quarter above the mouth of the gorge, there is still a strong current.

At a point about a half mile within the gorge and opposite the second bridge of the Gorge railway I made several soundings reaching to 138, 144 and 150 feet respectively. This deeper channel is on the New York side of the river. A quarter of a mile above this place one or two soundings were taken to a depth of 120 feet, while a few hundred yards above another one gave sixty-nine feet, though complete sections across the river were not undertaken. At these points the river cannot be more than three or four feet above Lake Ontario, and accordingly the channel here is very much deeper than in the upper part of the river.

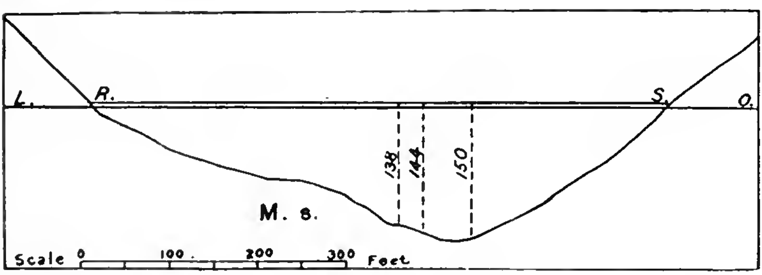


Fig. 12. Section across the river, a quarter of mile within the end of gorge.

SOUNDINGS IN THE RIVER BEYOND THE END OF THE GORGE.

At the mouth of the gorge, three soundings, less than 200 feet apart, were made from the Suspension bridge. The deepest of these was ninety-nine feet. At the time they were taken I did not suspect a deep channel both above and below the bridge. It is possible that intermediate soundings may show a continuation of the unfilled channel of 150 feet in depth. A third of a mile below the end of the gorge, at a point nearly opposite the Queenston dock the floor in the middle of the river reached ninety feet, but passing toward the New York side, a narrow gorge was found which had a great depth. Here a considerable number of leads were cast, reaching to 120, 135, 150 171 and even 183 feet, showing a remarkable chasm. The discovery of this channel was due to the suggestion of my boatman, James Humphries, who could not find bottom when fishing. The Lake Survey soundings below here reached only to a depth of ninety-six feet. This is at a level two to three feet above Lake Ontario. The current here runs at the rate of four or five miles an hour, so that it is difficult to hold a small boat in one position.

This drowned gorge is narrow, perhaps not over 200 or 300 feet in width. It has also precipitous walls, not merely shown by the rapid change of depth, but on pulling up the sounding lead on the western side, the upper part was bent over the inner tube in a manner to indicate a blow which it could only have received in being drawn up against an overhanging ledge. Again on sounding nearer the eastern side the lead was allowed to drag in order to ascertain the maximum depth. In bringing it up the weight caught so that it had to be again released by the men rowing backward. Here, at a third of a mile beyond the portal of the great Niagara gorge, is a submerged cañon trenching the outer channel. Combining the evidence here with that inside the gorge I have discovered what is now a drowned falls or rapid, formed when the lake level was 180 feet or more lower than now. This was an entirely unsuspected feature in the physics of the river (*See* figure 3, page 50), and was formed while the Niagara was small, else the inner channel would have been very much broader.

A little farther down, opposite Lewiston, the river shows a depth nowhere exceeding ninety-six feet, and below this point it is silted up so that the old channel is entirely obscured, with the modern river varying from twenty to sixty feet. In Lake Ontario, beyond the mouth of the river, the evidence of this silting is observed in the fan-shaped delta deposit covered by about twenty feet of water though at its outer edge by about sixty feet, beyond which is a sudden descent of the lake floor to

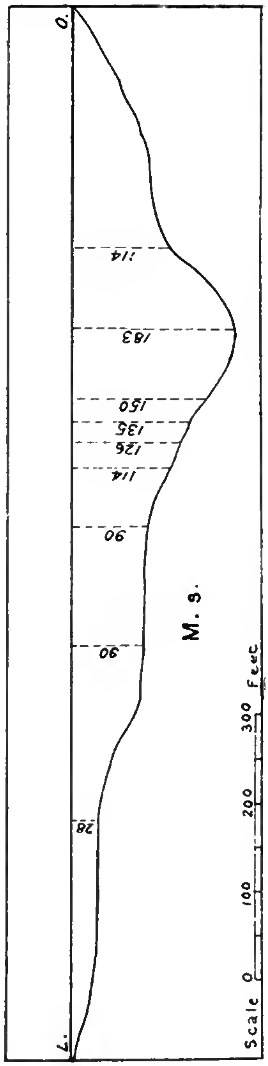


Fig. 13. Cross section of river above Queenston pier, about a third of mile beyond end of gorge, showing the very deep river channel of Niagara river before additions of Huron discharge. (Discovered 1905).

eventually 400 feet, which, however, is a pre-glacial trough, and affords no indication that the Niagara channel was once deep. Indeed it is only the deep channel described which shows that the waters of Lake Ontario were ever lower than ninety-six feet, after the birth of Niagara river, and it is even possible that it may now be partly refilled.

SOUNDINGS ABOVE UPPER RAPIDS.

The soundings in the river above the falls were made by the United States Lake Survey, and along a line between Chippawa and Grasse island the mean depths are reduced to sixteen feet. At a point below this section one sounding reached twenty-two feet. Southward the river increases to twenty feet in depth, and near the northern end of Grand island it is thirty-three feet. The depth of the upper river is extremely variable. At the International bridge, about two miles below Lake Erie, it reaches fifty-three feet, which is much below the rock barrier at the head of the rapids above Niagara falls. At a mile and a quarter above the bridge it is only seventeen to twenty-four feet.

DEPTH OF THE WATER ON THE UPPER RAPIDS.

This is determined by the ledge of rocks producing the Greens or First cascade. From the Goat island shelf outward, for a distance of 400 feet or more to the channel separating the outermost Sister island, the depth of water at present ordinary stages may be taken at an average of only one foot, as shown in Plates XII. A and B, page 77. (*See* also Plates XXXI. A and B). Above the outermost Sister island and beyond, where there is a fall of six or seven feet, Plate XXXI. B, the depth is between two and three feet and remains so for an unmeasured distance of perhaps 400 feet, beyond which the crest shows a rocky ridge with the water again reduced so that at times the ledge appears almost bare. This condition may then extend more than half way across the river, beyond which to the Canadian shore the river is much deeper, reaching perhaps in places to twelve or even fifteen feet, as, in a channel near the lower cascade, at the Electrical Development fore-bay, where crevices five feet deep were found in the floor. (*See* Plates XIII. A and B). Accordingly local, narrow, deep channels may occur.

For a distance of nearly 1,700 feet from Goat island, the mean depth now can scarcely exceed two feet, though before the artificial division, the water was probably a foot more. This shallowness on the First cascade is not so noticeable when the river is above mean stage. The average depth of the remaining distance of 1,600 feet across to the Canadian bank is assumed to be nine feet or less, while Mr. James Wilson places it at less than seven feet, although there are deeper channels, as mentioned. Except in some channels of the First cascade east of Goat island, the depth of the river does not exceed a mean value of more than three or four feet, and less than a foot and a half on the American falls. (*See* chapter XXI.) Accordingly eighty per cent of the water here is found to pass on the Canadian side of the Boundary Line.

Below the First cascade, the depth varies greatly, as seen on the shoals among the breakers.

View of Greens or First Cascade across Ontario Power Co. Forebay, (from hill above western side of Upper Rapids).

Plate XII. b.

View of First Cascade, New York Channel (from Goat Island).

View of Bed of River at Electrical Development Company's Forebay when water was drained off. The joints in the bed rock opened by solution of the limestone, leaving separated masses still in place.

PLATE XIII. B.

View of deep crevice opened in bedrock by the river currents at Electrical Development Company's Forebay.

CHAPTER VI.

ROCK STRUCTURE AFFECTING THE RECESSION OF THE FALLS.

ROCK STRUCTURE OF FLOOR OF UPPER RAPIDS, JOINTS, ETC.

From an examination of the receding crest lines one sees that the rate of recession of the Canadian falls varies according to its form—whether a regular crescent, or one indented by a V-shaped apex, these being alternating features. The structure of the rock beneath the rapids in a manner facilitates the work of the falls. The rock floor under these rapids, above the cataract, is everywhere composed of hard dolomitic limestone in beds of variable thickness—some being only a few inches thick while others are massive, especially nearer the brink of the falls. This rock floor is everywhere jointed, and these joints being opened up produce crevices as shown in Plates XIII. A and B, which are photographs of the river bed temporarily drained by the Electrical Development Company.

These opened joints give rise to the greatest erosive effect near the edge of the falls, as they expose blocks of rock to tremendous force of the current, already accelerated by a descent of fifty feet, so that the frontal masses are wedged off and further expose the lower beds to the action of the falls. Such results are well illustrated by the November fall referred to before (*See* Plate VII., page 31). At other points on Goat island shelf, the water is seen to impinge upon the separated blocks, and rebound, producing pleasing effects of the rapids.

As recognized over sixty years ago by Sir Charles Lyell, these rapids above the falls have not been produced by the Niagara river, but are a sloping surface dating back to pre-glacial times. I have discovered that the rocky floor of the rapids was formerly the site of a broad shallow pre-glacial valley, now reopened and forming the floor of Queen Victoria Park on the Canadian side, but still buried at Goat island on the New York side. For the cause of this Falls-basin, filled and heaped over with drift deposits, search for many years was made; but not until my recent investigations was it rewarded by the discovery that this basin, bounded on one side by the rocks beneath the rapids, connects with the buried valley extending southwestward around the rapids towards Chippawa village.

The rock ledge which determines the height of the river is almost horizontal on account of crossing the strike of the beds at a right angle. It is this structure which gives such uniform depth to the rim of the upper basin as shown in Plates XII. and XXXI. A and B.

The rim at the First cascade is a conspicuous feature from the head of Goat island to a point above Dufferin islands, yet upon approaching the western side it is reduced in height several feet as the rocky floor passes under the drift deposits near the islands. Indeed, had the drift ridge which formed the banks of the original Niagara river here been a little lower, the course of the channel would have been diverted half a mile or so to the west where the bed rock is lower than at Greens cascade. This change would have caused a reopening of the buried valley, with the lowering of Lake Erie and the formation of a cascade at its outlet. Then the rapids above the falls would not have been formed.

EFFECT OF FALLS-CHIPPAWA VALLEY UPON THE UPPER RAPIDS.

This Falls-Chippawa valley just referred to has left its impression upon the rapids. Looking down upon them from the

View of both falls, with the Upper Rapids descending side of a pre-glacial valley. Distribution of water dependent upon the rock-rim at the First Cascade. (From tower of Loretto Convent, July, 1905).

hills above, as shown in Plate XIV. (on page 82), one sees the smoother waters in front of the Canadian-Niagara Company's plant, and below the rapids at the Electrical Development Company's works. These waters occupy a transverse channel trending from the widest part of the Park obliquely to near the head of the present apex of the falls. The waters rushing down the river are diverted at this cross channel toward the Goat island shelf, thus piling up the greatest volume of water to accelerate the formation of the apex in advance of the receding falls. Still, as seen by the slope of the river, the increased height at the apex shows that the falls, which hitherto had been receding in the bed of the Falls-Chippawa valley, are now crossing the side of it.

This fact doubtless accounts for much of the recent reduced rate of recession, and partly for the fact that the apex has scarcely advanced in twenty years.

The greatest force of the falls has been expended along a line close to the present edge of the Goat island shelf, as is shown by the deep channel of 192 feet, which I found off Goat island, while the middle of the river below the falls is only eighty-four feet deep. The fall of rock which occurred in November, on the eastern side of the apex, caused a widening of the channel, a feature which is still continuing. After the survey of 1842 there was a great broadening of the gorge under the western part of the falls.

MODE OF RECESSION OF THE FALLS IN THE ROCK FORMATIONS.

In the near future much encroachment should be expected upon the upper part of the Goat island shelf from the undermining action of the main current of the river. On the other hand, the end of the shelf, being protected by great talus blocks, with but little water falling over it, may remain a permanent feature.

The removal of the heavy blocks of rock immediately under the bed of the river above the falls should not be overlooked, as there is a popular idea that the recession is entirely due to undermining by the removal of the soft shales beneath the limestone strata. In a certain case one bed alone has a thickness of eighteen feet, and is of the most durable character. Again, near the base of the limestone is a very massive bed projecting, on which the water is falling as already mentioned.

The Niagara limestones at the crest of the falls, have a thickness of eighty to eighty-eight feet. They form a coping over the Niagara shales with a uniform thickness of sixty feet. These last rest upon a very hard band of Clinton limestone from eight to ten feet thick, below which are the thinner layers of Clinton limestone—the whole here amounting to about twenty feet. These rocks partly pass below the surface of the river at the falls. (*See* figure 2, page 48.)

The Electrical Development Company has excavated a tunnel under the falls which terminates at a point 580 feet in a direct course from the present shore line. Its bed rests in the Clinton limestone. Here may be witnessed the imposing effects of the under side of the falling sheet of water, now plunging into the boiling cauldron. On the western side is a talus-bearing ledge, but east of the portal the ledge has been broken away. At this portal the top of the limestones is twelve feet above water level, or 112 feet above Lake Ontario. Beneath the Clinton limestones are five or six feet of Clinton shales. (*See* figure 2, page 48.)

For the character of the rock beneath the surface of the water it is necessary to examine the exposures farther down the gorge. This can easily be done, as the general characteristics are remarkably regular after allowing for the dip of the strata. The massive Clinton limestone is of a uniformly persistent character. Beneath the Clinton beds occurs a series of Medina rocks having a thickness of about eighty-five feet. These are composed mostly of red and mottled shales, having interbedded with them various layers of red and mottled sandstone, though the upper layers of sandstone may be white. These beds are very much jointed vertically, as well as laminated horizontally; and while the sandstone layers in some places reach a thickness of four feet or more, in the distance of a few yards, they are broken up into thin layers with intermediate bands of shale. (*See* illustration of such beds, Plate XXI. A, page 157.) The formation is one that is perishable, and seems to be very little strengthened by the harder layers, which are both laminated and jointed. From the top of the Clinton there is a depth of about 110 feet to the base of these more fragile rocks, which rest upon the bed of Medina gray sandstone, which has a thickness of from fourteen to twenty feet. This last is a resisting, durable band; but on account of the laminations, due to false bedding, being opened by weathering and frost action, it does not seem to be so imperishable as the massive limestones, but sufficiently so to give rise to topographic features. Beneath the gray band is the Medina red shale, with mottled layers, reaching to a depth of many hundred feet below the deepest part of Niagara river. Accordingly, when once the sandstone is removed, the excavation progresses rapidly until the force of the currents of water is counteracted by the depth of the river.

Among the first soundings which I took above the line of the American falls it appeared that the Medina gray sandstone had arrested the force of the river. Thus there was found a depth of only eighty-four feet to the terrace in the middle of the gorge, at 950 feet from the apex. By calculation, the top of the Medina sandstone band was thought to occur at about ninety feet below the surface, but this now appears to have been an ample allowance for the dip of the stratum, as in these violent currents, removing the finer débris, my sounding of eighty-four feet doubtless struck the surface of the gray band (*see* large map). Then to the side of it I found a drowned gorge 108 feet below the terrace mentioned (*see* figure 5, page 58), just outside the limit of the foaming waters near the Goat island shelf. At this point some of the officers of the ship had expected to find a shoal, as indeed I did myself.

DEPTH OF THE EXCAVATING POWER OF THE PRESENT FALLS.

In the crest line, at the time of Prof. Hall's survey, no suggestion of such a feature as this deep lateral channel appears. At first the V-shaped indentation of the crest line represented in 1819 was regarded as having some relationship with the deep channel of 192 feet. But the recent soundings under the falls, reaching to no more than seventy-two feet, show this not to have been the case. Here are unquestionably great fallen blocks, but the currents would carry the buoy off the higher points as indicated by the scratches on the lead. As the depth is only twelve to fifteen feet less than in the river farther down, this comparative shallowness seems to be due to the accumulation of rock, or to the rise of the river floor as occurs on the late river bed now exposed near the head of the cove behind Wilson terrace at Foster flats, on which floor at the end of the cove are great blocks of fallen rocks. In either case it now seems that the recession by undercutting is retarded by the talus slopes of great blocks; but it is accomplished by the sand and smaller stones in the churning cauldron, grinding off the faces of the softer shales, thus deepening the bed of the river behind and beneath the masses of fallen rock. At this depth the rock formation (figure 2, page 48) is composed of red Medina shale and mottled sandstone. There may be accumulations of twenty to thirty feet of fallen masses, among which erosion is occurring to possibly the limit of the heavy band of Medina gray sandstone; so that the excavating power of the falls may not be limited to eighty feet, but may reach 100 feet beneath the surface of the water.

The present reduction of the excavating power of the falls is in part due to the changing direction of the gorge, leaving the course of the pre-glacial channel and turning at right angles to it. This feature is confined to the recession of the last 1,000 feet, since Hennepin first saw the falls. But it does not account for the very deep channel which demands a lower level of the river, fifty feet of which is dammed by the recent rise of water at Whirlpool rapids. Here then arises the question, are the Whirlpool rapids so recent? This will be answered later.

CHAPTER VII.

ROCK STRUCTURE IN THE GORGE.

Thickness of strata and table of elevations.
Dip of strata.
Effects of dipping strata on the river.
Irregularities of capping strata of Niagara limestone.

THICKNESS OF STRATA AND TABLE OF ELEVATIONS.

Every one who has visited the falls can see that the same great ledges of rock rest at some places horizontally, and at others slightly rise or dip. The general thickness of the formations and their character was long ago one of the subjects in the study of the Niagara district, which gave the name of Niagara formation to the upper beds of limestones and shales. I believe that the first differential measurements for the purpose of determining the effect of the strata upon the recession of the falls were made by myself and appeared in 'Duration of Niagara Falls,' published in 1894,* but the measurements given were partly barometric, and not sufficiently accurate for the greater detail of the present work, which is based upon instrumental determinations.†

The measurements of the different rock formations are taken from various points so as to bring out the characteristics of the beds, as to their thickness, and their dip or slope, which have an effect upon the recession of the falls. These data are plainly expressed in the following table, which is also the basis for showing the rock formations in the various sections. They also serve for determining the direction and amount of dip of the different strata throughout the course of the Niagara gorge.

* Amer. Jour. of Sci., Vol. XLVIII., page 457, 1894.

† These determinations were made by levelling at various points by this survey and by triangulation of certain inaccessible strata in the gorge by Mr. George A. Rucker, and by measurements of different power companies.

TABLES OF ELEVATIONS OF STRATA IN NIAGARA GORGE.

Above Lake Ontario.	Mouth of Gorge, East Side.	Mouth of Gorge, West Side.	Near Devils Hole, East Side.	Above Foster flats.	Whirlpool point, East Side	North of Grand Trunk Railway bridge, East Side.	—
Surface of ground (adjacent).	333	345	340	330	345	348	326+
Surface Niagara limestone near or at edge of cañon..	322	322	312(+10)	305+25	330	291	300
Top of Niagara shale.......	309	(301)	(269)	256	(256)	236	(236)
Top Clinton thick band of limestone	248	240	209	195	195	175	175
Top Clinton shale..........	225	(218)	(189)	(176)	(176)	(155)	(155)
Top Medina series	219	(212)	(184)	(170)	(169)	(150)	(150)
Top Medina gray band sandstone........	135(+6)	133	....	71	70	63	(63)
Base of gray band and top of Medina red shale.........	(120)	111	... .	57	56	(41)	(41)

Above Lake Ontario.	Ontario Power House.	Canadian Niagara Co's. shaft near N.F.P.R. Co. house.	Canadian Niagara Co., No. 2, north end of pit.	Electrical Development Co., south end pit.	Niagara Power Co., N.Y., 4,700 feet from portal of tunnel.	Niagara Power Co. near intake.	Niagara Power Co., 8,000 feet from portal of tunnel.
Surface of ground (adjacent)	374	374	....	....	322	316	324
Surface of rock (adjacent) ..	272	264	....	....	(312)	(305)	312
Surface Niagara limestone near edge of cañon......	262	254	257	271	....	....	......
Top Niagara shale	186	175	166	160	178	164	......
Top Clinton thick band limestone..	126	116	104	(100)	118	102	......
Top Clinton shale..........	105	96	....	....	......	......	......
Top Medina series	99	90	....	....	......	......	......
Top Medina gray band sandstone.......	(15)	(5)	....	....	......	......	......
Base of gray band and top of shales	(—5)	(—15)	... .	....	......	......	......

Top of Clinton thick band at Portal of Niagara Falls Power Company 145 feet above Lake Ontario.

Figures in parentheses are interpolated; others observed.

From the mouth of gorge to Whirlpool and to Grand Trunk Railway bridge dip is 1 in 200. South 60° west.

Between Ontario Power Company's shaft (near their power house). Intake of New York Niagara Company, and Electrical Development Company's pit, the dip is 1 in 160. South 25° east.

Between Ontario Power Company's power house, the north end Canadian Niagara Company's pit and the south end Electrical Development Company's pit, the dip is 1 in 110. South 25° west.

DIP OF STRATA.

From the information given in the tables, and also shown in figured sections, it can be determined that the average dip of the strata from the mouth of the gorge to the railway bridges, or above, has a direction of south 60° west, amounting to one in two hundred or only twenty-six feet per mile. Before collecting all this information regarding the dip of the rocks it had been observed that the beds were disturbed at Hubbard point, a short distance above the railway bridges. (*See* Plate XVI. B, on page 117.) Indeed this point was a critical one in the history of the falls, as will be seen further on. From here southward there is a general average dip of one in one hundred and sixty, south 25° east, or about thirty-three feet per mile. From exposures in Victoria Park, and from the borings of the power companies, a local dip of one in one hundred and ten, south 25° west, is found. It is a thrust or twist, the axis of which crosses the gorge in the vicinity of Hubbard point, where the highest ridge of Niagara limestone is found.

From these very dry details, a reason appears for the existence of the ledge at the First cascade extending from Goat island to the Canadian shore. It has substantially a horizontal surface, except where broken near the western end by the beginning of the ancient valley passing under the adjacent drift hills. This gives rise to a broad and relatively shallow river of uniform depth. This ridge forms the First cascade and is in reality the rim of the Erie basin, over which the waters are passing out.

EFFECTS OF DIPPING STRATA ON THE RIVER.

From Niagara falls in a stretch of slightly more than two miles to the railway bridges the strata rise sixty feet, with variations in the dip of the beds owing to the change of direction of the gorge. From the railway bridges to the Whirlpool the beds are horizontal so far as one sees, but in reality they dip slightly crosswise of the river, tending to throw the deeper waters on the Canadian side. After passing this mile of distance the river turns at right angles at the mouth of the Whirlpool, and obliquely crosses the sloping beds. Below this, the gorge extends for a mile and a half to Devils Hole, in which distance the beds rise thirty-five feet. Here the cañon turns at a sharp angle and extends in a direct line to its mouth two miles below. Along this portion of the gorge the strata rise forty feet more, but at its mouth they occur about eight feet higher on the eastern side than on the western side.

The character of the rocks has, in a general way, been described when considering the formations beneath the falls. There is a remarkable regularity in the thickness and character of the different formations, except that the upper limestone grows thinner on passing northward towards the edge of the 'mountain.' On the other hand, where the upper limestone should have been thickest, its surface has been deeply denuded, forming ancient valleys, buried by drift where this has not been removed.

These valleys have had more to do with modifying the rate of recession of the falls than the variable thickness of the limestone. Beneath the capping bed of Niagara limestone there appears to be no reason for the rate of recession of the falls being modified by the changing character of the underlying beds themselves. On proceeding downward, the lower strata, in the cañon rise, besides which the slope of the river descends. Consequently, the effect upon the falls of the various harder or softer beds is determinable at any point, and really depends upon the height of the falls at any particular place, while the volume of water remains constant.

At the present time all of the Niagara and Clinton formation have been penetrated. Even beneath the falls themselves the hard bed of Clinton limestone, having a thickness of eight or nine feet in one layer, is only twelve feet above the surface of the river; but here all the underlying beds have been removed to the hard band of Medina gray sandstone which forms part of the floor of the river. This bed rises and the river descends so that it constitutes the formation at the mouth of the Whirlpool both above and below its surface. From this point on it can be seen to rise until it has a height of 133 feet above Lake Ontario at the western side of the mouth of the gorge.

Everywhere below the Whirlpool the river flows on the shaly beds of the Medina series. But this was not always the case in the history of the river, for at times both the hard Clinton limestone and the Medina gray sandstone gave rise to secondary falls which later were united with the main cataract. There is a tendency in these formations to produce three cataracts, as at DeCou falls a few miles to the west, and at Swazee beyond in the 'Short hills.' A more notable case occurs in the Genesee river, at Rochester, where there are three cataracts.

The narrows of the channel passing by Foster flats are occupied by impetuous rapids below the level of the sandstone, and these are due to obstructions by great rocks of limestones and sandstones which have fallen into the river. Even the Whirlpool rapids might be expected to owe their origin in part to the Medina band producing a cataract, but here the still deeper channel refilled by the fallen blocks of limestone has been found, showing such was not the case.

The Clinton formation beneath the sixty feet of Niagara shale is composed of about twenty feet of limestone overlying five or six feet of its own shale. As the upper member of this is generally composed of a very compact limestone in a single bed of eight or nine feet in thickness, it gives rise to a very strong topographic feature, so that everywhere in the gorge it stands out and forms a shelf receiving the crumbling débris from the overhanging beds. That this formed the floor of a secondary falls there is ample proof in the Wilson terrace and Smeaton ravine, features of so much importance that they will be considered in separate chapters.

The large terrace of Foster flats is a remnant of the old river bottom underlaid by the Medina sandstone, from which farther down the gorge the third cataract descended.

IRREGULARITIES OF CAPPING STRATA OF NIAGARA LIMESTONE.

The capping band of Niagara limestone at the outlet of the cañon is reduced to a few feet in thickness, although the formation attains 140 feet or more at the head of the rapids above the falls. As stated before, this thickness is greatly reduced in the trough adjacent to the falls in Queen Victoria Park on one side, and at Goat island on the other. This Falls-Chippawa trough was cut to a depth of sixty or eighty feet into the rock surface of the country, while in the vicinity of Hubbard point the Niagara limestones attain their greatest elevation, forming Lyell ridge transverse to the course of the river, to a height of from sixty to one hundred and ten feet above the trough mentioned. Although the ridge is high, the cañon has dissected it. Add to this irregular surface feature the buried Whirlpool-St. David valley, there might be found causes for great variation in the recession of the falls due to topographic features. Below the Whirlpool and also near the end of the cañon other transverse rocky ridges, of no considerable height, have to be crossed.

From what has been observed there is little in the structure of the rocks which would give rise to great variation in the recession of the falls during any period of constant height or moderately uniform discharge in the volume of the river. The inferior height of the falls at the mouth of the gorge should compensate for the effects of thinner hard capping rocks. The variations in the recession of Niagara, when considering the question as a whole, are dependent upon the changing volume and descent of the river, and upon the crossing of higher rock, or buried valleys, due to the ancient topography of the region.

The rock structure, as old geological formations, might be reviewed as a separate subject apart from its effect upon Niagara river. Knowing the general character of the formations in relation to the gorge, the next step is to see what work has been done by the river at different points regardless of the causes.

CHAPTER VIII.

CHARACTER OF THE GORGE EXCAVATED BY NIAGARA RIVER.

PREFACE.

Since men began to think seriously as to the origin of the gorge which is headed by the cataract of Niagara falls, few people supposed the cañon was due to other causes than excavation by the falls. Even as far back as 1789, at a time when the antiquity of the earth was almost entirely discredited, Andrew Ellicott hazarded an assumption as to the time that the falls had taken to recede from the mouth of the cañon to their site at that time.* Over half a century later a distinguished geologist attributed the formation of the gorge to faulting and fissuring of the earth's crust; but this was at a time when the theory of faults was resorted to as a cloak for ignorance.

The idea that Niagara falls had a beginning pre-supposed that the waters of Erie were once scarcely above the level of Lake Ontario, which were afterwards lowered. As far back as 1837 Mr. Thomas Roy† measured old beach lines about Lake Ontario which indicated that the water of that lake had been as high as that of Lake Erie. Later Prof. R. Bell of the Geological Survey described, at the head of Lake Ontario, the occurrence of high level beaches.‡ This was further amplified by the writer in 1882.**

*Locality cited page 20.
† In 'Geology of Canada,' 1863.
‡ In 'Geology of Canada,' 1863.
** 'Geology of Region about western end of Lake Ontario,' J. W. Spencer, Can. Nat., Vol. X., 1882.

The specific application of the former higher lake level to the reduction of the descent of the falls, and the subsequent calculations of the diminished excavating power, did not appear until in my paper, 'Duration of Niagara Falls,' which was published in 1894,* In the paper referred to I gave but little prominence to the height of the falls at their birth, but mainly considered the level of the lake when it was 135 feet higher than now. The omissions in that paper are now filled in. In anticipation it may be said that I made a survey of the river channel and marked its boundaries as they were just before the birth of the falls.

DEEP CHANNEL BEYOND THE GORGE—DROWNED RAPIDS.

The first section across Niagara river is taken at a point about 1,800 feet below the outlet of the gorge. Here the channel was not made by the cascading of the waters from the table land of the Niagara plateau, or from the Medina sandstones now protruding from the side of the escarpment, as the section is much beyond the former limit of the falls. At this point the banks of the river are from sixty to seventy-five feet in height, with higher slopes of the land immediately beyond, rising to 100 feet or more. The rock formation is Medina red shale. The breadth of the river is about 1,200 feet, and the western half of the floor deepens to ninety feet below the surface. (*See* figure 13, page 73.)

This floor is trenched by a narrow gorge reaching to 183 feet below the river surface or over 300 feet below the adjacent plain of red shales. This inner channel is from 200 to 300 feet in width. The small river flowed in this when the waters of Ontario stood at 180 feet or perhaps more, below their present level. The subsiding of the Ontario waters brought into existence a lower fall cascading from the Medina sandstone, and the now drowned rapids, below the new falls, exca-

* Am. Jour. Sci. cited before.

vated the channel to this depth. The deepest known soundings below this point did not exceed ninety-six feet, so that the discovery of this river channel is very important as proving that at a time long after the birth of the Niagara falls the descent of the river became 180 feet greater than now, or perhaps even more, as the subsequent refilling may have obscured the deepest part.

THE LOWER REACH OF THE GORGE SECTIONS.

The Niagara gorge commences at Queenston and Lewiston where the Suspension bridge crosses its outlet. At about 600 feet within it the section shown in figure 14 is situated.

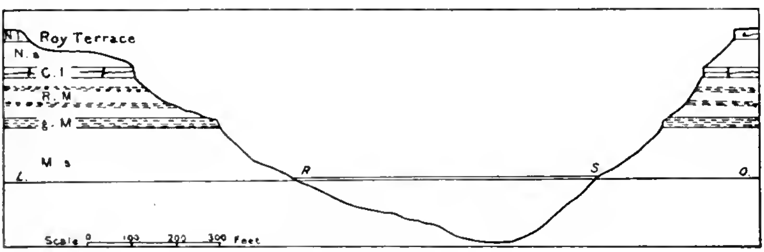


Fig. 14. Section of Niagara gorge, about 600 feet within its end. R. S., river surface; L. O., level of Lake Ontario; N. l., Niagara limestone; N.s., Niagara shale; C. l., Clinton limestone; R. M., red Medina shale and sandstone; g. M., gray Medina sandstone; M. s., Medina shale. Longitudinal and vertical scales the same.

It is 1,350 feet wide. Upon the western side is Roy terrace, under Brock's Monument, at a height of 285 feet, and having a breadth of about 300 feet, with the plateau rising to 340 or 345 feet beyond. The terrace was the river floor at the birth of Niagara falls, and its height and features will be described in Chapter xv. The river at the bridge is over 600 feet wide, and 750 feet just above. It reaches to a depth of 150 feet at a point a quarter of a mile within the cañon, while the surface of the river cannot be more than three or four feet above Lake Ontario. At Brock's Monument the ground is 329 feet above the lake. The talus slopes are 300 to 400 feet or more in width, extending from the base of the Niagara limestone (which is here only twelve feet thick, increasing to twenty or thirty feet immediately beyond the edge of the chasm), and sloping to the water's edge. At this point there are little ravines in the upper beds on each side, but these do not pass beyond the stage of gullies.

At about 7,000 feet from its mouth the cable of the Ontario Power Company crosses the river. Here the cañon is 1,145 feet wide, while the river has a breadth of only 480 feet. The ground at the edge of the gorge is 318 feet above Lake Ontario, while the depth of the river is sixty-three feet, or fifty-three feet below lake level. This first reach of the Niagara cañon extends above Niagara University in a nearly direct line for a distance of 9,000 feet from the mouth of the gorge (I—I on map), having a southward course. Here it bends sharply westward.

SMEATON RAVINE.

The occurrence of this curious feature for a long time seemed inexplicable, but it eventually proved to be a record in filling an intermediate gap in the earlier history of the Falls of Niagara. It is situated 4,000 feet above the mouth of the gorge and is a true cañon 500 feet long and 150 feet wide, bounded by the perpendicular walls of Niagara limestones, over the shales, which in the deeper part of the ravine are covered by talus, sloping downward to the band of Clinton limestone, at the depth of about 90 feet below the surface of the country. This band of limestone, however, has itself been incised for a distance of fifty feet within the brow of the gorge, but being at lower level it is actually trenched for a length of 200 feet. From the Clinton band is now a little fall of thirty-five feet with rapids below to fifty feet, or to a level of 175 feet above the lake.

At one time Smeaton ravine must have been supplied by a stream of nearly fifty feet in width. To-day there is only an intermittent supply of water such as occurs after heavy rainfalls. Even this has not been able to make a shallow channel on the rock surface exposed above.

It is shown on the map how the western bank of the original river sweeps around a lake-like expansion and just incloses Smeaton ravine. Also that above this is an insular bank of river deposits, or a bar, in mid-lake, which was sketched on the map after levelling its height, so that it may extend a little farther than shown.

When Niagara falls had receded to Smeaton ravine the stream was flowing behind the island shown on the map. This produced a cross-fall. As Niagara falls receded the expanded river channel became drained, after they had passed some distance above the island, owing to the supply of water for the cross-fall being cut off. This did not probably occur until Niagara falls had reached the angle of the cañon, some 4,000 feet above Smeaton ravine. At any rate the falls must have cut back a long distance before the cross-fall ceased to flow. The modern American falls have cut back not more than 200 feet in 600 years, since the two cataracts parted company, with seven per cent of the whole river discharge descending 167 feet, or lately somewhat more. The Smeaton fall had only a very small proportion of fifteen per cent of the present volume.

There is another side to its history. The Clinton limestone in the ravine is only trenched at its lower end. This shows that the level of the river was at about that of the limestones, else Smeaton fall would have had a greater descent, and also that the second cataract of the great river had just reached this point when the Smeaton fall ceased to exist, leaving only the deep lateral cañon. In this ravine is preserved the evidence of the height of the upper cataract during a mid-portion of the Erie stage of Niagara falls, while the terraces at the mouth of the gorge and at Foster flats record its height in the earliest and latest parts of it.

THE FOSTER REACH—DEVILS HOLE.

From the point beyond the bend of the river mentioned, Reach number 2 (II—II on map), extends to the outlet of the Whirlpool a farther distance of 8,800 feet, or 9,400 feet to the centre of the Whirlpool gorge. The Whirlpool expands so that in an oblique direction the line mentioned would extend another thousand feet in length to the opposite edge of the gorge. This addition, however, cannot be made to the medial length of the cañon.

This second Reach is perhaps the most important of any stretch along the course of the Niagara river, and at the same time is the most complex. The original Niagara river, outside of the gorge, has been surveyed by myself throughout this region. It widened out into a small lake along the upper part of Reach number 1 (*see* large map), as has been described when treating of the Smeaton ravine. So also the gorge in the second Reach broadens to even 1,750 feet and incloses Foster flats, but this is independent of the outer surface channel. Some of the changes in the physics of the river were described in a paper published in 1894.*

Devils Hole, which is a cave some five by seven feet at its outlet, in base of Niagara limestone, opens into a strongly carved lateral cañon, but smaller than Smeaton ravine.

Foster flats is 3,600 feet long, the lower end beginning at 2,300 feet above the end of Reach number 1. At its upper end is a remarkable little bay called Cripson or Fisherman Eddy. The river is reduced to a breadth of 280 feet at the narrowest part of Foster rapids, although it has a width of 900 feet immediately above.

At Foster flats there is a remnant of a terrace proper which once formed the floor of the river. Here is also Wilson terrace, where there was a cataract from the Clinton limestone. Overhanging it is Wintergreen flat, a remnant of the old floor

* 'Duration of Niagara Falls,' Am. Jour. Sci., Vol. XLVIII., p. 464, 1894.

of the Niagara river from which the main falls formerly cascaded. Figure 15 is a section at this point.

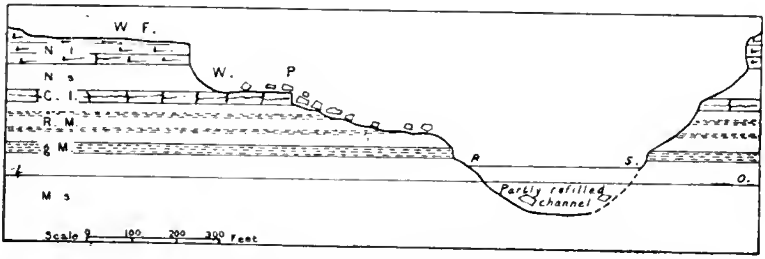


Fig. 15. Section across gorge at Foster flats. (Legend as before). W. T., Wintergreen terrace; W. P., Wilson point, a projection of the terrace of Cliton limestone, from which a ridge surmounted by huge blocks extends to the river.

In the gorge below Foster flats the soundings show a maximum depth of sixty-three feet, or fifty-three feet beneath the level of Lake Ontario. Accordingly the channel here is six feet higher than above the Foster flats. The deepest point below may not have been found, but although so nearly that of the section below the outlet of the Whirlpool, the history of the channels at the two points has been entirely different. Nor is there here a deeper inner channel. It is quite possible that the real bed of the channel in front of Foster flats has a less depth than the river above, but it is re-occupied with great blocks of fallen rocks, such as those on the bank adjacent to

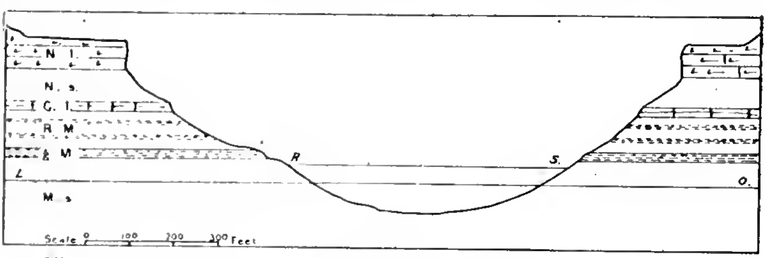


Fig. 16. Section of the gorge a quarter of mile below mouth of Whirlpool.

these narrows, at a point a short distance from their head, where the piles of detached blocks extend to the river edge, indicating sufficient material for any amount of obstruction, and now sufficient for holding the water twenty to twenty-one feet higher than below the flats (*see* figures 15 and 28). Owing to the velocity of the current among these boulders the depth of the rapids is immaterial, as it has no bearing on the excavation of this part of the cañon. Above Foster flats the elliptical form of the gorge contracts to one of uniform breadth of about 1,250 feet. The section of the cañon, between here and the Whirlpool, is given in figure 16.

WHIRLPOOL-RAPIDS REACH.

The old river banks are shown at the mouth of the Whirlpool. These, however, come under the study of those of the original river channel. At the mouth of the Whirlpool, the gorge is 900 feet in width, and here the river is only 460 feet wide. The Whirlpool gorge is widened out to the maximum breadth of 1,750 feet, while that of the cauldron at the water's edge is 1,150 feet across. The basin is an extension of a thousand feet to what would be the natural river course, now forming an eddy or tributary to the river proper, appearing as if it had been the old channel of the river itself.

The head of the Whirlpool is bounded by banks of clay, sand and gravel to a height of nearly 300 feet above its surface. (*See* Plate XI. A on page 67.) A cross section is shown in

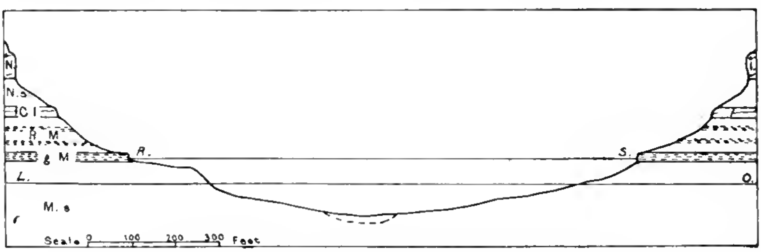


Fig. 17. Section across gorge at Whirlpool, between Thompson point and Colt ravine. Broken line shows river bottom outside this line.

figure 17, where the maximum depth of the Whirlpool is 102 feet, but in the river just outside 126 feet were found without the greatest depth of the river being measured (p. 64). This shows a depth of seventy-nine feet below lake level, or twenty feet more than that of the river between the Whirlpool outlet and head of Foster flats; and only eight to fifteen feet less than the greatest depth of the upper channel, which might also be expected here if the lead could be sunk 200 or 300 feet beyond the last point sounded. Immediately above the Whirlpool (at Sinclair point), the gorge is reduced to a breadth of 1,000 feet, but just beyond there is a short expansion to 1,200 feet. Then the gorge rapidly contracts to form the Narrows of the Whirlpool rapids. Here the chasm is reduced to 750 feet or less, while the channel itself is contracted to 350 feet in width.

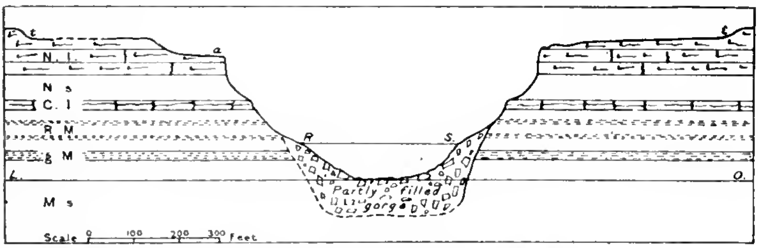


Fig. 18. Section across Whirlpool rapids at narrowest point, a third of a mile below Grand Trunk bridge. (Legend as before). t t, Original river limits; a, lower pre-glacial rock terrace.

All these features are in Reach No. 3, which extends from the end of the Whirlpool in a sweeping curve to a point 500 feet above Cantilever bridge, or for a total length of 6,200 feet from the middle of the river proper at the Whirlpool (III.-IV.). In passing upward from Reach 2 to Reach 3 the course of the gorge bends no less than 110° toward the southeast. Here is a section of the river which has attracted much attention.

More than sixty years ago Sir Charles Lyell thought that he* recognized in the Whirlpool extension of the gorge the course of an ancient Niagara river. That it was the course of an ancient stream is certain, but it was not that of a Niagara river draining the Erie basin in pre-glacial times.†

At the Cantilever bridge the river shows a maximum depth

* 'Travels in North America' (1841-42), Sir Charles Lyell. Also Proc. Geol. Soc., Lon., Vol. III., 1841, Ib., Vol. IV., 1843.

† 'Discovery of Preglacial Outlet of Lake Erie,' Proc. Amer. Phil. Soc., Phila., Vol. XIX., 1881.

of eighty-six feet and a buried channel extends to 185 feet below its surface. (*See* figure 21, Chapter XII.*.) Above the surface of the water the wall of the gorge rises 208 or 210 feet. Along this reach, while the gorge is reduced to such a narrow proportion, the old banks are strongly marked and show that the river had a breadth of 1,500 feet before the waters were concentrated within the narrow chasm. This feature proves that the constricted gorge was not entirely due to the shrinkage of the river at this point. These matters will be discused when considering the channel of the Whirlpool rapids.

THE FALLS REACH.

Above the railway bridges is another bend in the course of the gorge where it turns 40° westward, and extends thence in a direct course to the crest of the Canadian falls. It suddenly widens out from the end of Reach 3 (here 840 feet broad) to an average breadth of 1,300 feet. This width is, however, varied slightly, being reduced to 1,200 feet at Hubbard point, and increased somewhat opposite the American falls, as would be expected. Above the American falls it is again reduced so that the gorge has a breadth of 1,200 feet between Goat island and the western walls below the line of the Canadian falls. This is Reach No. 4 (above IV. on map), and has a length of 12,000 feet, but it bends towards the apex so that the length may be slightly increased. Thus the length of the cañon is about 36,600 feet from the Queenston Suspension bridge or about 36,200 feet from the brow of the escarpment.

After passing the end of Reach 3 the sudden widening of the gorge indicates a marked change in the history of the falls. Besides the uniform breadth the greatest depth to near their site is constant. This suggests that there was no material variation in the effective height of the falls in this portion of

* See Chapter XII. on Whirlpool rapids, showing section of boring.

the cañon. At Swift Drift point, 3,700 feet, and Hubbard point, 4,500 feet above Cantilever bridge, the gorge is slightly narrowed to less than 1,100 feet with a basin 200 feet wider between these points. Here the rocks are distorted, but fragments of the old river banks show that the river maintained the full breadth of 1,300 feet, although the gorge itself is somewhat narrower.

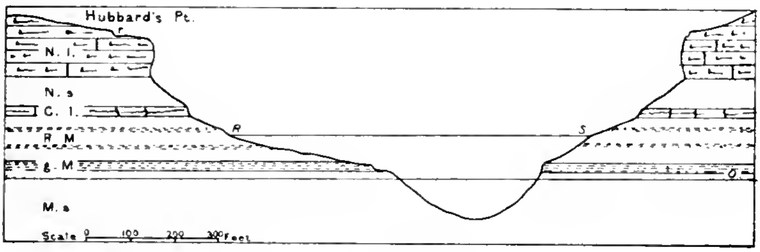


Fig. 19. Section across Gorge at Hubbard point. (Legend as before.) r., Remnant of terrace once a pre-glacial floor of the trough through Lyell ridge.

It would seem that there has been an average uniform recession of the falls throughout Reach No. 4 until approaching their present site. The surface of the river is about 100 feet above Lake Ontario, and the depth from 186 to 192 feet. The river itself has a breadth varying from 750 to 1,000 feet; in front of Hubbard point it is nearly 800 feet, though at Swift Drift point it is scarcely more than 500 feet wide. These are important features in considering the origin of the Whirlpool rapids gorge, and also the Falls-Chippawa trough.

At this point, also, it is found that the river crosses the highest ridge of limestone occurring anywhere along its course. The width of the cañon in front of the American falls reaches its maximum of 1,600 feet, which is due to frost action, and the broadening effects of the American channel. (*See* figure 6, page 58.) Above the Upper Arch bridge, near Carter cove, (*see* Plate XXXVIII. B) is the end of the drowned terrace which extends thence to the falls (*see* figures 3, 4 and 6), though incised by a very deep channel.

The last cross-section of the gorge (figure 20), is one from Goat island, over the Goat island shelf, and extends to near Table Rock. This shows the terraced river bottom with the deep channel, near the eastern side of the gorge. (*See* also longitudinal section, figure 3, page 50.)

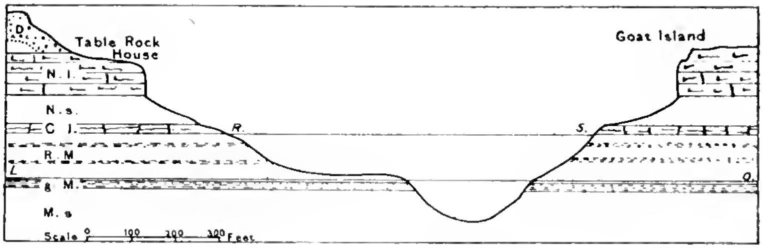


Fig. 20. Section across gorge from Table Rock House to Goat Island shelf, showing submerged terrace and deep channel; also, rock floor of Falls-Chippawa basin at Table Rock House.

This deep channel opens out into the wider one below the American falls and Carter cove, after passing the upper submerged terrace. The height of the rock wall here is about 160 feet above the river, while it is nearly 220 feet at Hubbard point, and the rock surface on Lyell ridge a short distance back from the chasm rises to 270 feet.

CHAPTER IX.

ORIGINAL BANKS AND BED OF NIAGARA RIVER.

Outlet of Lake Erie and the Upper reach of Niagara river.
Cañon reach above and below the Whirlpool.
From Smeaton ravine to end of cañon.
From mouth of gorge to Lake Ontario.

OUTLET OF LAKE ERIE AND UPPER REACH OF RIVER.

The character of the river above the falls has changed very little since the separation of the waters of Lake Ontario from those of Erie, when Niagara became an established river. Although this is the case the river is not such as should be expected from the features of the underlying rock surfaces. It is found that its depth reaches fifty-three feet, at a point two miles below the outlet of Lake Erie. This depth is reduced to from seventeen to twenty-four feet through a ridge of Corniferous limestone, which rises sixty feet on both sides of the river, half a mile away from its present banks, while some miles westward the rocky rim on the northern side of Lake Erie is very much lower. The Corniferous ridges had been dissected long before the birth of the river, as is further shown beneath the International bridge where one of the piers rests upon a glaciated surface at the depth of forty-five feet. The river at this point is 1,850 feet across, but at a recent stage, when five to twelve feet higher, it was nearly double that breadth, as shown by the now raised flats at the town of Fort Erie. This terrace belongs to the history of the river when the stream was first coursing across the rolling country with poorly defined banks, flooding the estuaries and leaving a suspicion of terraces at many points at about 340 feet above Lake Ontario.

From Fort Erie (12,000 feet from the lake), the distance to the rim above the Upper rapids along the western channel is seventeen miles, while along the eastern channel it is somewhat farther. Its breadth varies from 2,000 to 3,000 feet, and while its depth is rendered irregular by bars, the soundings show it to be thirty-three feet or more at points throughout the southern half of its course, although it is reduced to some twenty feet among the bars which cross the river at the mouth of the Chippawa creek. The country is a low plain, much of it rising no more than from ten to twenty feet above the lake. Indeed, if the surface of the river did not descend to nearly fourteen feet below lake level, at the head of the Upper rapids, it would turn the creeks at Chippawa and Tonawanda, with their tributaries and other low places, into extensive estuaries. This low country is slightly modified at a point from two to three miles south of the Upper rapids where the land rises nearly fifty feet above it, or forty feet above the lake. Similarly elevated ground appears on Grand island.

There must have been a slight depression in this ridge, like that in the Corniferous belt near Lake Erie, else the waters would have been diverted to a more western course. Below Grand and Navy islands the two arms of the river unite, and although it somewhat widens it is again reduced just below Chippawa. A greater breadth formerly obtained when the waters passed over the projecting flat point now forming the site of Niagara Falls, New York.

The rocky barrier obstructing the upper Niagara basin is shown by the line of Greens or First cascade of the Upper rapids, (*see* Plate XII. B, on page 77). The now uncovered rock floor composed of Niagara limestone, as seen at the upper end of Goat island, is 313 feet above Lake Ontario, while at the lower end of the island the underlying rock surface is only 265 feet. The floor of the river at the Ontario Company's intake, in front of Dufferin islands, is at 306 feet. Where the river sends a branch round Dufferin islands the rock passes under the drift, which at the southernmost bridge is 299 feet, while at the elbows behind the island, the slope descends to 286 feet with the buried valley still further declining westward under the drift, as shown by borings beyond the river under the floor of the Park adjacent. Throughout this region there are heavy hills of drift which rise above the former river banks behind Victoria Park to a height of from 375 feet to 400 feet above Lake Ontario, while about a mile distant in Lundys Lane a point of 465 feet is attained.

To the east of the river behind the point of land occupied by the city of Niagara Falls the altitude reaches 360 feet or more while on the lower plains there are some pronounced hilly elevations. These form a third ridge across the course of the original river, in which there was an ancient depression that permitted the first stream of Niagara water to flow from Lake Erie to the lower basin. It must have been less than thirty-six feet above Lake Erie else the waters of the upper lake would have coursed through a channel in the vicinity of Welland canal. The difference of altitude at the two localities was perhaps even less than five feet, but this slight amount caused the Niagara river to have its present location, in place of the outlet of Erie being situated near the Welland canal.

CANON REACH ABOVE AND BELOW THE WHIRLPOOL.

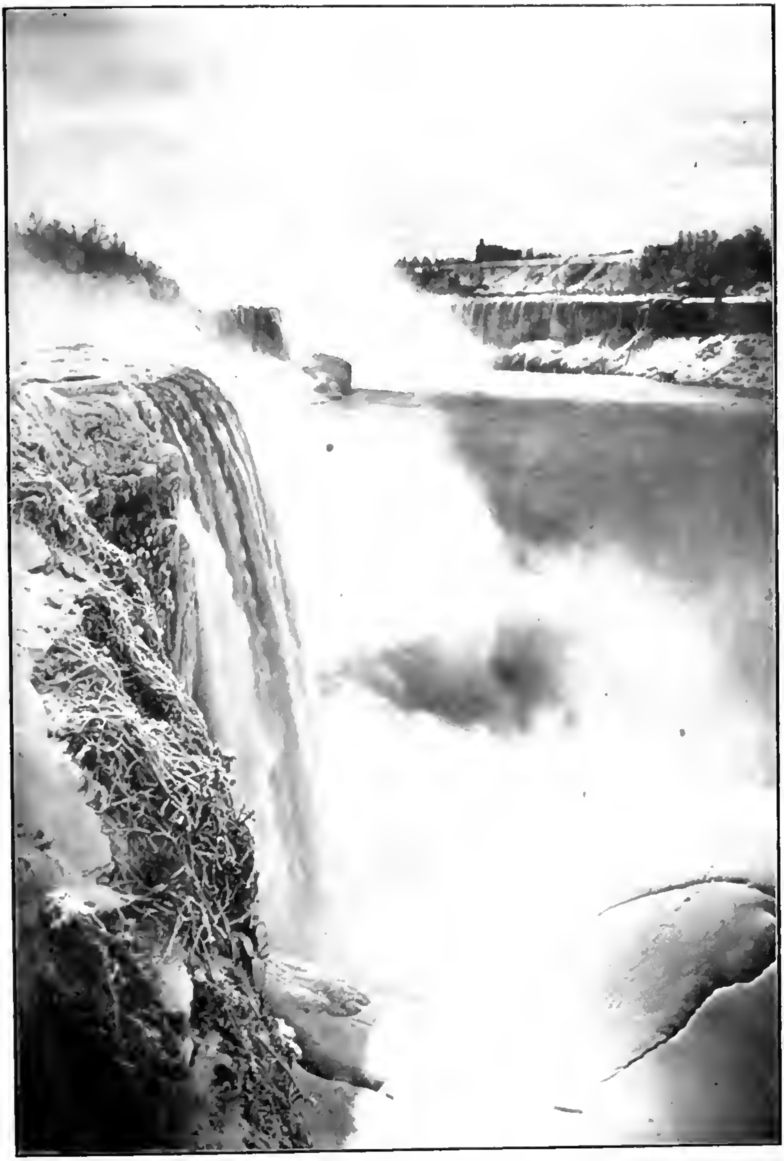
The feature of the Upper reach of the river, with a breadth of more than a mile, trending almost westward, abruptly terminating at Goat island and passing over the side of a narrow transverse valley at right angles to it shows a remarkable change in the physical conditions. Here at the end of the upper broad valley the American falls plunge over the eastern side of the gorge, on one side of the precipitous walls in front of Goat island, on the other the Canadian falls, in front of the widest angle of Victoria Park.

This view is represented in the panorama on Plate XIV. (on page 81). In it is also seen the eastern bank of the Falls-Chippawa valley, which has been uncovered by the rapids crossing it. The smoother water shows the deepest part of the preglacial channel. The apex of the falls is now cutting back and across the old bank, and this tends to reduce the recession of Niagara falls as mentioned on page 41. So long ago as 1841 Sir Charles Lyell attributed the rapids to ancient topography buried beneath the drift.

The modern Niagara river, after establishing its course along the Upper reach, swung round over the buried valley, whence its general course was determined by the low surface depressions, irrespective of the materials which formed its bed. So long as its lower extension was blocked by a rocky barrier the buried valley produced no effect upon the features of the river. The floor of its margin had a level now represented by an elevation of 316 above the lake, as may be seen adjacent to the intake of the Niagara Power Company at Niagara Falls, but the surface of Lake Erie is now fourteen feet higher than Greens or First Cascade.

This old terrace floor passes round an island in the southern part of the town, where there is a sharply cut terrace between it and the river, opposite Goat island. Through the town this old shore line has been obliterated by artificial grading, but it reappears beyond, and forms a distinctive feature of a terrace, where the Gorge Railway car shed is located, as shown on map, diagonally across from Hubbard point. (*See* also Plate XVI. B.) The banks on this eastern side were not generally high.

On Goat island a deposit of river gravel with fluviatile shells occurs near its southeastern quarter having now the same level of 316 feet. These deposits were described by Prof. James Hall and Sir Charles Lyell more than sixty years ago. Prof. Hall had also measured the terraces at this locality and compared them with others at Whirlpool point. The terraces at



Profile view of American Falls and Goat Island shelf, with terrace on Canadian side. (Winter scene).

lower levels did not belong to the original river banks, but marked the lowering of the waters at more recent date.

Adjacent to the falls on the Canadian shore were, at that time, high banks of the old river rising to 380 feet above Lake Ontario, back of which the country rose in Lundys Lane, a mile distant, to a point 465 feet above same datum. The terraces on the New York side have been mentioned first, for the reason that here is an extensive floor of the original river bed, while on the Canadian side, in the subsequent lowering of the waters and the removal of the material from the buried valley, the river has undermined the old banks, and all higher terraces have been washed down to the present river level in the vicinity of Niagara falls, to a depth of sixty feet below Hubbard point. Thus it is that the high bluffs bounding Victoria Park have a height of from 100 to 120 feet. These bluffs are well shown in Plate XV. (on preceding page), which is a winter scene.

From the northern part of the Park reservation the different terraces begin to be recognizable, and continue until they reach the vicinity of Hubbard point, where they are abruptly cut off by the encroachment of the western wall of the gorge. Here at Hubbard point is a remnant of the old floor projecting outside of the bank of the gorge for a breadth of 150 feet, and a length somewhat greater. This is shown on Plate XVI. A. Behind this fragment of the old floor, whose inner margin is at an elevation of 318 feet, there is a steep bank of a few feet. Back of this the hills of limestone rise in a short distance to a height of 370 feet at the circle in Wesley Park, where they are covered by only two or three feet of soil. On the opposite side the land has an equal height back of the brewery, Plate XVI. B, and at the site of the new post office it is covered by only a few feet of earth. Here the river crosses the highest limestone ridge in the whole Niagara district; so high that the river could never have flowed by this course had the ridge not been much lowered by the pre-glacial depression, where at Hubbard point the old glaciated surface was found. (*See* Plate XVI. A, also map.) It was this barrier at Hubbard point which determined the height and the level of the river until after the falls had receded past it, when the loose earth was rapidly removed from the Falls-Chippawa basin to a depth of sixty feet. The lower terraces are features of the subsequent history of the river.

The gorge at Hubbard point is reduced to a breadth of 1,150 feet and to 1,050 feet at Swift Drift point to the north. There is no evidence that the lower pre-glacial valley to the south cut to a lower level at the narrows of Hubbard point. Moreover, from Hubbard point southward the boundaries of the old river rapidly diverge, showing that the pre-glacial valley had a southward and not northward direction. (*See* Plate XXII., Chapter XIII.)

Below Hubbard point, for a half mile or more, the terraces on both sides are cut off, as the modern cañon is wider than the original valley. (*See* large map.) Just south of Cantilever bridge the gorge rapidly contracts and at the same time the old river banks grow wider apart. This feature is shown on map and in figure 18 (page 105), which is a cross-section about 1,700 feet north of the Grand Trunk Railway bridge, where also the lower terraces appear. The great terrace at this locality is strongly marked as shown on the large map and on Plate XX.

The bank has been deeply carved out by the currents, thus leaving a steep bluff. The inner edge of the floor has a height of 316 feet, with bluffs behind over twenty feet higher. Its distance from the cañon edge is 530 to 560 feet, but this also includes the lower terrace from 75 to 125 feet wide, the rock floor of which is only 280 feet above Lake Ontario. The upper terrace, upon reaching the vicinity of the cove between the Whirlpool rapids and the Whirlpool, has been cut off by the receding walls of the gorge.

On the eastern side of the river this terrace is equally well

PLATE XVI. A.

View of Hubbard Point (terrace in front of house) at *col* between pre-glacial valleys.

PLATE XVI. B.

View opposite Hubbard Point (with corresponding terrace in front of point.)

defined by the very sharp banks below the old Mount Eagle hotel (*see* Plate XXI. B), which have a height of more than twenty feet above the old floor, with an altitude of 316 feet at its inner edge. Here also are two lower terraces nearer the river, belonging to a later epoch, but the main terrace mentioned extends from the gorge for a breadth of 510 feet. This, added to the width of the gorge, about 750 feet, and that of the terrace floor on the western side, shows that the original river reached, at this point, 1,780 feet in width; but as this section is somewhat oblique the general breadth is about 1,500 feet. While the western bank has been abruptly cut off at the Whirlpool, the eastern one is still intact, but swings round so that the remains of the old floor have a breadth outside of the present gorge of only 150 feet at Whirlpool point. It continues for a distance of a few hundred yards beyond the outlet of the Whirlpool, where it also is truncated at the edge of the gorge.

At the point mentioned above the Whirlpool, where the terrace is abruptly terminated, the old river had a breadth reduced to 1,250 feet. Its bed was composed of drift which filled the buried Whirlpool gorge, on the other side of which the terrace reappears, showing a river breadth of 1,500 feet. At a quarter of a mile beyond Thompson point the banks show the breadth of the old channel to have been 1,400 feet and just beyond the terraces are suddenly cut off. At Thompson point, as well as at Whirlpool point opposite, the lower terraces coalesce, and are not so distinctly separable as above this locality. Indeed, from below the Whirlpool outlet to the mouth of the gorge no lower terraces remain like those above. The absence is striking.

Below the Whirlpool, where the terraces on the Canadian side end, there is a rock ridge which was crossed by the Niagara river when it commenced flowing. It surface elevation is about 330 feet. However, a few hundred yards beyond, a remnant of the old floor is again seen at Wintergreen flat, where the inner edge has an elevation of 316 feet, bounded by a bank fourteen feet higher. This flat, which was the bottom of the old river, has, at one place, a breadth of 500 feet, with its floor declining from 312 to 306 feet. This shows that the depth of the river was considerable. Opposite here, on the New York side, the encroachments of the gorge have removed the river bank.

A short distance below Wintergreen flat the floor of the old river re-appears in a lake-like expansion, with an islet covered with river deposits of rounded and flat stones in loamy soil. Here its edge is not always sharply defined, as the washings of the hillside and the cultivation of the soil have obscured the original water line. These deposits up to an elevation of 324 feet approximately represent the old water surface. Their elevation at the edge of the cañon is 318 feet above Lake Ontario.

In some places the river deposit has a considerable depth. It is ten feet deep where the Ontario Power Company's cables cross the river. North of Foster flats the river expanded into a little lake with a breadth of about 3,800 feet. The more sluggish character of the currents, and the smaller depth of water here, abundantly accounts for the less sharply defined western bank, while on the eastern side, which is now the outside of the bend of the river, from Devils Hole to beyond the cable crossing of the Ontario Power Company, the bank is more sharply defined back of the terrace floor which is from 100 to 250 feet wide.

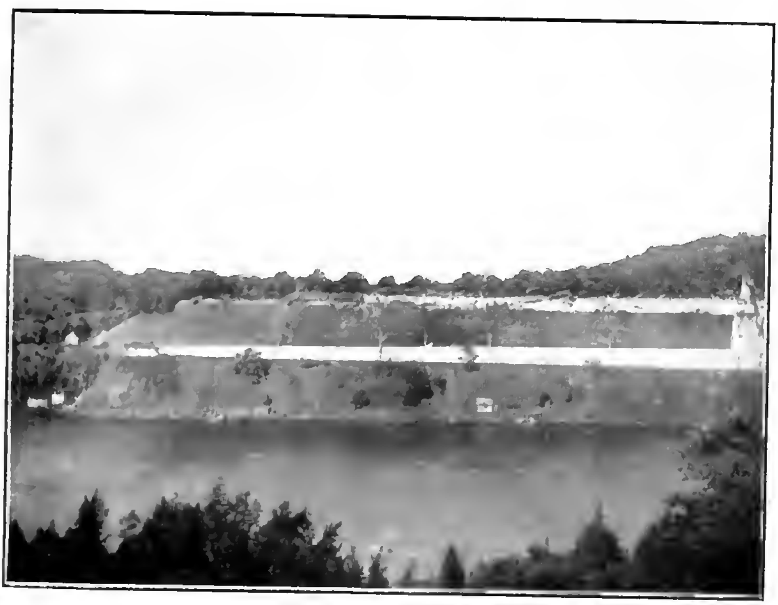
FROM SMEATON RAVINE TO THE END OF CAÑON.

Just beyond Smeaton ravine the old river banks contract to the brink of the gorge on both sides, where they are again truncated. Here the river cuts through a rock ridge with an altitude of about 330 feet, covered with a clay floor rising

PLATE XVII. A.

View of outlet of gorge cutting the Niagara escarpment (about 330 feet high with Brock's Monument, to the right).

PLATE XVII. B.



View of Iroquois terrace, at end of gorge, east side, here cut out of Medina sandstone.

beyond to 340 or 350 feet. This was the barrier which made the expansion or lagoon north of Foster flats. It was crossed by the river for a distance of 3,000 feet.

Beyond this last ridge the distance to the end of the gorge is 200 yards with the delta deposit at the end. (*See* Plate XVII. A.) Here the old river floor was about 322 feet higher than the present surface of Lake Ontario.

FROM THE MOUTH OF GORGE TO LAKE ONTARIO.

At the birth of Niagara falls there was no river below the escarpment, for the water cascaded directly into Lake Ontario. As the waters receded the river cut across the Medina shale for two miles. Beyond that point it flowed over drift clays and other material, exposing in places the Medina shale. At its lowest level the waters in the Ontario basin receded many miles from the present shore, when the deep channel at Queenston was excavated. (*See* Plate XXIX., Chapter XV.)

From this account of the river banks it will be seen that the early Niagara river can be traced from Lake Erie to what was then the margin of the lower lake, now Lake Ontario, at substantially a level which indicated but little slope of its surface; much less than that of the present upper reach. At first it may have been little more than a strait with ill-defined margins.

CHAPTER X.

WHIRLPOOL-ST. DAVID BURIED VALLEY.

SPECULATION AS TO ITS ORIGIN.

In treating of the features of the Niagara cañon the extension of it now occupied by the Whirlpool has been partly described (page 104). The lateral walls are precipitous, the same as the other portions of the gorge, but at its head only drift banks are seen. (*See* Plate XI. A, on page 67.) The heavy band of Medina gray sandstone, (*see* Plate XXVII. B), having a thickness of about twenty feet, reaches to ten or fifteen feet above the surface of the pool. At the head of the Whirlpool the gray band is absent for a breadth of 1,000 feet, while at a point between the Whirlpool and the Whirlpool eddy, it is removed for less than 600 feet.

As late as 1841 Prof. James Hall* had regarded the cove of the Whirlpool as an eddy in the course of the river, but in that year Sir Charles Lyell first recognized it as a part of a buried valley, and connected it with the embayment in the escarpment of Saint David,† supposing it to have been the course of a pre-glacial Niagara river. In 1881 I first showed that the Niagara river was not the outlet of the pre-glacial Erie basin. I then supposed that the channel was interglacial.

* 'Natural History of New York,' Part IV., Vol. IV., 1842.
† 'Travels in North America,' 1841.

This idea was repeated as late as 1901 by Dr. G. K. Gilbert.* Until the present investigation of the refilled Whirlpool rapids, and the discovery of the Falls-Chippawa valley, its true character could not have been known. The idea of any portion of the channel being interglacial I withdrew in 1887, and even at that time regarded the Whirpool rapids section as not representing the ancient course of any considerable stream. At that time I said, 'we are led to the conclusions that the course of the Niagara river above the Whirlpool and below is mostly of modern origin throughout, and not to any extent a drift-filled gorge re-excavated since the ice age.' 'The Saint David valley represents only the water course or water courses of local drainage before the ice age.'** For some years little attention was given to this channel. In 1886,† Prof. E. W. Claypole pointed out the occurrence of rock high up in Bowman ravine at the head of the Whirlpool cauldron. Again, in 1894, I measured the height to which these beds reached, using the United States Lake Survey topographic chart for the position of the stream. This map was very incorrect, showing the gully as extending from the middle of the Whirlpool, so that one had to infer that the buried channel was only about half the depth now found. Doubt, however, existed, and at a meeting of the American Association for the Advancement of Science, Prof. H. S. Williams suggested boring to settle the question, and offered the first subscription. This was not acted upon until 1905, when the work was carried out by the Geological Survey of Canada. The accompanying corrected map is from that of Mr. E. Gardner, Provincial land surveyor, extended by myself.

In 1841 Lyell distinguished between the precipitous cliffs of the modern gorge and the more gradual slopes of the buried channel. These last are capped with limestone having polished

* Atlas sheet of Niagara. U. S. Geol. Survey.
** Amer. Naturalist, Vol. XXI., p. 270, 1887.
† Report upon meeting of Amer. Ass. Ad. Sci., Sept., 1886.

rounded edges, but their slope never exceeds 45°, and rarely more than 30°, while that of the lower shale is much less.

SURFACE FEATURES FROM BOWMAN CREEK TO EDGE OF ESCARPMENT.

The loose materials at the end of the Whirlpool have been carried away by Bowman creek, which has made a deep ravine for three-quarters of a mile, in a direct line, in the very slightly undulating plain of from 340 to 350 feet elevation above the lake. If it were not for the deep gully of Bowman creek and its branches, there would be no trace of the buried valley upon the surface of the country. Beyond the head of this creek no further evidence of the valley appears above the ground which rises slightly higher. However, at about two miles from the headwater of the Whirlpool, the country becomes broken by several deep ravines among hills of drift covering the face of the Niagara escarpment, where it bends behind the village of St. David, but there is no St. David valley proper.

The country to the northeast of the buried valley is slightly rolling, as far as the brow of the escarpment, and covered with a clay surface. It does not rise more than 350 feet above the lake. But at its mouth and westward are deep deposits of sand and gravel rising in Berryman hill (Plate xxx.) to the unusual altitude of 442 feet. Prof. James Hall, in 1842, noted the occurrence of these materials to a depth of 150 feet in a well. Beneath the surface deposits of this region, outside of the buried valley, the limestone floor usually rises to about 330 feet above Lake Ontario.

To the northeastward of the buried valley, the country is only slightly rolling to the brow of the escarpment, and it is covered with a clay surface. Nearer the mouth of the buried valley there are deep deposits of sand and gravel.

From the mouth of the Niagara gorge the rock face of the escarpment extends westward for about two miles and a quarter (*see* large map), where it suddenly turns southward for three-quarters of a mile. Here it is covered by gravel hills mentioned, or continues in and forms the eastern wall of the buried gorge. As an escarpment the rocks are not shown farther than where the Michigan Central railway crosses the Town Line road. West of this point for a mile and a half the face of the Niagara escarpment is almost entirely obscured by rolling drift hills, although an upper terrace, with a rocky foundation, begins to appear. However, at nearly two miles from the point mentioned, a spur of the escarpment emerges from the sand hills. The upper portion is really an insular mass in front of a rocky terrace exposed when the waves of lake were making the Roy terrace 287 feet higher than now, at the date of the birth of Niagara falls.

This promontory led Sir Charles Lyell to think there was an embayment or expansion of the buried Whirlpool-St. David valley, and to compare it with the outlet of the gorge (*see* Plate XVII. A, on page 121); suggesting that the former had a great breadth, while the latter is reduced to a quarter of a mile. But this turn in the escarpment is not the enlarged valley of the buried channel, although many have followed him in this view. Nor was this strange, for over a considerable portion of this section it was only by making local inquiries and careful search that rock exposures were found. Thus an obscure quarry on Mr. Thomas Berryman's farm was found hidden in a field below the railway, and away from any public road. It has an altitude of 320 feet, and consequently is on the brow of the buried escarpment.

The occurrence of rock everywhere to the west was subsequently established, thus reducing the possible width of any buried valley. By digging along the course of the stream at one or two places to the east rock was found. At a point a few hundred feet west of the railway crossing of the St. David road is the head of the creek. It emerges as an enormous spring from beneath the railway, where it flows out of a now covered rocky cavern, as I am informed. Accordingly this feature, establishes the occurrence of rock at a height of 320 feet above Lake Ontario and, further, restricts the possible size of any buried valley.

Descending the hillside a few hundred yards to a point behind the old brewery building, and now almost entirely covered by earth, is an old quarry pit showing the surface of thin slabs of limestone at 254 feet above the lake. This point is at the outlet of the buried Whirlpool channel, not at the top of the escarpment, but farther down its slope. The outlet of the valley, between the approximately determined eastern edge and the ledge at the brewery, at this level, does not exceed 1,000 feet, if so much, while at the 320 foot level it is approximately 1,700 feet. Thus, at last, the confines of the old valley are delimited at its mouth.

The amount of interest which has been taken in this valley has justified this detailed study, as also that of the buried gorge, for it was necessary to determine what part the ancient trench had in the recession of the falls. Otherwise it would be only one of the many features of pre-glacial topography, which is generally characterized by rounded outlines. Indeed, until making this investigation, I should have considered the ancient valley much broader without knowing its depth, as did Lyell.

CHARACTERISTICS ABOUT WHIRLPOOL GORGE—ITS BREADTH.

From Whirlpool or DeVeaux point, on the New York side, directly across the river to Sinclair point, separating the Whirlpool rapids eddy from the Whirlpool, the Niagara gorge has a breadth of only 1,000 feet. At the broadest part of the Whirlpool the gorge is 1,750 feet wide. In a little ravine on the northeastern side, where the wall of the gorge passes under the drift at the head of the pool, one may closely determine its position on the eastern side. The distance from here to the exposed western pre-glacial wall with its rounded edges is 1,400 feet; consequently the difference in these measurements represents widening of the gorge due to the action of Niagara river. (*See* map, Plate xviii. opposite.)

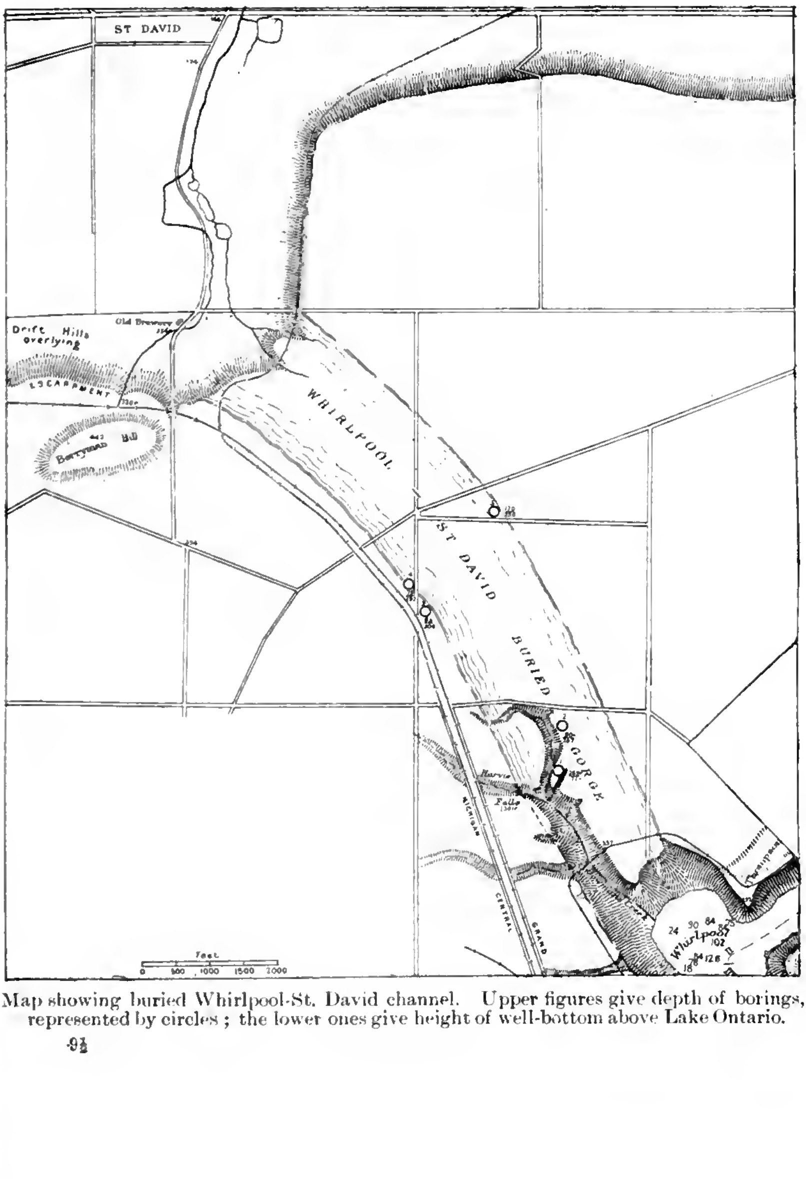
The western wall of the Whirlpool has not receded to any considerable extent, for immediately beyond the end of the Whirlpool fragments of the old rounded limestone edges appear, where their upper surface has an altitude of 290 feet; but this surface, being forty feet below the ridge penetrated by the river beyond the outlet of the Whirlpool, indicates that there was a much broader upper valley than the buried gorge itself. The absence of limestone above 290 to 300 feet for a breadth of possibly nine hundred yards shows here a rapid broadening of the pre-glacial superficial valley trending northward from Lyell ridge.

At the quarry of Bowman ravine the glaciated edges appear. The same feature is seen a few hundred yards still farther on, across the Electrical Railway embankment; and again on lot 42, where Bowman creek produces the Harvie waterfall in passing over the side of the old gorge into the deep ravine. Here the rock surface is 301 feet above Lake Ontario, and beneath forty-six feet of drift. From all these exposures the line of the western wall is discovered, and here it trends much nearer the north than was supposed. Midway between this last exposure and the brewery, where well No. 4 (*see* map p. 131) was just sunk, the rock is reached at seventy-five feet below the surface, or 292 feet above Lake Ontario. This shows it to be within the valley adjacent to the Whirlpool channel, but not within the gorge itself.

At well No. 3, which my driller sunk during the recent operations, the rock was found to be thirteen feet higher, or at 304 feet above the lake. Accordingly, these wells are at the edge of the trough, and by connecting them with the corresponding height at the brewery, the western wall of the buried gorge is established, showing a westward turn near well No. 4.

Of the location of the eastern wall we are not quite so well informed. The rock wall of the gorge is found near C on map (Plate xx.). The northern end of the outlet is located near the point where the Michigan Central Railway branch

PLATE XVIII.



Map showing buried Whirlpool-St. David channel. Upper figures give depth of borings, represented by circles; the lower ones give height of well-bottom above Lake Ontario.

to Queenston crosses the Town Line road between Niagara and Stanford. Just beyond it the line of railway skirts the escarpment on its descent to the lower plain and exposes the rocky wall. These terminal points established, they can be connected with a line curving as on the western side. At the intervening schoolhouse, where well No. 5 is situated (*see* map), a depth of 120 feet did not reach rock, with the surface at an elevation of 370 feet. This point is in and near the eastern margin. On lot 42 I sunk another well to ninety feet without reaching rock, and this was at a distance of 1,140 feet from the western wall. From all these observations I have been able to limit the breadth of the buried valley, which is 1,400 feet immediately beyond the end of the Whirlpool, to a breadth of 1,600 feet or perhaps 1,800 feet just before breaking through the face of the escarpment.

BORINGS IN THE WHIRLPOOL-ST. DAVID CHANNEL—ORIGIN OF MODERN WHIRLPOOL.

Although not quite complete, a survey has at last been made of the Whirlpool-St. David channel, after a period of much writing upon the subject, dating back for sixty-five years to the time when Sir Charles Lyell first recognized its character and suggested that the Whirlpool was due to the existence of this buried valley. The origin of the Whirlpool is now established as never before. The modern Whirlpool is the result of the reopening of a fragment of a buried valley after the falls had broken through its side at the present outlet. It is due to the Geological Survey of Canada that this question has now been so completely established, and I have to thank my assistant, Mr. Claude E. Eldridge, for the final supervision of the extremely trying operations, which enabled us to reach the depth mentioned later in this chapter.

On lot 42—where the deepest well was sunk, the position chosen was 630 feet from the rock exposure of the western wall, with the intermediate deep Bowman ravine between. This position was selected so as to be somewhat nearer the western wall of the buried valley than its supposed middle. The total depth attained was 269 feet, or seventy-one feet above Lake Ontario. Accordingly the well reached to a point only twenty-four feet above the Whirlpool level. Difficulties here arose so that the borings had to be discontinued.

That rock is absent in the buried channel to a depth much below the level of the Whirlpool is unquestionable, particularly does it so appear on account of the absence of the thick band of Medina sandstone above the level of the water at the end of the Whirlpool. The present survey establishes the existence of the pre-glacial cañon, with its upper edges rounded in a more pronounced form than was expected. As only soft beds of shale occur below the sandstone it is immaterial to the investigation of the recession of Niagara falls whether the ancient gorge reached scarcely to the level of Lake Ontario or below it.

CHARACTER OF DRIFT IN DEEP CHANNEL.

The following section represents the material penetrated at the deep well:—

	Feet.
Red clay with a few angular pebbles....	40
Rounded gravel..	2
Brownish sandy loam (dry)..........	38
Small angular gravel in red clay matrix.	4
Loam with fine angular gravel..	10
Angular gravel with some binding clay (very tough boring)..	26
Bluish clayey sand with some angular fragments..	66
Fine washed sand, gray colour, with remains of white spruce wood..	½
Clayey sand..	14
Bluish clayey sand..	20

	Feet.	
Angular gravel with earthy binding, pebbles size of pease or beans (extremely difficult boring)..	19	
Loamy sand with small angular pebbles.	27	
Extremely fine quicksand (angular) with clay binding, when mixed with water easily flows, but soon sets, so that it cannot be taken up by pumps....	2+	268½+

In this last bed the casing was bent, and at the same time the quicksand flowed in and filled the tube for several feet. Throughout the whole depth the dryness of the materials, not holding even the water poured into the boring, rendered operations very difficult. Water occurred in the lowest quicksand only.

The materials found in the well show a strong contrast with the stratified sand and waterworn gravel covering the edge of the Niagara escarpment and filling the old mouth of the gorge where, in sand pits, they have been exposed for fifty feet or more. In Bowman ravine, cut through the deposits in the Whirlpool channel to a depth of nearly 300 feet, very few boulders were seen. So, also, at the end of the Whirlpool, the accumulation of boulders, left after the 300 feet of drift have been washed away, is relatively very small. These show that the few larger stones in the drift are almost exclusively granites, quartzites, and other transported crystalline rocks with rarely a boulder of Niagara limestone from the adjacent walls.

FOSSIL WOOD BURIED IN DRIFT.

The fossil wood occurring at a depth of 186 feet, as mentioned in table, was kindly determined by Prof. D. P. Penhallow of McGill University, who found it to belong to *Picea alba*, or white spruce, in a fair state of preservation, although buried there for probably more than one hundred thousand years. Of it he says: 'This species is known in the Pleistocene, where it has been recognized in only a few instances; the black spruce, *Picea nigra,* being, on the other hand, very common and well defined types of such deposits.'

BREATHING WELL.

Boring No. 1 was found to be a breathing well. Upon reaching a depth of 226 feet, when the end of the pipe was in the coarse gravel bed, an inward suction was observed. At this point it was deemed necessary to dynamite the end of the casing in order to insert a smaller tube as the outer casing had become bent in the gravel. Immediately after the explosion, and for another day or two, a strong inward draught continued. Subsequently, at a time when the water in the Whirlpool was particularly high, there was an outward current amounting to a blast. So strong were these currents it hardly seemed possible that such could occur except in proximity to fissures in adjacent rock. However, as the continued borings showed the absence of rock, this breathing appeared to be due to the character of the porous gravel, not associated with caverns, and depending upon atmospheric conditions, and the height of the river in the Whirlpool. As the deeper borings were made when the temperature was below freezing point, water poured into the inner casing froze into solid ice at the depth of 226 feet, on account of the suction of the cold air between the outer and inner casing.

CHAPTER XI.

ST. DAVID CHANNEL BELOW THE ESCARPMENT.

Pre-glacial surface shown by depths of wells. Survey of the banks of Niagara river below gorge section.

PRE-GLACIAL SURFACE SHOWN BY DEPTHS OF WELLS.

As shown upon the large map the trend of the buried Whirlpool-St. David valley, as it approaches the escarpment, has a direction much more to the northward than was formerly supposed. It then curves westward as if it had originally left the plateau region a mile or more west of the present site, with a narrow ridge of rock, between it and the lake valley, subsequently removed by wave or atmospheric action, which thus produced the indentation in the Niagara escarpment.

The topography here is not that of an ordinary embayment at the mouth of a valley, and its structure is so peculiar as to challenge attention. There is nothing in the topography suggesting a channel in this northwestern direction, and a northeastern one would require a sharp turn in the course of the river. As a consequence an examination of the wells to the north of St. David was made. The records will be given in Appendix III.

Below the brewery already mentioned (page 129), the surface slopes to the Bell terrace plain, with its edge situated beyond the hamlet of St. David, so that this has a breadth of a mile or more. Nearer the Niagara river the Bell terrace becomes quite narrow and is underlaid by Medina red shales and sandstones, which are only slightly covered with surface accumulation. In the vicinity of St. David these rocks are wanting, but they are replaced by deposits of sand and gravel forming a terrace of a mean height of 168 feet above the lake, while a lower point at St. David village is 164 feet.

On this platform are several wells in sand and gravel reaching to a depth of sixty feet, where water is obtained. Adjacent to the road, a quarter of a mile south of the village, at Mr. Woodward's, there is a well of 130 feet, but below sixty feet very little water was obtained. It is not certain whether the well terminates in drift deposits or Medina shale, but even if the drift reaches this depth the bottom of the well is still forty feet above Lake Ontario (or only seven feet below the surface of the Whirlpool). Another well, on lot 96, on this same terrace, is ninety feet deep. Several other wells to the north of St. David show the presence of rock to a height which would preclude a buried channel in that direction; but such might have skirted the Niagara escarpment to the northwest.

Mr. J. F. Scovell* called attention to the existence of a buried channel between St. David and the Niagara river, on account of finding some deep wells, and also because of the absence of Medina shale at certain points on the western bank of the Niagara river. The result of an examination of the wells shows that such is the case. On lot 34, a well is said to have a depth of eighty-one feet without reaching rock, while at another one, just sunk, rock occurs at forty feet. On lot 64 there is an absence of rock to a depth of ninety feet, while a quarter of a mile to the north (lot 66), rock is found at sixty feet. On lot 80 the well did not reach rocks at sixty-eight feet. Nearer the river (lots 19 and 20) no rock was found at a depth of eighty feet. These features would indicate here a channel about twenty feet below the lake level.

SURVEY OF BANKS OF NIAGARA RIVER.

These consist of Medina red shales for a distance of about two miles north of Queenston village, but on passing Field point

* Proc. Amer. Asso. Ad. Sci., Vol. XXXIX., pp. 245-246, 1891.

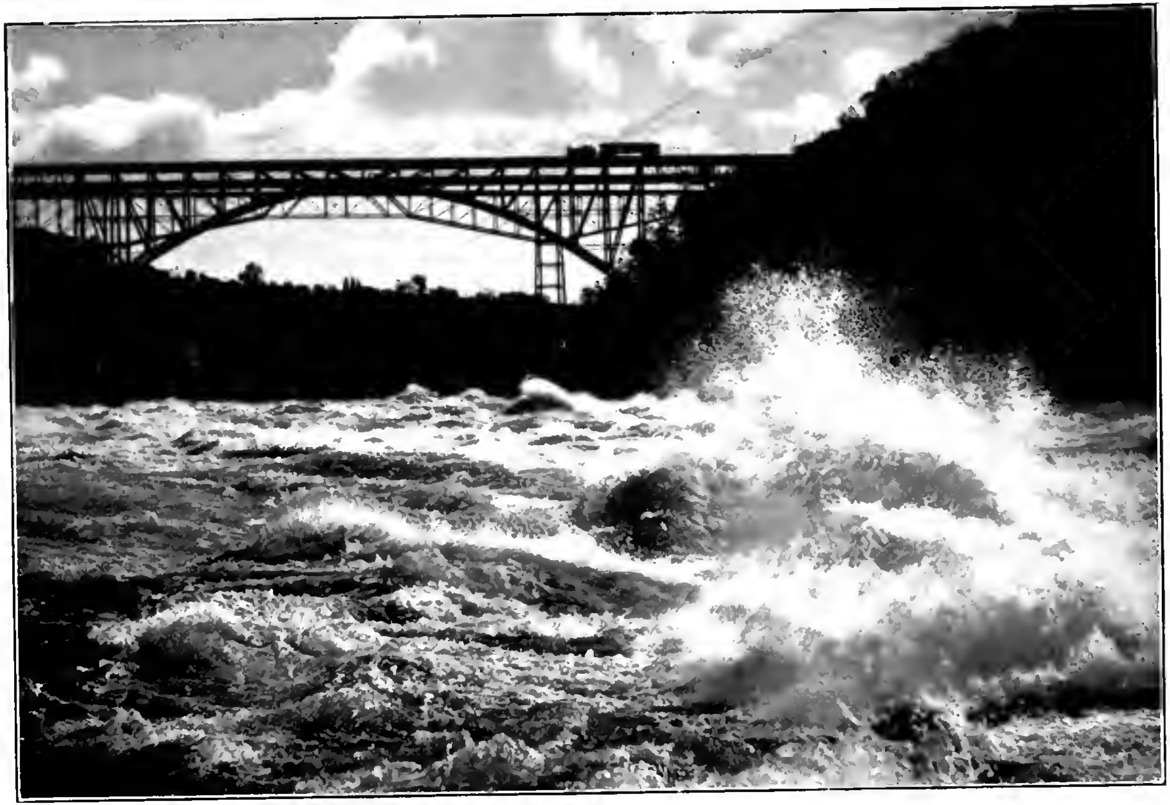
such beds disappear beneath the water. The banks everywhere form steep bluffs from forty to sixty feet, and even higher on receding from the river. (*See* Plate XXIX.) In the cove of Hogshollow only blue clay and other drift material appears. About a mile and a half below Field point, at a place just north of Slinglands point, the shales rise to the surface. Lake Ontario is only about three and a half miles farther away. Thus along the west bank of the river a buried valley is found to occur. The eastern banks of the river below a point two miles from the mouth of the gorge consist mostly of drift clay. Whatever shales underlaid the old topographic features they were largely reduced to a level below that of the lake, along the lower course of the river, especially on the eastern side.

From the data thus obtained it appears that there was an old channel coursing from St. David to the Niagara, but so far there is nothing to show that it had any great depth, nor, on the other hand, that there is not a deep one. Even this may have belonged to a local drainage, and may not have come from the Whirlpool-St. David valley. An old channel in the softer shale should have been relatively much wider than the chasm cut through the Niagara limestone.

On the other hand, a buried valley may possibly be found extending northwestward (but not northward) to the lake, but only one or two wells in this direction have been examined.

There may be a complexity of the drainage features of preglacial times in this region, which are not yet understood, but they are unimportant if they do not show a depth throwing light upon the bottom slope of the Whirlpool-St. David gorge.

PLATE XIX.



View of Whirlpool Rapids, looking up.

CHAPTER XII.

NARROWS OF WHIRLPOOL RAPIDS.

IMPORTANCE OF THIS SECTION.

This section of Niagara river, which is a continuation of the Whirlpool-St. David gorge, is so very important as to require special attention. The reason of this lies in the problem whether at this locality a drift-filled valley existed, so that the Niagara river simply removed the unconsolidated drift, or whether the Whirlpool headed in an amphitheatre of hard rock, requiring the falls to excavate the gorge out of solid rock, as it is doing to-day. If the falls encountered drift, it would rapidly be removed, and the present comparatively slow rate of recession would not be applicable here.

The older investigators of the falls did not consider this question, but thought there was a uniform rate of retreat from the mouth of the gorge to the present site. Dr. Julius Pohlman,* one of the earliest writers in the renaissance of Niagara studies, thought that the buried channel reached far up toward the present site of the falls, and accordingly believed that the time required for the cataract to re-open the drift-filled valley, and recede past the Narrows, was one of short duration. This being the case, there appeared no limit to the length of the pre-glacial channel, even to near the present site of the falls

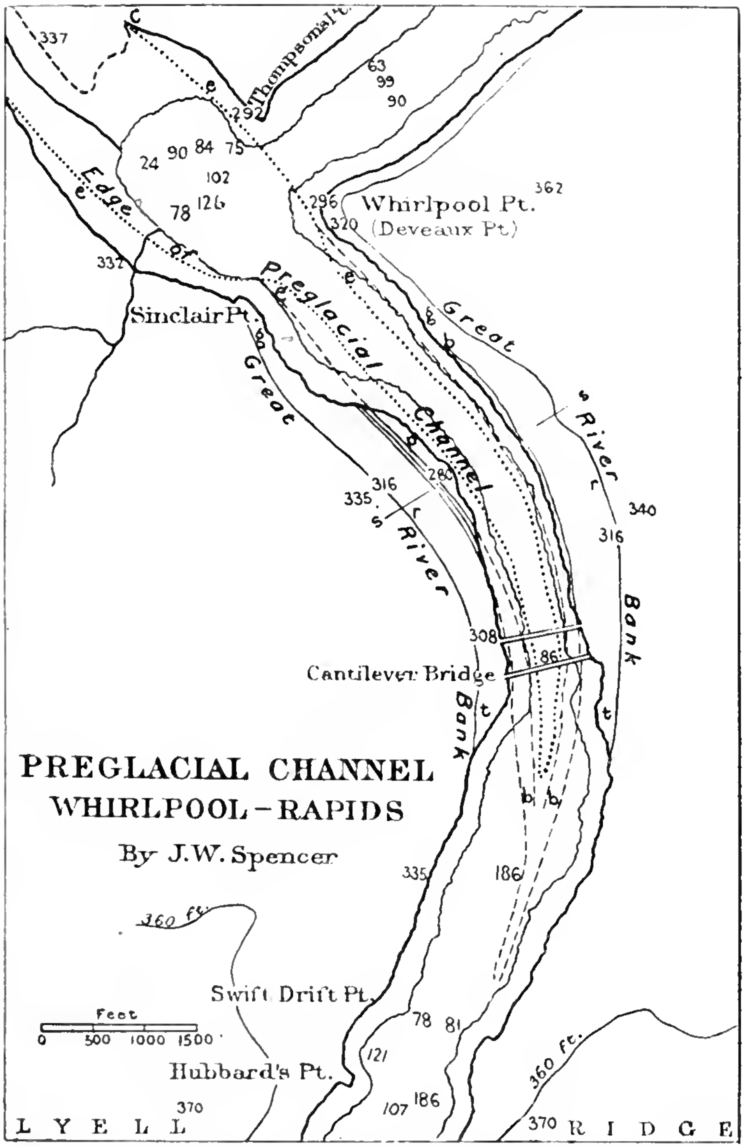
*Proc. Amer. Asso. Sci., Vol. xxxii, p. 202, 1883. Ib. Vol. xxxv, 1887.

themselves; nor to the shortness of the period since the cataract broke through the barrier at the Whirlpool, which is midway in the length of the gorge. From this one point alone will be seen the extraordinary need of discovering the true character of the Whirlpool rapids. But there was another problem of equal magnitude, namely, to account for the enlargement of the cañon immediately above the Narrows. Hence this was one of the most critical sections in the investigation of Niagara. Several have written upon the subject, myself among the first, and I fully appreciated the difficulties of this part of the river. It was not until 1899 that the invaluable borings at the Cantilever bridge were made, and not until now were the necessary soundings taken to throw light upon the question. Throughout the field work I did not consult my older writings, but made the re-investigations in the light of new facts, which are presented with a closing discussion on the problem.

SURVEY OF THE FEATURES ABOUT WHIRLPOOL RAPIDS.

The survey shows that the pre-glacial trench at the northern end of the Whirlpool is 1,400 feet wide. At Sinclair point, between the Whirlpool and Whirlpool eddy, 2,000 feet to the south, the ancient trench, together with its modern enlargement, is now 1,000 feet wide. This eddy is in a cove 1,500 feet long and 1,300 feet wide, and its upper end merges into the Narrows, eventually reduced to about 750 feet wide. Descending to the water level the Medina gray band is incised by 1,000 feet at the end of the Whirlpool. Under Sinclair point, just referred to, the breadth of the river is only 600 feet, and this, to some extent, includes the enlargement of the gorge by the modern river. At the eddy it increases to 850 feet, while in the Narrows it is reduced to 350 feet. South of Whirlpool point (Plate xx.), the eastern walls of the gorge have fallen, so as to widen the pre-glacial valley. This feature, together with the encircling form left at Sinclair point

PLATE XX.



Map of Whirlpool rapids. The Eddy and Narrows section inside the great river banks (g r t); the lower pre-glacial terrace, P., truncated at both ends, but restored by broken lines (e e b): approximate edge of pre-glacial valley represented by dotted lines heading near b b, though the shallower channel continued toward Lyell ridge, opposite Swift Drift point; S—S, position of section figure 18.

shows the sudden contraction of the buried cañon producing here the head of an amphitheatre.

Comparing this structure with modern topography the head of the deep ancient gorge should be looked for at Sinclair point below the eddy; but what was the character of the tributary ravine? To answer this question one need not go far afield. At a point from five-eighths to seven-eighths of a mile south of the Cantilever bridge (*see* map, Plate XX.) there is the Lyell ridge of Niagara limestone, rising on both sides of the river to 370 feet above our datum. In ancient times this was trenched, as at Hubbard point, down to 317 feet above Lake Ontario, with a resulting rounded topography. At a short distance north of Hubbard point the present gorge at Swift Drift point is contracted to a breadth of scarcely more than 1,000 feet. In the cove between these points there is no evidence of the drainage in either direction. This impression slowly grew upon me day by day, living with the falls for a long time, and learning almost every feature. Indeed, on the eastern side, at a point where the Gorge railway descends, I could not help fancying I saw the head of the Whirlpool rapids ravine in a little cove adjacent to which the rocks showed polished and rounded surfaces (opposite to b b on Plate XX.).

The greater breadth of the cañon is the result of subsequent excavations by the falls. The Narrows of the rapids are inside another valley depression. Thus, at the railway bridges, the floor on the western side has an altitude of 308 feet, while on the eastern side it is slightly less, with the rocks beyond rising twenty feet or more. A third of a mile to the northward there is another inner valley with a glaciated bed at 280 feet on the Canadian side, while on the New York side the preglacial trough is not represented, as the wall is at 294 feet, with the present gorge 750 feet wide between them. Here the buried valley has been uncovered by the modern river, whose outer banks were more than twenty feet high (above their margin at 316 feet), and 1,500 feet apart where the strong currents carved out sharply marked terraces before the river shrunk into a narrow pre-glacial channel now found to be shallow. (*See* Plate XXI. B.)

BORINGS AT CANTILEVER BRIDGE.

The boring at the eastern pier of the Cantilever bridge, by a diamond drill, and the recovery of the core, brought to light the character of the refilled Whirlpool rapids section. It was thus proved that the buried rock was absent to a depth of 185 feet below the surface of the river, or eighty-seven feet below that of Lake Ontario (page 60). Out of the total thickness of the 185 feet, 124 feet were found to consist of blocks and boulders of limestone, and sixteen feet of sandstone, all with clay between. A table of these borings is given on a following page. Some of the blocks had a thickness of ten or twelve feet, as in the vicinity of seventy-five feet below the river surface. The talus slope extends beyond the overhanging cliffs of Niagara limestone for a distance of 220 feet on one side, and 222 feet on the other, with the breadth of the river 410 feet, and a maximum depth of eighty-six feet (figure 21).

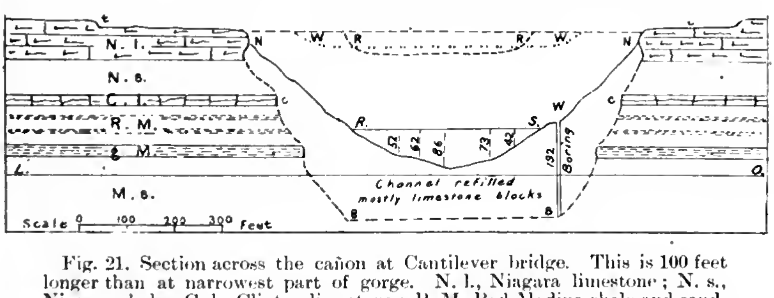


Fig. 21. Section across the cañon at Cantilever bridge. This is 100 feet longer than at narrowest part of gorge. N. l., Niagara limestone; N. s., Niagara shale; C. l., Clinton limestone; R. M. Red Medina shale and sandstones; g. M., Medina gray sandstone; M. s., Medina shale; L. O., Level of Lake Ontario; R., level of river; W., boring on eastern side; N C B B C N, approximate form of refilled channel; Pre-glacial channel between limits of W—W and R—R; t—t., terraces showing boundary of Niagara river before it sunk into Whirlpool Rapids channel.

If this section be now examined, as shown on a true scale, with the uniformity of the declination on both sides, one is struck by the great steepness of the covered slope from the edge of the cliff to the bottom of the well; also with the fact that the slope of the western side should be the same as on the eastern. This leaves the impression that the bottom of the gorge must have been kept open by a more vigorous current than now obtains, or by one excavating the bed of the channel and removing all the débris as rapidly as it fell into the current. How much deeper the middle of the buried channel is than the bottom of the well cannot be known, but its depth reaches to almost the same level below the surface of Lake Ontario as the river channel above this point. Accordingly, a much greater depth can not be expected.

TABLE OF BORINGS AT EASTERN PEIR OF CANTILEVER BRIDGE.

		Feet.
Surface of ground*	to	253·6
Lime rock (fallen block)	"	251·25
Boulder	"	247
Black slate	"	243·9
Cavity	"	243
Boulders	"	238·6
Lime rock	"	237·25
Clay and boulders	"	234
Clay	"	231
Bastard lime rock	"	229·5
Clay	"	228
Bastard lime rock	"	225
Clay	"	223
Bastard lime rock	"	222
Clay and boulders	"	218
Bastard lime rock	"	217
Clay	"	213
Bastard lime rock	"	211·5
Clay and boulders	"	208
Lime rock	"	206·5
Clay and boulders	"	203
Lime rock	"	202
Clay and boulders	"	198
Boulders	"	197
Clay	"	178·5
(Bottom of casing)	"	176
Lime rock	"	175
Clay and boulders	"	171

*Surface of ground about eight feet above the river, which is nearly ninety-nine feet above Lake Ontario. Datum assumed at 300 feet, which is the top of the coping of the tower here. The figures are taken directly from the Section of the Railway Engineers. It should be noted that some of these masses of limestone are large; but they are not in their natural place, as both these and the blocks of sandstone mentioned occur at depths in the channel far below the levels at which their beds occur. In short, they are refilling a channel which has been cut out of red Medina shales.

		Feet.
Lime rock	to	161
Clay	"	159
Lime rock	"	147·6
Clay and boulders	"	139
Sand rock	"	135
Clay and boulders	"	131
Sand rock	"	128
Clay	"	127
Sand rock	"	121
Clay and boulders	"	119
Sand rock	"	116
Clay	"	111
Sand rock	"	110
Clay and boulders	"	93
Sand rock	"	92
Clay and boulders	"	82
Sand rock	"	81
Clay and boulders	"	80
Clay and boulders and little red shale	"	62
This is bottom of channel.		
Red shale bed rock	"	57

ACCUMULATIONS IN THE CHANNELS OF WHIRLPOOL AND RAPIDS COMPARED.

Glancing now at the character of the material in the refilled gorge here, and comparing it with that filling the Whirlpool-St. David channel, the contrast is striking.

In the latter mentioned trench the accumulations are sands, angular gravels, a little loam, rarely a boulder, and such boulders as do occur are found to be composed of crystalline rocks. A little red sandy clay covers the surface. This drift material is now known to an actual depth of 269 feet. Only one or two blocks of Niagara limestones were observed on the sides of these deposits; so, also, the boulders which have accumulated at the end of the Whirlpool are, almost entirely, transported crystalline rocks. The contrast of this glacial material with that in the boring at the Cantilever bridge, which is composed of fallen Niagara rocks, is conclusive evidence of the newness of the Whirlpool rapids gorge to the full depth of 185 feet below the surface of the river.

AMOUNT OF EXCAVATION AND REFILLING AT THE NARROWS.

Here is a cañon of unequalled narrowness reaching to a depth of 395 feet below the adjacent floor of the outer valley.

In the section it is found that ninety-two feet are composed of hard limestone, twenty-five feet of softer red sandstones, not counting the thinner layers which are perishable, being non-resistant, (as shown in Plate XXI. A, on page 157), and twenty feet of very hard gray sandstone, with the base of the lowest of these beds forty-one feet above Lake Ontario. The lowest 128 feet of the refilled gorge is excavated out of soft shale, which could not supply any of the limestones or sandstones found throughout the lower depth in the boring.

When the full force of the current was diverted into the smaller pre-glacial channel most of the shale beds were swept away, and also some of the thinner layers of limestone and the friable sandstone, although some shales remained—to the extent of forty-five feet out of 255 feet—the total of such beds found here. Some shales produce clays in the interstices between the boulders when protected from the stronger currents.

It is now possible to compare the cross-section of the modern chasm with that of the gorge at its maximum development on one hand, and on the other, with the small pre-glacial valley which gave rise to the narrow cañon at the Whirlpool rapids. As shown in figure 21, the area of the cross-section of the whole channel, including the buried portion brought to light by boring, is 248,000 square feet; that of the modern gorge is 156,000 square feet; thus leaving the buried portion represented by 92,000 square feet. Of this last amount, 69,000 square feet consists of hard limestone or standstone blocks or boulders.

The area of the Niagara and Clinton limestones, and the gray band of Medina sandstone, which have fallen from their natural position into the gorge, together with that portion removed in pre-glacial days, amounts to 87,000 square feet. The difference between these figures represents 18,000 square feet removed from the natural bedding in the gorge in pre-glacial times. That is to say that the ancient valley had a cross-section of this area; which if distributed with a breadth of 600 feet its depth would be thirty feet, and this form would be somewhat favoured by the occurrence of the lower shelf at 280 feet beside the Narrows. This form of section is represented at (*a*) figure 18 (page 105). On the other hand, if the width were 400 feet, about that of the river to-day, the depth should have been forty-five feet as shown at R R (figure 21).

In these calculations some errors rise from treating the mass of fallen boulders, having interstices filled with clay, as if composed of solid rock in its natural bedding. Allowing for this structure would leave a decrease of the fallen mass, and an increase in the size of the pre-glacial valley. On the other hand, with the removal of the clayey matter by the strong current of the river, much material from the thinner beds of limestone and sandstone would be carried away, and allowance here would decrease the area of the pre-glacial gorge. However, whether the ancient channel were a little larger or a little smaller than here represented, the analysis shows that at this point a deep gorge did not exist. Accordingly, this buried, partly refilled cañon, nearly 400 feet deep, was excavated by the modern falls when the river surface was somewhat lower than now. The ancient valley diverted into it the waters of the river, so that the concentrated force would remove the débris and leave walls as steep as those discovered by the deep boring.

Upon the recession of the falls beyond this section, favoured by the backing of the water into the gorge below, the bottom of the channel could not be kept open; accordingly, below the bottom of the river, which is eighty-six feet deep at the Cantilever bridge, the channel is reoccupied by fallen rocks as shown by the borings at the bridge. Just below the bridge the Whirlpool rapids descend impetuously fifty-two feet to the Whirlpool. Unquestionably these rapids are formed by blocks fallen into the channel from the overhanging brink of the chasm, though the greater part of the refilling occurred earlier, without producing the present rapids which have been completed only after the falls had receded to near their present position, which accounts for the freshness of the walls, and the absence of any indentation where Muddy creek runs down the western wall at the Narrows.

CHARACTER OF THE ANCIENT VALLEY AT NARROWS.

So far attention has been primarily given to the modern character of the channel at the Whirlpool rapids. Thanks are due to Mr. P. W. Currie* for calling attention to these boulders and fallen blocks found in the borings. This channel is excavated in an outer valley which has an elevation of 308 feet above Lake Ontario on its western side at the railway bridges. From a quarter to a half mile northward there is a fragment of a lower rock cut terrace, having a width of 125 feet, and an elevation of 280 feet. That it is ancient is shown by its glaciated surface. It is represented at (*a*), figure 18 (page 105). Here is the narrowest part of the gorge—only 750 feet wide, or a hundred feet narrower than at Cantilever bridge, where there is no remnant of the lower terrace. (*See* map, Plate xx.) The lower terrace does not remain on the eastern side where the wall of the gorge rises fourteen feet higher. Such removal has been occasioned by the currents encroaching on and undermining the eastern more than the western side. Still the breadth of this inner valley, with its depth, seems to have been sufficient to produce a cross-section of 18,000 square feet with the pre-glacial channel unable to carry the whole volume of the river.

This conclusion is derived from the fact that the inner channel is situated within a broader outer one bounded by steep banks shown in the view and on Plate xxi. B, and at t t figure 18, These letters represent the margin of the great river. The outer channel continues to Sinclair point, where the western

* Trans. Can. Inst., Vol. VII., pp. 7-14, 1891.

bank is abruptly terminated at the brink of the chasm at the Whirlpool. Above Sinclair point, and extending past the eddy section (on map Plate xx.), the falls excavated a cañon much wider. This broad amphitheatre at the eddy was not the product of the falls acting within a narrow chasm, but it shows that much of the water flowed over the whole end of the outer channel before the main stream was contracted in width.

A channel with a section as estimated above, could take the greater part of the volume of the river, while a portion of it was being diverted by way of the Chicago overflow into the Mississippi drainage. This condition continued until the falls had receded in the ancient valley to a point, where it was too small to direct the forces of the cataract, after the return of the full volume of the river, when the water overflowed the sides of the chasm and recommenced the broadening of it.

Thus it appears that the pre-glacial trench at the Whirlpool rapids, beginning in the amphitheatre at the head of the Whirlpool, somewhere between Sinclair point and a few hundred feet to the south of it, extended upward and southward through the section of the Narrows. In order to permit part of the discharge to still flow over the floor of the main outer valley, and at the same time divert most of the force into the main channel, its depth must have been less than the thickness of the Niagara limestone, so much less that at first there was a great fall at its lower end occupying the whole outer valley. This occupancy of the floor of the pre-glacial channel was like the lateral discharge of the waters over the wall of the falls beyond the present apex. In this way was formed the cove at the eddy, broader than between the Sinclair and Whirlpool points. But the greater force of the river in the pre-glacial valley must have deepened the channel sufficiently to withdraw the water from the outer and broader one. Such a feature is shown by the contraction of the eddy section at the end of the Narrows, when the river no longer spread its waters over the broad

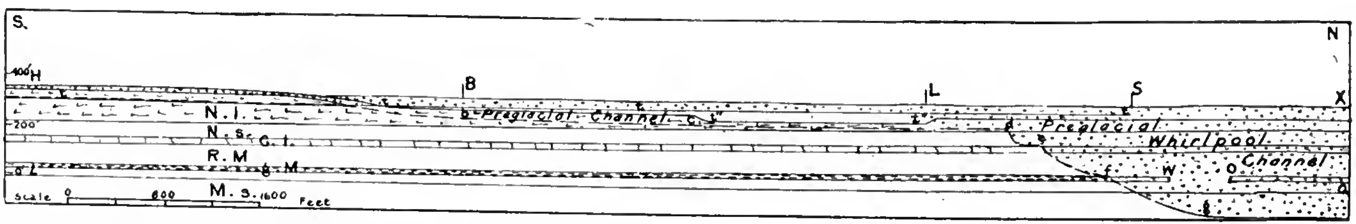


Fig. 22. Longitudinal section of pre-glacial channel from the Lyell ridge to the Whirlpool. N. l., Niagara limestone; N. s., Niagara shale; C. l., Clinton limestone; R. M., Red Medina sandstones and shales; g. M., gray Medina sandstone; M. s., Medina shale. H—Hubbard point; B—Cantilever bridge; L—limit of Narrows; S—Sinclair point; X—near present head of Whirlpool; H t d e f g—bed of pre-glacial valley filled with drift; t t t t—modern strong terrace at 316 feet; t''—t''—terrace at 280 feet; W. O., position of Whirlpool outlet; L. O., level of Lake Ontario.

channel. Thus is satisfactorily explained the features of the eddy section. A characteristic of such an old gorge would be the descent from the head of the slope by steps over the harder Niagara, Clinton, or Medina sandstones, which are represented in the longitudinal section figure 22.

It is not to be supposed that the ancient valley terminated abruptly at the upper end of the Narrows, for the pre-glacial land surface beyond this point continued to rise for a distance of three-quarters of a mile to Lyell ridge, the rocky summit of which has an altitude of 370 feet. This ridge formed the divide between the Whirlpool valley and the Falls-Chippawa basin trending in the opposite direction (*see* Plate XXII.). Even in pre-glacial times the full height of the ridge was interrupted, as the ancient erosion at the divide had reduced it by fifty feet to a height of 320 feet at Hubbard point. In studying the features upon the ground there was always a strong impression left that the stream proper headed in a little cove opposite Swift Drift point, where the Gorge railway commences its descent, and that the basin or cove between Swift Drift point and Hubbard point was one like many upon the summit of divides which drain in both directions.

WHIRLPOOL RAPIDS NARROWS—ROCK EXCAVATION BY MODERN RIVER.

From careful measurements from soundings, and particularly from the borings at Cantilever bridge, the results show that the pre-glacial Whirlpool gorge did not extend much above Sinclair point, though a small channel led into it. Therefore, the falls, except at the Whirlpool, have had to excavate all of the gorge out of solid rock, as they are doing to-day.

It has been mentioned that various observers thought that a buried channel may have reached to nearly the site of the present falls. This was not, however, my earlier impression. I did not then closely define my views beyond stating that 'at this point the Niagara river took possession of the eastern side of a drift filled valley.'* But later my opinion was made quite clear, namely, that the channel of the modern river 'maintained a full breadth and depth, but the constriction applies to the gorge alone,' that is, the inner one which was filled with drift. 'The depth of the depression was the greater in the centre, and the river took possession of a deeper portion, and upon the removal of the drift, sunk within the gorge.' 'This shallow-buried valley began in Johnson ridge' (that is the Lyell ridge at Hubbard point) 'just above the railway bridges, and extended to the Whirlpool, whose cauldron is only a deeper extension of the same channel.'† The views expressed in 1894 were only an *avant courier* to the present work, and it is no little satisfaction that they have been so fully sustained.

Subsequent to my contribution just mentioned Mr. F. B. Taylor, who has been one of the principal investigators in the later history of the lakes, contributed a paper upon this subject in 1898. In this he thought that there was an amphitheatre at the head of the Whirlpool, located at Sinclair point, but he did not consider the importance of the little valley which supplied the waters for the small ancient cataract.

With this modification, Mr. Taylor's conclusions agree with mine formerly expressed. The head of the amphitheatre evidently descended by a series of steps which extended into the eddy section. The origin of the Narrows of the Whirlpool rapids section is now set forth, namely, that the larger part of the river was concentrated into the narrow pre-glacial valley, while another portion of the lake drainage overflowed by way of Chicago. So long as a considerable portion of the river was concentrated into the channel it would not be widened except by the undermining of its sides.

Eventually this ancient valley was not large enough to take

*Amer. Jour. Sc., Vol. 3, xlviii, pp. 455-472, 1894.
†Ib. Vol. 4, vi., 439-450, 1898.

PLATE XXI. A.

View of Section of Medina Red shales and sandstones, on Gorge Roads, just below G.T.R. bridge.

PLATE XXI. B.

View of Original River bank, outside of the Narrows of Gorge, in front of Mount Eagle.

the volume of the river, increased by the portion of water temporarily diverted at Chicago. In order to account for the Whirlpool Narrows, Mr. Taylor formulated a temporary withdrawal of the Huron waters while the falls were passing the rapids. He thought the temporary diversion was occasioned by certain changes of the outlet of Algonquin lake, before the waters were finally backed southward by the rising of the barrier at Lake Nipissing. I had not found anything to sustain this view, because the old shore line of Algonquin lake cut off the overflow of Lake Huron to the south until the barrier was broken through by the rise of land at the Nipissing outlet. His hypothesis required reduction of volume as complete as before the original addition of the Huron drainage.

Mr. Taylor's temporary diversion proved only partial. It was due to the overflow at Chicago into the Mississippi drainage, and not to glacial dams as he supposed (*see* chapter XXVII.). The amount of diversion was sufficient to cause the withdrawal of the water from the shallower portion of the channel, at the Whirlpool rapids so that the falls produced a cañon 750 feet wide, in place of 1,200 feet as elsewhere.

WIDENING OF THE GORGE ABOVE THE RAPIDS.

As the outer channel at the Narrows is 1,500 feet wide, with the gorge reduced to 750 feet, and as there was a small temporary reduction of Huron discharge, which reduced the volume of water here, the question arises as to what caused the rapid enlargement of the gorge to a breadth of 1,300 to 1,400 feet above the Whirlpool rapid Narrows. This width should be reduced somewhat on account of frost action and under cutting of the cliffs by the river, so that the original banks above here have been undermined and completely fallen away; however, a little farther up, at Hubbard point, they again appear, showing the river to have been 1,200 feet wide. As the pre-glacial channel became too narrow to direct the course of the river, now enlarged again, it would flow around the head of this channel and over the side of the narrower chasm, as it did at an earlier time round Wintergreen flat, and now over Goat island shelf to the side of the apex of the present falls, and break over the sides until it could widen a gorge sufficiently large to receive the volume of the falls. To emphasize this feature the river was not shooting through the confined channel as that beneath the Cantilever bridge to-day but through one of moderate depth, and was breaking over a large periphery with the consequent undermining effects. From that time to the present, facts now known show that there has been no great change in the character of the gorge, except that there has been a large amount of undermining of the walls and falling in of the original river banks.

CHAPTER XIII.

FALLS-CHIPPAWA BURIED VALLEY.

WELL BORINGS, DEPTH OF DRIFT AND ABSENCE OF CHANNEL WEST OF GORGE.

Reference has already been made on former pages, to the apparent rock basin at the falls as noticed by Hall, Lyell and Julius Pohlman. Later, Mr. Scovell ascertained that there were deep wells to the west of the Clifton House, and thought that a buried valley extended from the present site of the falls to St. David valley. Learning that there were deep wells I provisionally followed Mr. Scovell, and I regarded the Whirlpool St. David valley as a tributary to a greater but shallower channel to the west (1894).

The valley above the falls is wide; the outlet of the Whirlpool-St. David valley was supposed to be broad, though it is now found to be narrow. Then, again, the river at the Upper rapids was nearly in the direct course of Pohlman's Tonawanda drainage. Consequently these broader features favoured the location of the supposed valley and provided a working hypothesis, especially as the cañon-like form of the Whirlpool-St. David trench had not been surveyed.

On commencing to re-investigate the physics of Niagara falls the first work to be done was to determine how this falls basin could have been originated by streams flowing westward of the present course of the river toward St. David. In order to ascertain the origin of this basin, which is excavated to sixty feet in depth out of hard limestone, the depths of a very large number of wells were obtained; some of which were ninety feet before reaching the rock surfaces. The buried rock floor was then determined by taking the levels of the wells. The result showed that the pre-glacial surface was too high for a trench extending from the falls northward upon the western side of the river.

The rock floor of the country west of the river, from the town of Niagara Falls and along Lundys Lane, was found to have a general elevation of 340 feet above Lake Ontario, while the pre-glacial surface of the basin at the falls was reduced to 258 feet.

VALLEY INDICATED IN DEEP WELLS ADJACENT TO FALLS.

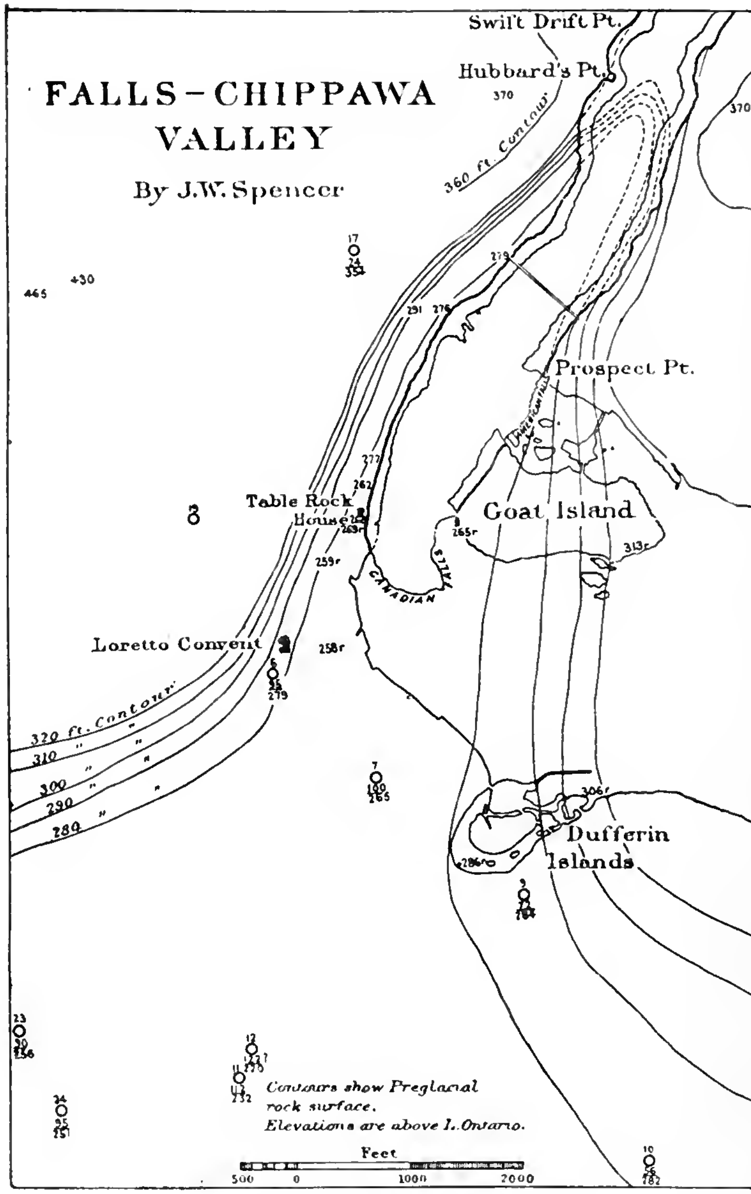
To the southward deep wells were found. West of Victoria Park, on the property of the Carmelite monks (well No. 6), borings reached a depth through the drift of ninety-five feet, showing that the floor at a point 700 feet back of the upper edge of the drift hills was reduced to 277 feet above Lake Ontario. This proved to be at a point on the side of a buried channel. A number of other wells had been sunk, which are shown on the maps. As a result of the sinking of these wells a deep trough was found between the rocky floor south of Drummondville and the rising floor adjacent to the Upper rapids, and at Chippawa. The breadth of the upper part of the trough was most plainly brought to light, as it was crossed by the pipeline of the Ontario Power Company in an oblique direction, exposing depressions in the rock for a distance of 2,400 feet, or along a direct section across the old valley of about 1,700 feet, with the rock bed absent above the level of 259 feet. On either side the rocky rim rose to 320 feet or more. Accordingly the re-opened basin at Niagara falls extended southward under the drift hills.

It was then ascertained from other deep wells, some three miles distant, that the rocky floor under the flat surface of the country was reduced to a similar depth as that of the basin at the falls. This suggested a trench. It now seemed that a valley had been discovered which furnished a large stream for excavating the Whirlpool-St. David valley. This was before fully analysing the evidence bearing upon the Whirlpool rapids. Indeed weeks elapsed, with additional data added from time to time, before any attempt was made to carry new investigations in the direction where they subsequently led. Had I then published, a serious error would have been made. The importance of the features at Hubbard point would have been overlooked, and it would have been stated that the ancient Chippawa creek had been turned into the Whirlpool-St. David channel in conformity with the present topography.

SOUTHWARD ENLARGEMENT OF FALLS-CHIPPAWA VALLEY.

At Hubbard point, also opposite Swift Drift point beyond, the floor of a pre-glacial valley was 317 feet above level of Lake Ontario. This depression was made in the limestone formations of the Lyell ridge, which here crosses the course of the gorge, and rises back from the river to 370 feet. If one stands at the eastern end of the Upper Arch bridge and looks at the broad valley, bounded on one side by the Upper rapids, and on the other by the terrace-hill of Victoria Park, and then turns in the opposite direction, the terraces on the Canadian side are seen to swing round to near Hubbard point, and appear to meet the corresponding ones on the New York side, which, close to the end of the bridge, are underlaid by rock at or near the surface. The view presents an amphitheatre nearly closed at the northern end and widening out to the south, suggesting a former topography draining southwestward. Applying measurements: Up the Ferry road leading from Clifton Hotel the rock was everywhere shown to be near the surface, for it

PLATE XXII.



Map of Falls-Chippawa pre-glacial valley.

was rececently exposed in the sewer-cuts. On the map (Plate XXII.), the boundary of this ancient basin was taken at the level of 320 feet above Lake Ontario, as the rocky floor above rises somewhat slowly, while at Hubbard point the old floor has an altitude of 317 to 320 feet.

Opposite the Ferry road, across to the corresponding point in Prospect Park, the valley has increased from 1,200 feet at Hubbard point to a breadth of quite 2,500 feet, though it is only 3,500 feet to the south of Hubbard point. Another traverse of 3,000 feet brings us opposite the southern corner of Goat island. From the rocky shore near the upper end of the island, across the gorge to the terrace behind Victoria Park, is a distance of 3,500 feet; but as the Canadian rocky rim here is buried, the additional amounts that must be added to this breadth are not definitely known.

At another section 3,000 feet southward at the Carmelite monastery, the distance, from the rocky edge of the Upper rapids at Goat island to the well (No. 6), is about 4,700 feet. As this well is within the valley the additional distance to the buried western side is not known. Thus the picture of the widening of the basin to the southward, although heading only at Hubbard point, is supported by actual measurements, and the enlargement broadens from 1,200 feet to over 4,800 feet in a distance of less than two miles, while the depth increases about sixty feet in this distance. At even 270 feet above datum its breadth in the Park is 1,600 feet. As before pointed out, nowhere north of the immediate vicinity of this channel, as at the Upper Arch bridge or anywhere northward, are there any remains of a pre-glacial floor lower than 280 feet. This broadening and deepening to the southwestward, with a slope descending from the highest ridge at Hubbard point, forced the conclusion that the Falls-Chippawa valley was a pre-glacial feature with the drainage in the opposite direction to that of the present day.

Parenthetically let it be stated that at this higher Lyell ridge at Hubbard point, while its surface was due to atmospheric action on the Niagara limestones, the erosive features may have been determined by a physical disturbance of the strata (*see* Plate xvi., page 117), which on its northern side has a general southwestward dip and on the other side a southeastward.

ORIGIN OF UPPER RAPIDS AND FALLS BASIN.

Thus was discovered the Falls-Chippawa trough or basin which revealed the origin of the Upper rapids of the Niagara river, in that their slope belonged to the pre-glacial surface of the southeastern side of the Falls-Chippawa depression.

FALLS-CHIPPAWA VALLEY SOUTH OF VICTORIA PARK.

The establishment of this Falls-Chippawa valley was not completed by the data already given. There was a space of three miles southwest of Victoria Park that required investigation. At Chippawa village, in well No. 8, the rock floor has an elevation of 298 feet. The floor here is actually lower than at the intake near the upper end of the Dufferin island channel, where it is at 300 feet. A little below this point, at the elbow of Dufferin channel, the old surface is 286 feet, and in Logan's well (No. 9), nearby, rock is two feet lower. At another well (No. 7), a short distance to the westward, the rock surface is reduced to 265 feet, or only seven feet higher than the lowest part of the floor of the channel in the southwestern cove of the Park, which was formerly covered by a gravel bed, since removed in laying the water pipes of one of the power companies. Thus the old southeastern side of the Falls-Chippawa basin is established. The Carmelite well (No. 6), near Loretto convent, shows the rock floor at 279 feet; this is on the lower part of the rising northwestern boundary. The definite limits of this boundary have not been ascertained, but within a short distance the rock may be expected at 330 or 340 feet.

About three-quarters of a mile west of the Carmelite well, at another (No. 13), the depth is said to be 100 feet. If this be the case the rock floor is reduced to 266 feet; and even if somewhat higher it indicates an embayment of large size into which the Falls-Chippawa basin expands on receding from Niagara river. At a mile to the southwest of this latter point, the Malone well (No. 20), reaches rock floor at 312 feet above Lake Ontario, while the Grey well (No. 21), three-quarters of a mile farther southward, shows the rock at a level of 267 feet; so that the boundary line is somewhere between these two last mentioned points. (*See* Plate XXII. and also large map where wells are indicated.)

At half a mile south of the Grey well is the Ferry well (No. 22). It is situated just north of the creek. The rock surface is at 259 feet. Thus it is found that the embayment sweeps southwestward into a greater basin between the ridge of Niagara limestone on one side, and the Corniferous limestone on the other.

Returning now to the cove south of the convent, the southeastern side may be located by the Glasgow well (No. 10) where the rock surface is at 282 feet, or sixteen feet below that at Chippawa village. Again in the middle of this buried embayment, at Montrose Roundhouse, the rock appears at 256 feet (well No. 23), and in Kister's well nearby (No. 24), at 251 feet. Near the middle of the valley are two Clark wells, one of which (No. 11), shows a depth of 112 feet to the rock. Some of the quicksand from the bottom had been kept by the owner, Mr. Patrick Clark. Here the buried floor is at 232 feet. In a southwestern direction, nearly half a mile beyond the creek, is the well of Mr. Emanuel Read (No. 25), which reaches rock at a level of 236 feet above Lake Ontario.

LATE REVERSAL OF DRAINAGE AT THE FALLS.

The last mentioned wells show the deeper part of a buried channel, which is nearly 100 feet below the level of Lake Erie, whose elevation is 326 feet above Lake Ontario. This feature opens up another question, namely, what became of the drainage of the Falls-Chippawa basin before the mantle of drift was spread over the Niagara peninsula? Following up this investigation a new outlet for the Erie basin has been discovered, and will form a sequel to the chapters on Niagara falls.

The reversal of the course of drainage of the Niagara district has been established by well borings; still, had one not blindly gazed upon the topography about the falls it would have been of itself apparent even without measurements already set forth in a former part of this chapter. The whole basin from Hubbard point clearly suggested a topography opening to the south, which now anyone can see at a glance, as shown in map, Plate XXII.

Had not the drift hills adjacent to the Upper rapids been too high the water would have coursed a mile westward, when it would have swept around the triangle between Victoria Park and Chippawa village. In this case the river would have established its course in the deeper channel without forming the Upper rapids. The tendency of the river to sweep round and remove these drift hills is shown in the broad flat of Victoria Park, and in the cove which contains Dufferin islands.

LOWER TERRACES OF FALLS-BASIN.

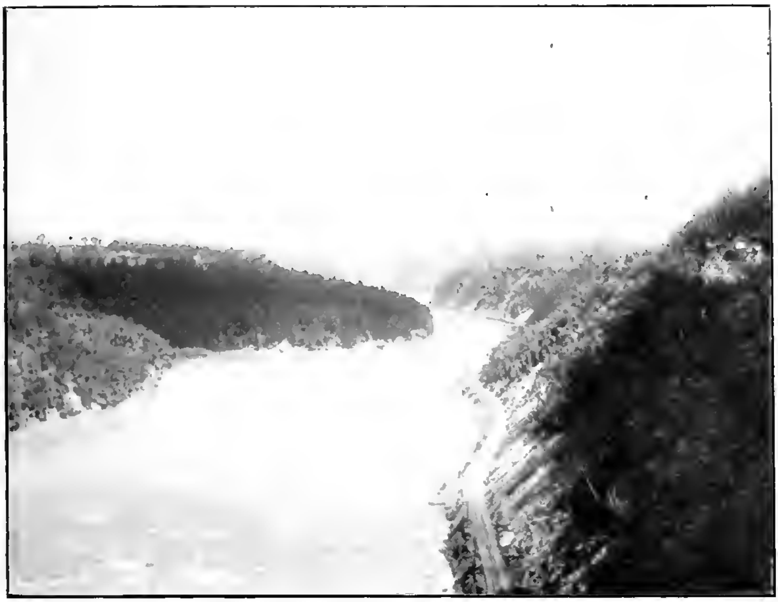
The lower terraces of the Falls-basin, below the one described at about 317 feet (page 115), are of minor importance as they only mark the lowering of the stages of the river during the recession of the falls. In Victoria Park the undermining of the higher terraces has led to the formation of one high bluff, yet on approaching its northern end a terrace is distinctly separated, at an elevation of 308 to 310 feet. It continues about a third of a mile north of the Upper Arch bridge where it is cut off at the edge of the chasm. It is composed of commingled river gravels and earthy deposits. Its equivalent occurs at Prospect Park and on Goat island, and its level is that of the rock floor at the Narrows, where crossed by the railway bridges. This last feature suggests that this terrace was formed in quieter water held back by the higher floor in the vicinity of Hubbard point.

Another terrace is shown at 292 feet, having a lower rock floor in front at 280 feet. The lower rock floor in the vicinity of Table Rock House at 265 feet, and a still lower fragment at 258 feet, are remains of the bed of the Falls-Chippawa basin, uncovered by the modern river.

RESULTS OF FINDING THE FALLS-CHIPPAWA VALLEY.

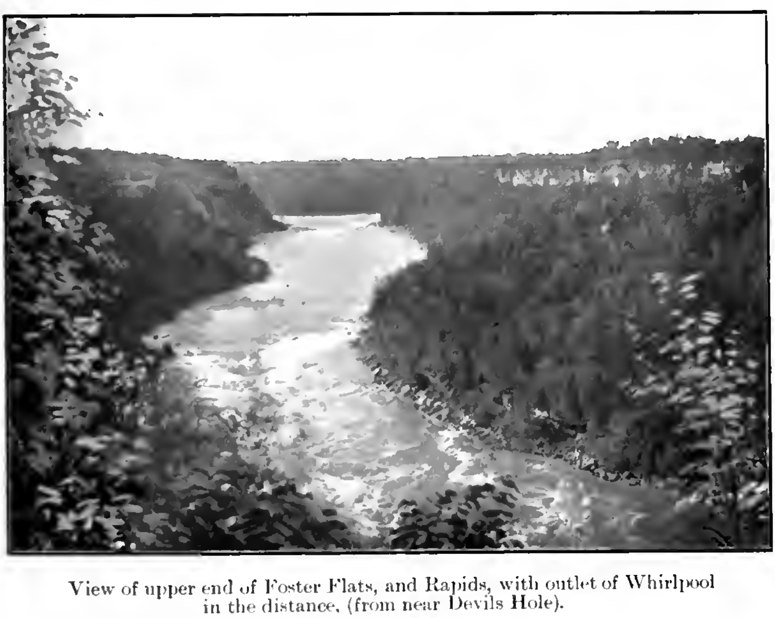
The account here given of the Falls-Chippawa channel is, I believe, the first suggestion of its existence. It certainly is the first proof of its discovery, with the topographic features opening to the southwest. These, as described in this chapter, establish the origin of the Falls-basin and that of the Upper rapids, and reveal the existence of the deeper trough out of which the falls are now beginning to emerge, with consequent retardation of their recession. They also show the former reversal of drainage in this district. Lastly, the investigations here described led to the finding of the great ancient outlet of the Erie basin, which, as earlier discoveries showed, received the pre-glacial drainage of the Upper Ohio river.

PLATE XXIII. A.



View of southern end of Foster Flats, obstructing gorge, with rapids cutting round, (from Whirlpool Point).

PLATE XXIII. B.



View of upper end of Foster Flats, and Rapids, with outlet of Whirlpool in the distance, (from near Devils Hole).

CHAPTER XIV.

FOSTER FLATS—RECORDING CHANGES OF HEIGHT OF FALLS AND VOLUME OF RIVER.

SIGNIFICANCE OF THIS SECTION.

Midway between the Whirlpool and the bend of the river beyond the Devils Hole is an extensive terrace projecting far into the gorge. This is surmounted by other terraces and huge fallen masses of rock, the whole producing a sloping promontory extending into the cañon at a level lower than the floor of the country trenched by Niagara river. This is shown in Plate XXIII. A.

Standing upon the highest of these terraces, called Wintergreen flat, which is a fragment of the late floor of the river, and looking northward, there appears to be a densely wooded flat obstructing the river beneath. This is shown in Plate XXVI. B.

The name 'Foster flats' was derived from that of a settler of early days, and locally the main terrace is known by this appellation, which also appeared on charts of the river many years ago. Lately, however, the Park Commission called it the Niagara glen. In the true sense of the word it is not a glen as it occurs on one side of the river only, in the form of a terrace surmounted by others or flats wherein the whole scientific importance lies. The term 'bottom' could also be appropriately used. Foster flats was not mentioned in scientific literature until I drew attention to their bearing upon the history of the Falls, 1894.* Foster flats furnish by far the most important records in the history of Niagara throughout the gorge.

CHARACTERISTICS OF FOSTER FLATS AND ASSOCIATED FEATURES.

Foster flats (*see* large map) begin at 11,000 feet from the mouth of the gorge, in a little eddy at the point of the wedge where the river is about twenty feet above the lake. Then they broadens out and extends up the cañon for a distance of 3,600 feet. At first the terrace in front of the talus has a breadth increasing from 60 to 100 feet in a distance of less than 300 feet from the end of the flat, with an elevation of about twenty feet above the river. Here is a sudden rise to thirty-five or forty feet, whereupon the terrace rapidly broadens out to 300 feet. On its lower surface there are almost no fallen masses until reaching 600 or 700 feet from the lower end. (*See* map Plate XXIV., also figure 23.)

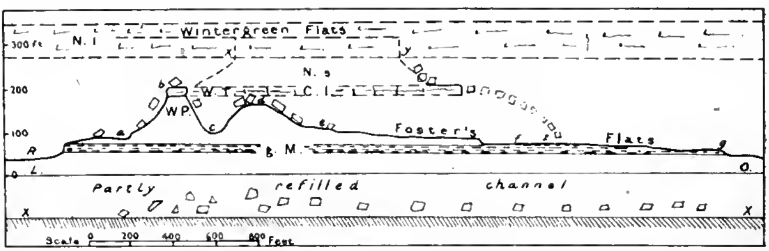


Fig. 23. Longitudinal section of Foster flats. R.—river surface above flats (below Flats river is 20 feet lower). L. O.—level of Lake Ontario; X. X.—approximate bed of channel partly refilled with blocks producing Foster rapids; a b c d e f g, profile 200 to 300 feet from edge of river; showing steps nearer the river at f and g. Spur of fallen masses at d with valley c at flat-level. W. P., Wilson point (or end of spur) of Clinton limestone with trail of blocks in front extending to river rapids. W. t., Wilson terrace of Clinton limestone (C. l.), 100–200 feet wide, ending at lower end in a spur of fallen masses. g. M.—gray Medina band forming part of floor of flats; N. l., Niagara limestone wall behind, with spur (Wintergreen flat) projecting 400 to 500 feet between x and y.

At a thousand feet from the northern end, the plain has a breadth of nearly 800 feet, reaching from the river to the foot of the talus slope. Here is the end of the medial ridge, which

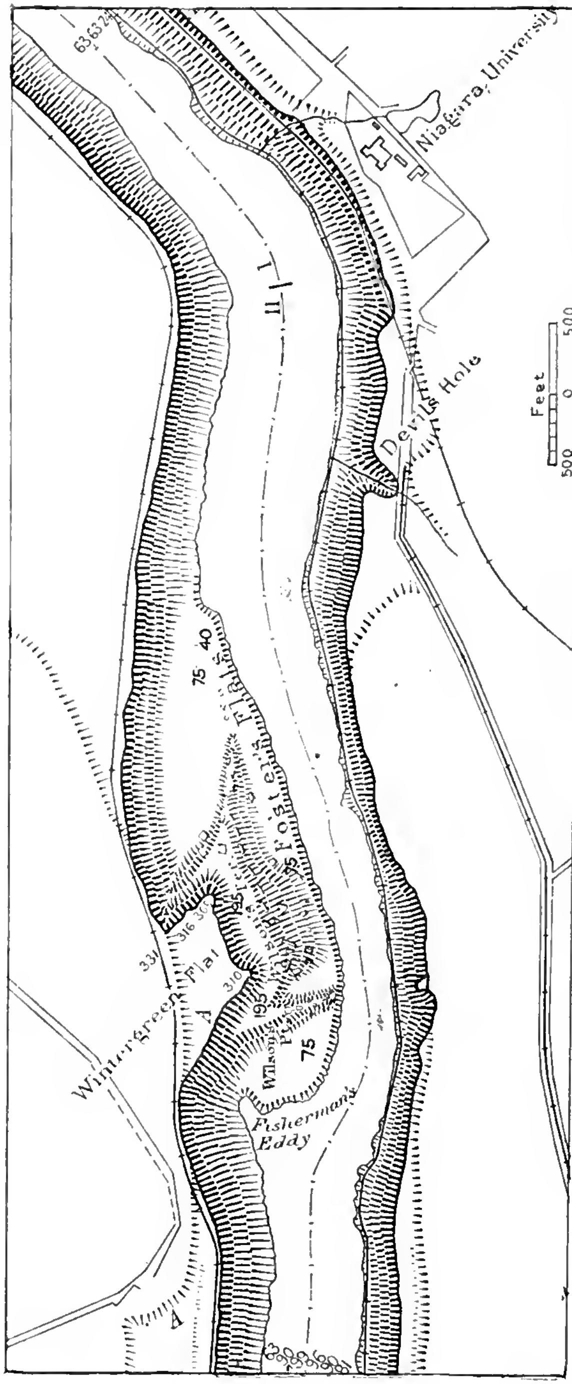
* 'Duration of Niagara Falls,' by J. W. Spencer, cited before.

extends from under Wintergreen cliffs, and incloses a cove of several hundred feet in length, the floor of which rises from seventy-five feet above Lake Ontario at end of spur, to 115 feet at its head, where it is characterized by fallen blocks. Wilson ridge, traversing the flats, is 150 to 200 feet from the river, with the terrace in front, nearly fifty feet above the water. From the end of the ridge to the Pavilion is about 800 feet. Midway is an abrupt rise of ten feet to the higher terraced floor, which in front is seventy-five feet above the lake, rising backward somewhat rapidly to the foot of the Wilson ridge. At a short distance above the Pavilion the terrace is surmounted by higher ground partly composed of natural strata, but these are mostly buried by fallen blocks which represent a tongue of débris extending from the higher ledges crosswise of the river. Many of these blocks rest upon large rounded boulders and stones which belonged to the bottom of the river. Beyond this spur is an embayment along the course of the intermittent drainage streams, with the floor having a height corresponding to that of the terrace. Farther on is another spur. Here the disturbed strata extend directly to the cliff above the water, and are covered by great fallen blocks. The end of the ridge is seen in Plate XXV. A, which also shows the rapids in front of the flats.

Passing the second spur, or Wilson point, the slope rapidly descends to the surface of the main step or terrace, which extends to the upper edge of the flats 600 feet beyond Wilson spur, with a height of seventy-five feet above Lake Ontario. The two cross spurs shown on map are composed of blocks derived from Wintergreen cliffs, and from Wilson terrace. Indeed, it is from the blocks of these spurs that the river is obstructed so as to give rise to rapids situated here.

The descent of the river from above Foster flats to just below the Pavilion, is about fifteen feet, while between here

Plate XXIV.



Map of Niagara gorge at Foster flats and rapids.

and the lower end of the Flats it is only five feet. (*See* map, Plate XXIV.)

The terrace at the upper end of the old river bottom shows that the forces of the river were still at work here at the same level as that which obtained while the falls were at the lower part of the flats, but a great change occurred immediately above them. As the terrace bends round from the narrows to the foot of the cliffs, close to the talus banks, it is indented by a trench leading to Fisherman eddy (also called Cripson eddy), cut through the underlying thick Medina beds; so that although there is no permanent stream the rains and frost action have excavated a large gully out of the hard rocks.

While the main floor is generally underlaid by the Medina band of gray sandstone having a thickness of fourteen feet, with spurs covered by fallen blocks surmounting it in front of Wintergreen cliffs, yet the lower end of it has a level below the surface of the Medina sandstone. This shows that its origin and preservation are not entirely due to the durable rocks contained in it. So, also, with regard to the shales and red and mottled sandstones of the overlying spurs. Indeed these spurs are the remains of the Wilson terrace (W. P. figure 23) which once extended across the river, when the intermediate falls from the Clinton beds had not yet united with the upper Niagara falls, which union is found to have taken place here. The *cul de sac,* behind Wilson terrace, continues broad, heading in the marginal wall of the cañon from which Wintergreen flat projects, but the apex is beyond the limit of the old river bank.

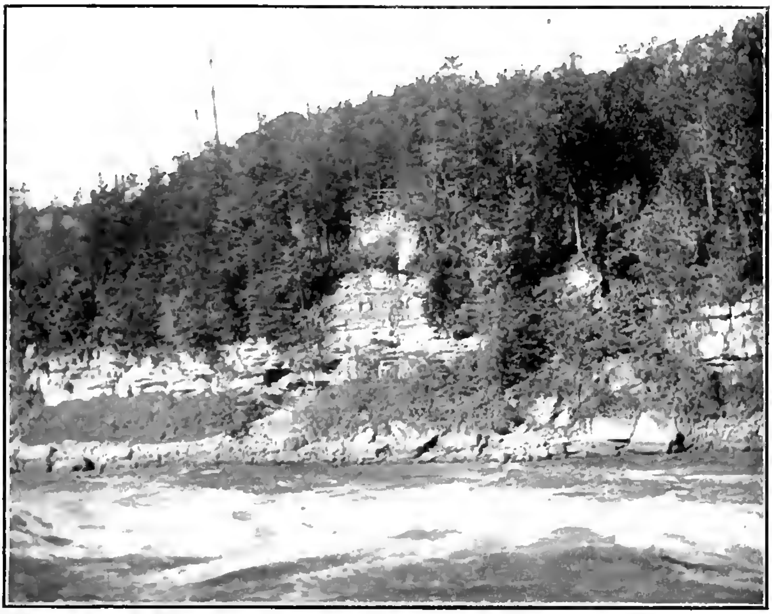
On descending the cove and receding from the cliffs the blocks become more scattered and almost disappear, in strong contrast to those at the head—(one of which measured fifty by forty by twenty feet)—showing how the river grinds up or dissolves the great masses which fall into it. Here on the terrace is a feature of the river floor showing what would be expected if the present channel could be drained. This floor was the old bottom of the river when the waters were descending upon it from the second cataract.

The northern face of Wintergreen flat shows a broad V-shaped incision, over the edge of which the river once cascaded. In front of the old river bank at Wintergreen flat its inner edge has an altitude of 316 to 318 feet, with a floor sloping downward to 305 feet at the northeastern angle. Thus the river must have reached a depth of over ten feet. The present form does not show the shape of the crescent when Niagara falls were located here. The northeastern angle of Wintergreen is undercut as if by currents rounding the point. The precipitous cliff is forty-five feet to the talus, which now slopes sixty-five feet to the Wilson terrace, at an elevation of 195 feet above Lake Ontario. The point, 310 feet on map, is still more under-cut, as this was the last spur at the apex of the falls of smaller volume, before the union of the upper Niagara and Clinton cataracts. This feature locates the middle of the original river and gorge, when the upper falls were cascading on the Clinton or Wilson floor, as is more plainly seen in the field than on the map.

WILSON TERRACE OF CLINTON LIMESTONE AND ITS REMAINS.

This terrace is due to the massive bed of Clinton limestone of eight or ten feet in thickness resting on another ten feet of thinner limestones. The upper bed is extremely durable, while the lower beds are somewhat yielding. Again, these strata rest upon the more perishable red shales and sandstones of the Medina series. Here occurs a conspicuous flat which I have called the Wilson terrace, in honour of Mr. James Wilson, who turned these wilds among the huge masses of fallen rocks into a wonderful park, unlike any other in eastern America.

In front of the talus below Wintergreen cliffs the Wilson terrace has a breadth of 100 to 200 feet. Below the eastern angle



View of head of Foster Flats, and of Wilson Point, where the upper and middle cataracts united.

View of Cove and widened channel, where Foster Flats are abruptly cut off at their head.

of the upper cliffs (310 feet above the lake), the spur of Wilson terrace (map and Plate XXXV. A), extends outwards across the course of the river, and terminates 400 feet from the edge of the cliffs with detached masses beyond. On the southern side of this spur the terrace is bounded by cliffs twenty feet or more in height, in front of which is a talus strewn with blocks of fallen Clinton limestone. These are now lying outward where they were broken off as the currents undermined them by the removal of the softer strata beneath. It seems strange to see the effect of the river undercutting in front of it instead of on its margin, but this spur is a remarkable record of the union here of the secondary falls and the upper Niagara falls.

In front of the main face of Wintergreen cliffs, there is a great assemblage of fallen blocks below the level of Wilson terrace. One of these blocks, though now split in two, is eighty feet long, twenty feet wide above the ground, and eight or nine feet thick. It lies crosswise of the course of the river. It is the fallen edge of the Wilson terrace undermined from the lower side of the river, when the falls were still cascading over it, and it lies only a short distance below its natural position. In this locality are found an immense number of these great blocks, and they show that the Wilson terrace must have extended across the river, being the floor of the channel into which the upper falls cascaded, but located nearer the Canadian side than the present channel of Foster rapids, as shown in Plate XXVI. A and other figures.

POT-HOLES IN FALLEN BLOCKS.

Here are found pot-holes in fallen blocks, formed beneath the falls, after the blocks had broken loose and were resting on the slopes below, as shown by the holes which now have a vertical position. Three of these pot-holes in one block have a diameter of eighteen inches with a depth of three feet or more. Another one had a diameter of from three to four feet, and a depth of eight feet with the bottom broken out. (Plate XXVII. A.)

A little specimen of a pot-hole illustrates their mode of formation. A lead sinker for a fishing line with a conical shape and a length of three inches and diameter of one inch had been lost in the Upper rapids. When recovered it was found to have made a pot hole only a quarter of an inch larger than its own diameter. The sinker itself was very little reduced in size. It seems that the sand became imbedded in the lead and this acted as a grinding tool to bore out the pot-hole. So it is that the round polished pot-holes are made by the sand being ground between the stones and the rock itself, and these pot-holes are due more to such an abrasion than to direct action of the pebbles, which would soon be ground away.

DISTINCTION BETWEEN NIAGARA AND CLINTON BLOCKS.

The Clinton blocks can easily be recognized. They are never more than eight or ten feet thick, while those derived from the Niagara cliffs may have a much greater thickness. The Clinton blocks have more or less the form of great slabs and can thus be distinguished from the thicker and more cubical Niagara ones. Minute examination, however, would show other characteristics for distinguishing the two kinds. Upon the Wilson terrace there are a great many fallen blocks from the Niagara cliffs. So, also, beyond the remaining terrace among the Clinton masses, even down to the river edge, the Niagara blocks occur in great numbers. These show that Wintergreen flat must also have extended much farther toward the middle of the river after the recession of the Upper falls than now appears.

NORTHERN SPUR OF WILSON TERRACE AND COVE BEHIND.

From under the northeastern point of Wintergreen cliffs the Wilson terrace tapers to a point 200 or 300 feet distant.

The base of this wedge is about 100 feet across. Towards the point some transverse fissures dissect the mass. Beyond we find these surface blocks first separated, though in their natural position, and farther on they are tilted. This feature extends for another 300 or 400 feet. This is the narrow medial ridge on Foster flats. While some blocks of Niagara limestone occur upon the surface of the spur near its base, yet the fallen blocks of the ridge are those of the thick Clinton band which had been undermined on the removal of the underlying strata. That this ridge is part of the old Clinton floor, of which remnants extend as far southward as Wilson point, there is no question; but the occurrence of this cove behind the spur of Wilson terrace already mentioned, presents difficulties.

The Wilson floor was the bottom of the river receiving the waters of the upper cataract; Foster flats in the same manner received the falls from the Clinton limestone, but in the cove the evidence of an intermediate water fall from the Clinton bed does not appear. The apex of the cove in the northern side of Wintergreen flat is beyond or outside of the original banks of Niagara river, where the floor was 316 feet above the lake. Outward of this at a distance of 400 feet the floor is lowered by ten feet (*see* map Plate XXIV.); consequently this cove, heading where the water was shallowest, could not have been made by the current of river. Its origin is not apparent.

This feature is at variance with the physics of the normal falls, and cannot be overlooked. An island surmounted on the ridge, as suggested by Mr. Gilbert, would have had to be in front of the main course of the river, as it was passing the deepest channel, where Wintergreen flat is now located, with the apex of the lateral falls not in the middle, but on the outer edge of the gorge, where the water must have been shallowest. This is a very strong reason for discarding the idea of an island of such extreme narrowness as to be less than its height above the Clinton rocks, besides which the necessary débris of Niagara limestone does not appear. The occurrence could scarcely be expected as it would not be consistent with the Clinton floor of the intermediate falls.

The present channel is an encroachment of 400 feet or more upon the eastern side of the gorge. Accordingly, the river must have passed over the transverse spur of Wilson point with the Wilson terrace as the northern spur, for a remnant of the floor is still preserved beneath Wintergreen flat. This conclusion is confirmed by the features shown in Plates XXIII., XXIV. A and XXVI. A, and XXVI. B, indicating that the outer point of Wintergreen flat was near the middle of the river, which, from the views, is seen to be diverted entirely out of its course to the eastern edge of the gorge. At the spur of Wintergreen flat (310 on map) is a projecting point showing the place where, at one time, was the apex of the falls which cascaded to the Clinton floor below, with a lateral shelf, like that of Goat island, over which the waters were still flowing hundreds of feet in advance of the apex.

The intermediate falls from the Clinton limestone became rapids in places, over the harder upper layers of the Medina series, as shown by the rising ground at the cove, and also by features well shown at the lower end of Smeaton ravine. These rapids soon passed to the softer layers until the channel reached the Medina gray sandstone band.

UNION OF NIAGARA AND CLINTON FALLS—THEIR HEIGHTS.

The Wintergreen flat was the floor of the upper falls. The Wilson flat, which was the floor of the intermediate cataract, indicates the separation of the two falls, the latter descending from the Clinton limestone band into the river flowing over Foster flats and covering the floor of Medina sandstone. Behind the northern spur, and also above the terrace south of Wilson point, the absence of the Clinton limestone bed of the middle falls shows changed conditions.

PLATE XXVI. A.

View of Channel with Foster Rapids, passing around Foster Flats, and under-cutting the eastern side of gorge.

PLATE XXVI. B.

View looking down on North End of Foster Flats and River, from outermost point of Wintergreen Flat.

With the Wilson terrace abruptly ending, the Clinton and Niagara cataracts finally united at this point, but they did not excavate more deeply than before their union. At the time of the union the course of the current was obliquely from the Canadian to the New York side, and it is found to have been diverted by the walls of Wintergreen flat and Wilson terrace. A higher buttress nearly opposite 310 on the map, occurs on the New York side. This, however, has not the form of a terrace, but is the sloping edge of the plateau above (Eldridge). This feature of the falls breaking through a barrier and leaving buttresses on both sides is repeated at the present outlet of the Whirlpool (Plate XXVII. B, on page 190), where they have considerably reduced the present breadth of the cañon.

The union of the two cascades easily explains the cliffs facing up the river on the southwestern side of Wilson point. These were undermined by the currents sweeping against them and causing the blocks of Clinton limestone to fall outward in a direction opposite to that of the course of the river. The upper cataract had a height of 120 feet measured from the edge of the old channel at Wintergreen flat to Wilson terrace and from this floor to Foster flats, the Clinton or second cataract fell another 120 feet (taking the mean height of the flats which rise somewhat immediately below). During the epoch of the Clinton falls the volume of the water was only 15 per cent of the total present discharge (Chapter XX.). As the retarded river below Foster flats has now a depth of only sixty-three feet the former depth of the water may be taken as not exceeding ten feet or less with free drainage; but the barrier at Wilson point may have temporarily increased the depth of the river above, after the addition of the Huron drainage.

The distance from the mouth of the gorge to Wilson point, which is the last remnant of the Clinton floor before the union of the two cataracts, is 13,400 feet. The united falls now receded another 600 feet to the head of Foster flats, when the great change in the physics of the river occurred. The lowering of the Ontario waters on this section had as yet no other effect than that of affording an easy slope for the drainage.

THIRD OR MEDINA CATARACT—CHANNELLING FOSTER FLATS.

At Foster flats another record of great change in the features of Niagara river is found. With the emergence of the floors of the river, by the lowering of the Ontario level, thus drawing off the water from the Clinton channel, a third fall came into existence, due to the occurrence of the heavy band of Medina gray sandstone. The volume of the river was not yet increased, so that a small channel was sufficient to take the stream with rapid descent.

The narrows at Foster rapids have been formed by obstructions of fallen blocks derived mostly from the eastern wall, as the river has been creeping that way and undermining that side (*see* Plates XXVI. A and B). Some blocks have rolled off the end of Wilson point. This blocking of the channel has occurred since the backing of the Ontario waters into the Niagara gorge at a later date.

INCREASED VOLUME OF THE RIVER.

After the upper united falls had passed Wilson point they descended 240 feet directly to the floor of Medina sandstone, yet they could not penetrate it. So they continued until they reached the head of Foster flats. It is immaterial how far the third fall lagged behind the united upper ones. The flats are 35 feet higher than the river to the south of them, which is 99 feet deep. The modern falls with their present height have an effective erosive force of 80 to 100 feet below the river surface. Now it is found that the force of the river was sufficiently increased to penetrate the original floor to a depth of 135 feet. This actual deepening corresponds to the increased

Large pot-hole, with bottom broken through, formed in block of limestone after it had collapsed beneath the Falls when they were at Foster Flats.

PLATE XXVII. B.

View of Thompson Point and buttress below, (looking across outlet of Whirlpool).

mechanical power of the falls, due to increased volume, when the falls were passing this section. The penetration of the flats by the third cataract seems to have been when the falls were at the Whirlpool, for here the surface is lowered some 30 feet below the level of the flats, but the Whirlpool reaches to an increased depth of about this amount, below the floor of the channel outside of the pool,—with the consequent lowering of its surface, so that the falls were here able to excavate to the greater depth, than is now seen further down.

The sudden widening of the channel occurs immediately above the head of Foster flats, as may be seen in the map and in Plate XXV. B, as well as also the deepening observed in the soundings between here and the Whirlpool, where a complete section of the broad U-shaped channel was obtained. The river in front of Foster flats is about 300 feet wide, while just above it attains 900 feet, but beyond this local enlargement the mean width of the river is only 650 feet. The united upper and middle falls together had receded only 600 feet when the great enlargement took place. As there was no increase in the height of the falls, this enlargement could only have been due to a greater volume of water, such as the addition of the Huron discharge to the Erie drainage and the Niagara river, which actually occurred. (*See* Chapter XXVII.)

Opposite the upper end of Foster flats, upon the eastern side of the gorge, is found an indentation in the cliff. It extends for about a thousand feet to a rocky promontory, and the general outline suggests a former connexion between it and Wintergreen flat. The conclusion arrived at, concerning these features, is that this is the locality where the increased volume of the river became effective, producing falls oblique to the general course of the river, as the waters were cascading into the smaller and more ancient channel which was insufficiently large to take the increased discharge, so that this was carried down and passed over the side of the chasm into the channel below. Such a condition necessarily in time excavated a broader cañon which assumed a normal form by the recession of the falls.

The distance between the upper edges of the cañon is abnormal, reaching to 1,700 feet. This gave the impression that an extraordinary volume of water had been required to excavate such a great breadth. Below the Whirlpool the old banks of the river were 1,500 feet apart, while the gorge has a breadth of 1,300 feet. Above Wintergreen flat the former channel widens to 1,650 feet, while at Wintergreen point the gorge itself is reduced to 1,200, and farther down its breadth is 1,400 feet. The elliptical form (as shown on the map) is not a usual feature.

That the course of the ancient river was over Wilson point is unquestionable. The deeper small channel on the side, with the Medina falls, directed the course of the now enlarged river, with the increased quantity of water pouring into the western side, obliquely, as just mentioned. This naturally crowded the gorge upon the eastern bank, as shown in Plates XXVI. A and B, and accounts for the widened cañon here, beginning to expand out of its natural course into an elliptical form just above the head of Foster flats, and the residual upper terrace of Wintergreen. These features, both in the gorge and at its outer edges, establish the position of the falls when they received the increased volume of water from Lake Huron.

The slope of the banks, in the curve of the river below Foster flats, on the eastern side of the gorge, is much less than in front of them, where there has been more recent undermining of the lower formations. On the Canadian side frost action is shown both above and below Wintergreen flat where the walls have fallen away from 50 to 100 feet, cutting off abruptly the original river bank which extends from back of the Whirlpool to a point 1,400 feet from the head of Wintergreen. Below Wintergreen the terrace has also fallen away so that the wall of the gorge is now back of the position of the old shore line.

At Wintergreen, the original banks are well preserved. A few hundred feet farther on the old shore line reappears and recedes from the present brink, showing what was a lagoon or expansion of the river. (*See* large map.)

Upon the revision of the physics of the Whirlpool gorge, no evidence was found to show that there had been an increased volume in the river in this section, but the old banks were strongly cut terraces indicating great width the river, not merely to the Whirlpool, where the western shore has been undermined and fallen away, but also to below Thompson point, and between it and the head of Wintergreen flat.

To repeat, the strongest proof of the augmentation of the river at this point is found in the penetration of the former floor of the channel above Foster flats, of which they are a remnant. These have a height of seventy-five feet above Lake Ontario, so that the soundings above them, in the channel 650 feet wide, reaching to fifty-nine feet below the lake, show that the increased discharge was able to penetrate 135 feet into the solid rock floor which received the earlier volume, and carried it to the third cataract situated farther down the gorge. The surface of the river has been lowered thirty-five feet or more since the receding third fall subsequently penetrated Foster flats. Indeed this depth of penetration corresponds to the height of the falls at this locality, in the changing physics of the river.

REVIEW OF FORMER CONCLUSIONS.

This revision of the study of Foster flats is made *de novo,* eleven years after the first writing on the subject. That the falls had receded, under a reduced descent of the river and volume of water, to the point was then shown. But between this locality and the head of Whirlpool rapids difficulties then arose, to which only suggestive hypotheses could be applied. Owing to the lapse of time I was not guided by any preconceived theories in the present revision of the work. Nor did I refresh my memory by reading my earlier contributions, so that the present interpretation has not been the result of previous impressions. It is satisfactory to me, to find how well the early pioneering hypotheses have withstood the test of time and re-investigation.

In 1894 I concluded that the great increase in the volume of the water took place when the falls were at the head of Foster flats, stating that:—'After passing Foster flats the chasm shows the effect of a greatly increased force, for the gorge is again widened and the terrace below washed away. . . . The magnitude of the erosion indicates an increased discharge which was produced by the turning of the waters of the Huron basin and adding them to the Niagara drainage. The effects of the greatly increased volume of water were to widen the chasm and cut away part of Foster platform, but leaving enough to tell their history (page 466†). This is one of the discoveries in the physics of the river, furnishing a time element in computing the age of the falls.

While three cascades were distinctly recognized, the upper and middle falls were not then known to have united here, for the detailed structure at the flats had not been studied so closely as during the present investigations. The depth of the river at Lewiston was thought to be only ninety-six feet, so that the great descent of the Medina falls and rapids was not known.

In 1888* I discovered that the Huron waters only lately turned into the Erie drainage. This paper was soon followed by others. One of these was an essay on Niagara falls, published within a few months, by Mr. G. K. Gilbert, in which he has based his studies of the changing physics of the falls mostly upon my work. Two of the most important discoveries, which he adopted, are the change in the Huron drainage, and the position of the falls when their volume was increased. Writing of

† Duration of Niagara Falls, cited before.

* Proc. Amer. Ass. Ad. Sci., Vol. XXXVII., pp. 197-199, 1888.

these in 1895, he says: When the falls had receded to just beyond the end of Wintergreen flat (that is the high level terrace above Foster flats), 'probably at about this time the whole amount of water in the river was increased in a manner to be considered later.' (p. 222.†) This had been explained by me in 'Duration of Niagara Falls' (p. 446). Again he says: 'By the tipping of the basin, the lake (Huron) was made gradually to expand towards the west and south, till the last waters reached the pass at the head of the St. Clair river. Soon afterwards the water ceased flowing through North Bay outlet' (p. 229). This was his form of adoption of the change of the Huron drainage found by me in 1888.

A little later Mr. F. B. Taylor‡ worked out an explanation for the Whirlpool gorge. He thought that the waters of Lake Huron turned into Erie as I had set forth, but that they were again withdrawn, owing to changes in ice dam, when the falls were passing the Whirlpool rapids and that later when Niagara falls were just south of Cantilever bridge, the full volume of the Huron discharge was again added. Had it not been for the new evidence of the character of the Whirlpool rapids, the problem might remain unsolved.

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† National Geographic Monograph Series, No. 7, New York, 1895.
‡ Bull. Geol. Soc. Amer., Vol. IX., pp. 59-84, 1898.

CHAPTER XV.

TERRACES ABOUT END OF GORGE, AND LAKE LEVEL BELOW THE PRESENT.

ROY TERRACE AND LAKE AT BIRTH OF FALLS.

The main banks of the river at the birth of the falls crossed a ridge extending to half a mile south of Brock's Monument and Hall point, where the old shore line has been removed by the falling of the brink (*see* large map and figure 24). Beyond this ridge an indistinct water line occurs at a corresponding height, showing the temporary level of water in the Ontario basin at about 322 feet above its present level. Near the point where Brock stream crosses it, about 500 feet inside the escarpment on the western side of the gorge, is a well marked bench which I shall call Roy terrace in honour of Mr. Thomas Roy, who made a study of the Canadian terraces adjacent to Lake Ontario as long ago as 1837.*

The inner edge of this terrace has an elevation of 287 feet, and 284 feet farther out, while there is a subordinate one near brink of gorge at 275 feet for the inner and 268 feet for the outer edge. This is the flat in front of the shelter of the Electric railway at Brock's Monument. Its maximum breadth may be taken at 300 feet, with the rocky banks behind rapidly rising to Brock's Monument forty-two feet higher. The total

* Cited in Geology of Canada, 1863.

length of this terrace is 900 feet, but the last 450 feet are beyond the mouth of the gorge and are composed of delta deposit of river stones of various sizes, while the southern part is underlaid by rock. The northern side of the delta terrace forms a steep slope to a lower terrace. This marks the floor of the

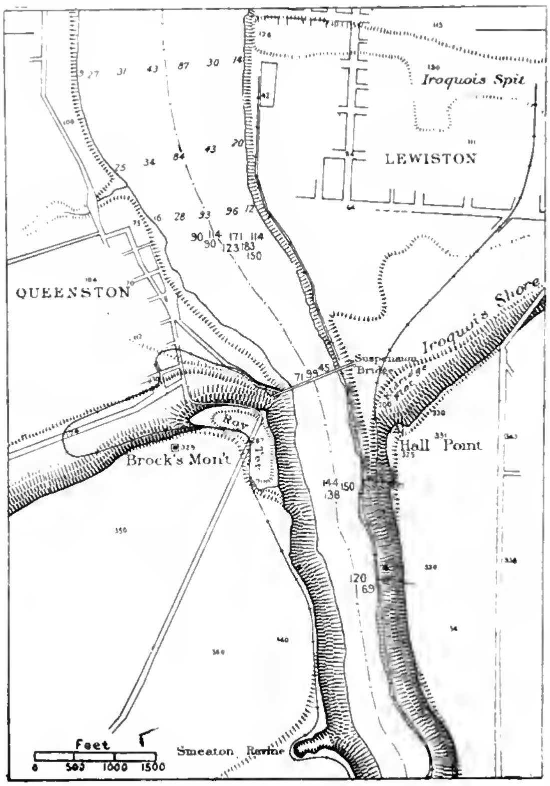


Fig. 24. Map of terraces at end of Niagara gorge. (Reduced from large map).

river at the time when the falls had their birth. (Plate XXVIII. on opposite page.)

On the rocky face of Brock cliff the Roy terrace soon becomes indistinguishable. Though this old water level has not been continuously explored it appears to occur at many points along the brow of the Niagara escarpment, where the

View of Roy Terrace (R T) formed immediately after Birth of Falls, which receeded to F, with a height of about thirty-five feet; g, cross ravine recently formed; Brock's Monument, situated on rocky bluffs about forty feet higher. Below monument the terrace declines slightly in a delta accumulation beyond. Depth of cañon about 330 feet.

front part of it seems to have been cut down by the old lake waves for twenty or thirty feet below the rising ground back of it. Still the recognition is easiest where the waves carved shore lines out of the soft drift material.

About half a mile west of the road, from St. David southward, an old shore line becomes conspicuous, bounded by low rocky bluffs. At a mile and a half farther on, but still east of the Welland canal, a spur of the Niagara escarpment stands out prominently above the plain below. The *col* connecting this outlying spur with the escarpment behind forms the floor of the terrace just to the eastward. Its height is 287 feet. In the region of De Cou falls (thirteen miles from Niagara river) at 283 feet, and on the opposite side of the great valley of Twelve-mile creek, the inner side of the terrace, with a rocky bluff behind it, has an elevation suggesting that it is at the same level, as at Roy terrace. The feature is repeated above Jordan, about seventeen miles from Queenston, with apparently the same elevation. But no survey has been made that can give the proper extension of this terrace. Suffice it to say that Roy terrace at the mouth of Niagara river plainly indicates that the height of Niagara falls, at their birth, was about thirty five feet.

ELDRIDGE FLAT.

On the eastern side of the mouth of the gorge there is a cut terrace about 100 feet wide and 200 feet high, shown on the map and named Eldridge flat. Its preservation is no doubt due to the harder beds of the Medina red sandstones distributed among shales, but its form is that of an old shore line, which represents a pause in the lowering of the Ontario waters.

BELL TERRACE.

Bell terrace is the next. On this is located the road from Queenston to St. David and westward. At the crossing of this road over the Electric railway its height is 174 feet. With a breadth of a few hundred feet it extends to St. David, where the average height is 168 feet, although it is somewhat lower at the corner of the hotel. At St. David it widens out to half a mile or more, back of which are the drift hills in front of the Niagara escarpment. Behind Merritton it is more difficult to separate from the topography, but it reappears as a distinct feature at other points, as east of Jordan. I have noticed the same terrace at points ten miles east of Hamilton. It is sometimes narrow, rising rapidly to the hills behind, or even cut away at points on the side of the escarpment. Again, it is broad.

From Niagara river westward its edge forms a steep bluff behind the old Iroquois shore line, which is thirty-five or forty feet below. The Bell terrace is seen on the one hand rising gently to the bluffs behind, and on the other descending abruptly to the Iroquois shore line in front, this makes the terrace a strongly marked feature in front of the Niagara escarpment.

Adjacent to Niagara river, at a few feet below its surface, the Bell terrace is underlaid by red sandstones and shales of the Medina series, and these, in part, no doubt, give rise to the persistency of the prominent features. But it is not everywhere on such a foundation. At St. David, and for some distance westward, the wells, to a depth of sixty feet in sands and gravel, show that the Medina sandstones are wanting, and that the terrace form is due to wave action on superficial deposits. Here is evidence of its being the floor in front of an old shore line. The inner edge of this terrace rises more rapidly than that of the Iroquois plain in front, which may be due to the washings from the hills.

This old terrace, which I have named in honour of Dr. Robert Bell, who had made most of the studies in this region before 1880,* marks a pause of considerable duration in the sinking of the waters in the Ontario basin, and its occurrence, as connected with the study of the recession of the falls, is important.

* Geology of Canada, 1863. Report upon Surface Geology.

IROQUOIS BEACH.

Again the waters sunk to the Iroquois shore line, which, at the mouth of the Niagara river, has an elevation of 135 to 137 feet. This is the most conspicuous and perfectly preserved strand about Lake Ontario. On the western side of the Niagara cañon it is simply a cut terrace in front of the steep bank in front of the Bell terrace; it is carved out of a clayey soil. From this line the old lake bottom almost imperceptibly slopes outward. While the gravel beach characterized it elsewhere it is entirely wanting here, with the result that the determination of the exact water line is not practicable within the range of two or three feet, as the washes from the hills behind have somewhat modified its inner edge. With this qualification by the use of the level I found it to have a height of 130 feet at Queenston. (*See* figure 24, page 198, also map Plate XXXIII.)

On the New York side, the old shore is more strongly marked than on the western, as the joint action of the river and lake currents have washed away the talus slopes of the 'mountainside,' and left a floor of Medina sandstone at 135 feet. In front of this terrace is a steep slope to a much lower one, beyond which a sand and gravel ridge rises at the village of Lewiston, with features such as characterize the Iroquois beach. It is a few hundred feet wide and slopes about twenty feet to the plain in front. At the end of the spur above the river its height is 126 feet, but where it joins the main Iroquois shore it has risen to 137 feet, where the crest of the spit is taken at a slight elevation above the water line.

Looking at these features from the western side of the river one would suppose they were two shore lines a few feet apart; one of sand and gravel, the other of rock. But the former declines gradually to the end, and the slope of the spit, determined instrumentally, indicates that it is one of those spits commonly formed beneath the water level where rivers enter lakes or seas. The well developed Iroquois beach was one of long duration, sufficiently so to allow the building up of gravel ridges often 300 to 500 feet wide, and fifteen or twenty feet thick. This beach marked the longest pause in the lowering of the waters of the Ontario basin, while the falls were receding to Foster flats, which, together with other beaches and Smeaton ravine, record the story of the early Niagara falls.

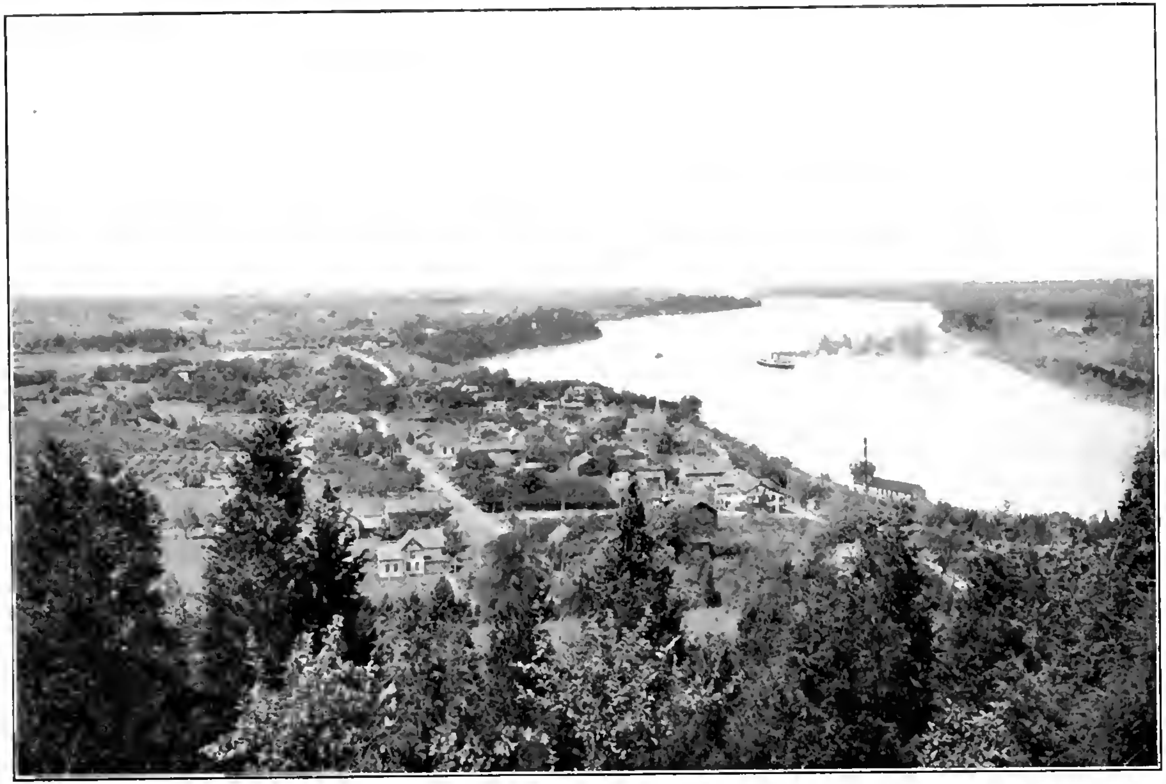
THE LOWER TERRACES.

Behind the Iroquois spit a lower terrace is seen at seventy-five feet. Farther down the river, two miles below, at Field point, the old river bed and bank are well shown where the floor is composed of gravel overlying shale or clay deposits. Here the effects of the river were strongly marked, in channelling out the surface, or depositing bars. The height of the raised river bottom is about forty feet at the upper end, and somewhat less at the lower, with the surface channels increasing in depth. Opposite, on the eastern side, is a cove forming a deep indentation in the generally high bank with an elevation corresponding in height, while the edge, below Field point, is marked by a lower water line of twenty feet or less.

At the mouth of the river is a somewhat extensive river flat in front of the town of Niagara-on-the-Lake. Its height is only three to five feet above the water, behind which is a steep bank. The whole story is not told, as the lake continued to recede much below the present level. But this terrace was made after the lake level rose again from the extreme subsidence, but before the recent lowering.

DELTA OF NIAGARA RIVER AND FURTHER SUBSIDENCE OF LAKE.

It is an undetermined question whether these lower terraces record only the original subsidence of the lake waters, or whether after the original shrinking of the lake to a smaller area, with the subsequent rise, the lake surface may not have



View of Niagara River beyond end of gorge, from brow of escarpment above Queenston.

been slightly higher than now, so that the lower terraces mark a second subsidence, due to the cutting down of the St. Lawrence outlet. Lower water lines of the Ontario basin are now drowned. The Niagara river below Lewiston has been refilled with river deposits so that its depth is now reduced in places to only thirty or forty feet. Near the lake the river is seventy-two feet deep. Beyond the mouth there is a fan-shaped delta extending nearly four and a half miles, at first covered with only twenty to thirty feet of water, but with forty-eight to sixty feet near the edge. Beyond this margin, there is an abrupt descent to 100 or 150 feet, with the lake further increasing in depth beyond. The submergence indicated here is a repetition of the features about Burlington bay, at the end of Lake Ontario, which has a depth of seventy-eight feet behind a beach five miles from the end of the lake mentioned long ago by myself.* With regard to the delta of the Niagara river, to which Mr. Gilbert called attention as evidence that the lake level was from 100 to 200 feet lower than now, it may be said that as the delta deposits at their very edge rise to within about sixty feet of the surface, and as there are no indentations in the isobaths beyond, they do not of themselves furnish any evidence of greater subsidence of the lake than this amount, although the accumulations may have been heaped up in deeper waters immediately beyond, now covering the topography of the pre-glacial basin of the lake.

From other proof a lower water line might have been inferred, such as that of the ninety-six foot sounding at Lewiston. Until the present time this depth of the river below the end of the gorge had furnished all the evidence of the former greatest emergence of the Niagara channel. Now, however, the deep sounding to 183 feet affords the first demonstration of the late great subsidence of the lake waters affecting Niagara river.

* 'Geology of the Region about the Western End of Lake Ontario.' by J. W. Spencer, cited before.

The shore line represented by the delta, I have taken as the equivalent of one now raised and tilted at the eastern end of the lake, which Dr. Gilbert stated passed under the lake waters at Oswego.

The lake level, so far as it affected Niagara river, must have sunk to that of the deepest sounding, thus lengthening the channel by eleven miles and a half, which below the surface drift is entirely excavated out of soft Medina shale. The sinking of the waters below the level of Iroquois beach brought into existence the falls from the Medina sandstone, descending 320 feet to the deep river channel mentioned—a much greater height than was suggested by previous evidence. This is shown by soundings, to have been diminished only thirty-three feet, at a third of a mile within the gorge if indeed the channel here is not partly refilled.

LOWEST LEVELS OF WATER IN ONTARIO BASIN.

If the deformation of Iroquois beach be considered as a whole it is found that between the head of Lake Ontario and Prospect farm, east of Watertown, the differential rise amounted to 367 feet. This warping of the land must have affected the rocky rim of the Ontario basin, seventy miles below the outlet of the lake; so that the waters, if the continent stood sufficiently high, could have been lowered another 500 feet. But of this amount only a little more than the depth of the great sounding is necessary to account for the deep channel of the Niagara river unless it be further refilled.

FINAL BACKING OF THE WATERS TO THEIR PRESENT LEVEL.

After the time when the waters in the Ontario basin shrunk far away from the Niagara shore the tilting of the land at the outlet of Ontario caused the lake to rise again, thereby overflowing low lands at its head, and submerging part of the Niagara gorge. The final movement was at a late date. Thus was impeded the free flow of the river with the consequent effect upon its slope.

On the return of the waters to what height did they rise? Some years ago I brought forward evidence suggesting that it rose to about seventy-five feet, as represented in terraces at Queenston, Lewiston, and by certain gravels at the Devils Hole.* It is possible that these last may have fallen from the deposits of upper river gravel; consequently the evidence here is doubtful. The rounded boulders beneath fallen blocks on Foster flats cannot be accepted as proof. At the outlet of Lake Ontario well marked terraces occur on both sides up to sixty feet or even higher, in keeping with those along the sides of the lower Niagara river. Whether these shall be found dipping as if passing under the lake in going westward, or resting almost horizontally (as is suggested at many points), is uncertain without a complete survey. But the probability seems to be that the terraces of seventy-five feet were formed, while the water was originally sinking in the lake basin. This backing of the water would reduce the descent of the river, with some effects upon the lower rapids. To whatever height the lake rose after its late subsidence, the subsequent fall of the waters has been accomplished by the Saint Lawrence river deepening its channel.

* 'Another Episode in the History of Niagara Falls,' Am. Jour. Sci., Vol. VI., pp. 439-450, 1898.

CHAPTER XVI.

GLACIATION AND DRIFT ADJACENT TO NIAGARA RIVER.

Glaciation in Niagara district. • Character of clayey and stony drift. Character of sand ridges. River deposits with shells.

GLACIATION IN NIAGARA DISTRICT.

The glaciation, or polished and scratched surfaces of the rocks, establish the character of the country before the glacial period was closed, and sharply defines the work performed by the modern river, which at different places has re-exposed the old drainage surface. Thus, in the excavation for the aqueduct pipe of one of the power companies in the Victoria Park, the southern edge of the buried Falls-Chippawa valley was found scratched and polished. Again, on rising from the lower terrace at the Whirlpool rapids, a few feet to the higher floor the rocky bank of the ancient valley is found polished. This proves that the broad channel at the Narrows was pre-glacial. So also at the Niagara quarry, on Monroe's farm, and beyond at Harvie fall, the Whirlpool-St. David valley shows its upper edge to have been rounded and polished. At the last mentioned place the direction is S. 10° W. just outside of the trench, the trend of which here is N. 20° W.

During the summer of 1905 extensive excavations for sewers were being made on Ferry road and on the street beyond, in Niagara Falls Centre, which showed that the upper rocks had been planed off to a remarkably level surface, highly polished and slightly scratched. Here the elevation of the surface rock is 354 feet; the direction of the striations is S. 45° W., approximately in the same direction as this section of the river, but as the old valley bends more to the south the course of the scratches becomes oblique to the axis.

At the Queenston quarry, on the mountain point southeast of St. David, the main striation is S. 60° W. with fainter lines S. 60° E. and S. Here were observed some deep grooves. It may be stated that the course of the glaciation rarely coincides with the trend of the Niagara escarpment or other surface features, but is oblique to them, often at high angles, thus showing that these were not produced by the action of the ice, which only polished their surfaces. The glaciation is of the highest value in determining which depressions are old and which new. At various points adjacent to the river, now concealed, the polished surfaces have been observed; as for instance at Hubbard point and opposite to it.

CHARACTER OF CLAYEY AND STONY DRIFT.

The drift along the river above Dufferin islands is composed of clay mingled with small stones and a few boulders. In Niagara Falls Centre, at the head of Ferry road, upon digging sewer-trenches, drift twenty-four feet deep was found lying over the polished rock. Here it was a reddish sandy clay with very few pebbles and occasional angular stones of granite and other material. In the bluffs overlooking Victoria Park, rising to 100 feet or more in height, some of the layers are sand, but these occupy the buried valley.

The ridge of Lundy Lane trends westward from Drummondville (or Niagara Falls South), for a distance of somewhat more than two miles. Near the monument to the battle of Lundy Lane the high drift ridge is composed of sand and gravel. In a well nearly a mile west, at a point where the surface has an altitude of 425 feet, the depth to rock is ninety feet, mostly through sands and gravel. At well No. 2, over the buried Whirlpool-St. David valley, the surface clay has a thickness of eight feet, quicksand fifteen feet, bluish clay

Stratified sand-beds at Berryman's farm.

fifteen feet, red clay fifteen feet, with sands or angular gravels below, as was described in the deep well No. 1 reaching 269 feet. These materials usually have some clay mixture. At well No. 4 the bottom layer of drift resting upon rock consisted of a sort of quicksand of extremely fine texture and angular form, which, with water, easily flowed, but set so quickly that it was difficult to pump it out of the casing. At the Whirlpool the clays have a thickness of forty feet.

CHARACTER OF THE SAND RIDGES.

Speaking generally, the plateau of the Niagara district has a remarkably level or slightly undulating surface covered with red clay soil such as characterizes the drift at Niagara Falls Centre, shown in the sewer, or at Well No. 2. The ridge at Lundy Lane is an exceptional feature. A smaller hill of like character occurs south of the post office of South End, but there is still another higher hill—the Berryman—rising high above the immediate brow of the escarpment just west of the outlet of the Whirlpool-St. David trench, where the face of the escarpment is covered by drift hills.

From the summit of this hill a declining ridge extends in both directions; that covering the buried valley disappears within a half mile to the east, being indented with deep valleys. Extensive gravel pits here show the structure of the materials to a depth of fifty feet; also a well to 100 feet. They are composed of sand and gravel with well marked stratification, but in false bedding dipping in both directions:—that is, outward towards the low country of Lake Ontario, and inward towards the plateau. This structure is shown in Plate xxx.

The pebbles are mostly from one to three inches long and form only a subordinate part of the whole. Many are composed of granite and quartzite, but the greater portion are limestone or reddish sandstone fragments which have been transported from the Hudson river or the Trenton formations on the northern side of Lake Ontario, with rarely a fragment of Niagara limestone. These deposits overlap the clays which cover the angular gravels of the buried channels. That these accumulations transported across the lake were deposited in water is unquestionable. They even occur to a height of 75 to 100 feet above the summit of the escarpment, so that they could not have been redeposited from other drift hills in this region.

The transporting ice which supplied the material seems to have been attracted by the pre-glacial valley here, and to have deposited its load in melting, where the currents could stratify it. A repetition of this phenomenon is seen at Font hill, where similar deposits occur building up a higher mound which blocks the head of the 'Short Hills' valley. (The buried Erigan channel.) The Lundy ridge also is adjacent to the buried Falls-Chippawa valley, and the sands have considerable depth.

RIVER DEPOSITS WITH SHELLS.

As pointed out long ago by Lyell and Hall, there are river deposits containing fresh water shells. Hall describes these on Goat island, and Lyell those which occurred in Victoria Park back of the late Cedar island, before the gravel pit was recently obliterated. The same shell deposits occur on the high point just at the outlet of the Whirlpool and elsewhere. They were accumulated in the quieter waters when the river covered these now drained terraces.

CHAPTER XVII.

LAKE BASINS AND METEOROLOGICAL CONDITIONS AFFECTING THE FALLS.

Drainage area. The Erie ratio.
Mean rainfall and evaporation from Lake basins.
Modified conditions in the Erie basin.
Humidity.
Temperature.
Velocity of the wind.
Relationship of evaporation to rainfall.

DRAINAGE AREA—THE ERIE RATIO.

In the investigation of the physics of Niagara falls the problems of the fluctuations of the lakes, of the discharge, and of the changing areas of the lake basins supplying the waters of the Niagara are fundamental questions and require presentation here, although the data have been derived from the already collected meteorological notes, some of which consist of tables that will be presented in Appendix IV.

*Drainage Areas.**

Area of watershed or drainage basin of Lake Superior:

	Sq. Miles.
In Ontario	30,780
In Minnesota	6,800
In Wisconsin	3,160
In Michigan	7,860
Water surface	31,800
	80,400

The U. S. Lake Survey gives the total area as 76,100 including a water surface of 32,100 square miles.

* Altitudes in Canada, James White, pp. 182-186, 1901. Also Rept. Engineers, U.S.A., Appendix FFF., pp. 2861-2, 1903.

Area of watershed or drainage basin of Lake Huron:

	Sq. Miles.
In Ontario	35,400
In Michigan	16,700
Water surface	23,200
	75,300

This area includes,

Georgian bay	5,600
North channel	1,600
St. Mary river	150
Saginaw bay	1,050
Area of islands	1,700
	10,100

Area of watershed or drainage basin of Lake Michigan:

On adjacent land	40,200
Water surface	22,300
	62,500

Area of watershed or drainage basin of Lake St. Clair and river:

In Ontario	4,160
In Michigan	2,160
Water surface	445
	6,765

Area of watershed or drainage basin of Lake Erie:

In Ontario	5,480
In Ohio	11,950
In Michigan	2,990
In New York	2,210
In Indiana	1,270
In Pennsylvania	580
Water surface	10,000
	34,480

The U. S. Engineers give the total area of the Erie and St. Clair drainage basin at 40,800 square miles, including 10,600 square miles of water surface.

Area of watershed or drainage basin of Lake Ontario:

In Ontario..................	11,255
In New York................	14,275
Water surface...............	7,450
	32,980

From the foregoing tables it will be seen that the total area of the Niagara drainage basin is 259,445 square miles (White's tables) or 254,700 square miles (U.S. Lake Survey). The area of the Erie-St. Clair basin is 41,245 square miles (White), or 40,800 square miles (U.S. Lake Survey).

In studying the physics of the falls it will be seen that this separation of the Erie drainage from that of the total amount of the Upper lakes is necessary, for at one time the Niagara river received only the water from the Erie basin, and part of that from the St. Clair. Thus the drainage area of Erie compared with the entire area drained by Niagara is sixteen per cent, or about one-sixth of the whole region.

MEAN ANNUAL RAINFALL AND EVAPORATION IN THE LAKE BASINS.

The mean annual rainfall of the different lakes has been computed for the period between the years 1882-1905; and both the mean annual and mean monthly rainfall will be found in Appendix IV.* The average rainfall has been found to be in the basin of:—

* Rept. Lake Survey, 1903, pp. 2878-9; for data since 1898 Annual Rept. of Weather Bureau.

—	1882-98.†	1882-05.	1882-90.	1891-00.	1901-05.
Lake Superior....	26.27 inches.	27.26 inches.	26.17 inches.	27.06 inches.	29.64 inches.
Huron & Michigan	32.12 "	32.00 "	33.06 " *a*	31.04 " *b*	32.40 " *c*
St. Clair-Erie.....	34.08 "	34.46 "	34.12 "	33.75 "	36 23 "
Ontario	36.87 "	36.87 "	37.31 "	36.00 "	38.20 "

Rainfall and the evaporation based on the discharge (1882-1898) in terms of cubic feet of discharge per second:—

—	Rainfall.‡	Evaporation.	Evaporation.
For Superior basin..................	147,164 (s-f)..	69,954 (s-f)..	13.75 (inches.)
Michigan-Huron "	325,857 " ..	203,831 " ..	20.29 "
St. Clair-Erie "	102,308 " ..	77,820 " ..	26.10 "
Ontario "	89,557 " ..	57,507 " ..	23.67 "

(s-f means cubic feet per second.)

The evaporation in inches is corrected for the fall of lake level at the close of the period of observation.

The first period of rainfall given above is adopted from the Lake Survey. The other groups of years are selected on account of surveys of the recession of the falls having been made in 1890 and 1905, and the renewed rainfall since 1900. The earlier records are too incomplete at certain points to satisfactorily extend the table. In fact, one should expect that the average rainfall in the Superior basin errs on the side of being too high, on account of the diminished precipitation north of Lake Superior, where there are only a few stations, some of which have not been organized many years. For instance, at Nipigon, a large river discharges into Lake Superior, here it is 20·24 inches, while to the northeast, at Martin falls, it is reduced to 14·16 inches. The same feature occurs north of Lake Huron.

† Engineers' Rept., 1903, p. 2860.

a, b, c. Corrected by adding Huron rainfall in the means of the two Lakes.

‡ Engineers' Rept., 1903, pp. 2860-1.

Accordingly, the future revision of the rainfall may somewhat reduce the average discharges of the basins of Superior and Huron as compared with those of Michigan and Erie. This question also has a bearing upon the recession of Niagara falls. From the above table it will be seen that the average rainfall in the different basins varies, but this alone does not account for the reduced height of the lakes since 1900.

MODIFIED CONDITIONS IN ERIE BASIN.

Although the drainage area of the higher lakes is larger than that of Erie, the proportional rainfall is less. The proportion of the Erie precipitation to the whole amount in the Lake region, exclusive of Lake Ontario, is 17·7 per cent, or slightly greater than that of the Erie area compared with the whole, which is 16 per cent. The determination of these proportions will be found to have a direct bearing on the physical changes of Niagara falls.

The evaporation depends upon the humidity, temperature, wind, the proportion of lake surface compared with the whole drainage basin, and whether the lakes themselves have varied in size. It has been found that Lake Erie at its birth was of very small size. It had an area of 1,000 to 1,500 square miles compared with 10,000 square miles at the present day. Consequently the difference would have to be treated as a land area suffering less evaporation in former times.

Humidity.

Upon investigating the question of humidity the average amount from 1882 to 1898 was found to be, for—

Lake Erie.	73·6	per cent.
Huron and Michigan.	76·4	"
Superior.	76·4	"
Ontario.	74·9	"

In Appendix IV., the monthly humidities are also given for Lake Erie.

Temperature.

Evaporation depends upon the temperature, so it is given, for—

Lake Erie (1882-'98) was.	48·0 F
Superior (1882-'98).	35·9 F
Huron and Michigan.	42·08 F
Ontario.	44·1 F

See Appendix IV.

Velocity of Wind.

For the same period the average velocity of the wind, for—

Lake Erie.	10·4
Superior.	9·05
Huron-Michigan.	10·3
Ontario.	10·7

See Appendix IV.

Relationship of Evaporation to Rainfall.

The question arises:—Can the amount of evaporation be determined from meteorological conditions alone? On this subject, Prof. Alfred J. Henry and Prof. Norman B. Conger have made some calculations for various points on all lakes. But different stations vary greatly, with the evaporation on the southwestern side of the lakes being much greater than on the northern or eastern sides. The results of these calculations based upon the shore stations are too high for mid lake, because the determining temperature of evaporation (temperature of the surface waters) is, at some seasons of the year, from 10° to 20° higher than obtains in mid lake.*

Thus no valuable information throwing light upon this problem from the calculations of the shore stations is obtainable. The differential character of the meteorological phenomena is of value in forming impressions of changing conditions at the same stations in different localities.

* Weather Bureau Bulletin No. 213, p. 22, 1899.

CHAPTER XVIII.

FLUCTUATIONS OF THE LAKES.

LAKE ERIE—NOTE ON POSITIONS OF OBSERVATION.

The fluctuations of the lakes are primarily dependent upon the meteorological conditions such as those already mentioned. But in times past the more wooded portions of the country of the lake region must have modified the fluctuations, with possibly other causes not considered. The data covers fifty years or more of continuous observations, with fragmentary information recorded many years still farther back. First, they throw light upon the variable discharge; secondly, upon the present stability of the Niagara region, so far as differential movements of the earth's crust are concerned; and thirdly, the deepening of the outlets of the lakes, &c.

The two most important points about Lake Erie for observing the fluctuations are at the intake of the Welland canal, Port Colborne,* and at Cleveland.† Observations at Buffalo

* From the records obtained through the kindness of Mr. J. L. Weller, Resident Engineer, Welland canal, and of Mr. James White, Geographer, Interior Department, Ottawa, and Mr. Butler, Deputy Minister of Canals, Ottawa.

† The fluctuations at Cleveland are from Report of U.S. Engineers' Lake Survey for 1903, 1904 and 1905.

and at the western end of the lake show greater variations than at Cleveland, where the waters are less likely to be piled up or lowered by the winds. Besides this, Cleveland and Port Colborne are along the line showing the greatest amount of former differential change of level indicated by the raised beaches. Around the head of Lake Erie as far as Cleveland there has been very little unequal elevation in the earth movements, while from Cleveland northeastward an unequal elevation of the deserted beaches is strongly marked by a rise of 120 feet in a distance of 164 miles to Fonthill, Ontario; or of 100 feet in a distance of 144 miles to Sheridan, N.Y. This last distance is in a more easterly direction. Indeed, nearly all of the rise occurs eastward of Madison, Ohio, which is forty miles east of Cleveland.

From the daily fluctuations at Port Colborne, in its relation to the sill of Lock No. 27 of the Welland canal, the monthly and annual averages of the lake have been calculated since 1849. So, also, the same information has been obtained with regard to the fluctuations at Cleveland since 1854. Authentic continuous records at Buffalo date back to only 1887. From these tables the average daily fluctuations during periods of five years, fifteen years, and other groups of years have been compiled in order to compare them with the surveys of the recession of Niagara falls.

For the mean height of Lake Erie at Buffalo, before continuous observations were made, an approximate result can be obtained by adding 0·12 to the levels at Cleveland. These mean levels are compiled from U. S. Engineers' tables without deduction of 0·33 of a foot required by the latest precise levelling to sea level datum. The necessary correction has been made for Port Colborne.

MEAN QUINQUENNIAL FLUCTUATIONS OF ERIE.

—	Fluctations of Lake Erie at		
	Pt. Colborne.	Cleveland.	Pt. Colborne below Cleveland.
1850–55	572 73*	......	......
1855–59	573 26	573·55	– ·29
1856–60	573·40	573·63	– ·23
1861–65	573 25	573·18	+ ·07
1866–70	572·60	572·66	– ·06
1871–75	572 28	572 42	– ·14
1861–75	572·71	572·75	– ·04
1860–75	572·80	572·85	– ·05
1876–80	572·75	573·02	– ·27
1881–85	572·92	573·18	– ·26
1886–90	572·80	572·93	– ·13
1876–90	572·82	573·04	– 22
1891–95	571·66	571·92	– ·26
1896–00	571·57	571·86	– ·29
1901 05	571·76	572·04	– ·28
1877–05	572·20	572·46	– ·26
1855–05	572·49	572·67	– ·18
1891–05	571·66	571·94	– .28

The Buffalo record for the short period shows differential fluctuations similar to those at Port Colborne, when compared with Cleveland. As the monthly and annual fluctuations are

* Elevations refer to mean tide at New York. From the last determination of lake levels by precise levelling, a difference of 1·08 foot was found between Canadian altitudes and those of engineers of U.S.A. Of this amount, 0·75 of a foot were required to be added to Canadian tables, which has here been done; and 0·33 of a foot taken from U.S. levels of Lakes Erie and Ontario, but owing to the small amount this latter has not been deducted. If corrected, the differences between the levels, at the two points, would be very small, but would show a constant change from plus (+) to minus (–) signs. (See James White's Dictionary of Altitudes, p. viii, 1903.)

given in Appendix v., the investigator will derive fuller information by comparing special years, either for the discharge of Niagara river at any particular time, the lowering of the lakes, or the differential fluctuations in regard to their significance.

FLUCTUATIONS OF ERIE AND HURON COMPARED.

Upon the fluctuations of Lake Huron depend the discharge of St. Clair river or outlet of the lake. From the differential fluctuations of the two lakes the question of the lowering of the Huron outlet is partly determined; but the problem of the stability of the region is not assisted by a comparison of these lake levels, as any rise in the upper lake would be indeterminable on account of the lowering of the outlet. In Appendix v., the mean monthly and annual fluctuations of Lake Huron are given. Only the annual fluctuations of Lake Superior are given in table in next chapter, but these are not directly connected with the recession of the falls.

On account of the lowering of the lake outlets the mean level (1891-1905) should be adopted as the standard height, though the general average has been followed, where not otherwise expressed. The correction of — 0·33 has not been made in the following table as it occurs in both columns.

MEAN QUINQUENNIAL FLUCTUATIONS OF HURON AND ERIE.

Fluctuations.	Sand Beach. (L. Huron).	Cleveland. (L. Erie.)	L. Erie below L. Huron.
1855-60	582·58	573·54	−9·04
1861-65	582·25	573·18	−9·07
1866-70	581·41	572·66	−8·75*.
1871-75	581·67	572·41	−9·26
1876-80	582·04	573·02	−9·02
1881-85	582·42	573·18	−9·24
1886-90	581·93	572·93	−9·00
1891-95	580·43	571·92	−8·51
1896-00	580·17	571·86	−8·31
1901-05	580·54	572·04	−8·50
1855-1889	582·08	573·00	−9·08
1890-1905	580·42	572·00	−8·42
1855-1905	581·55	572·67	−8·88

In connexion with this temporary fall of Lake Huron it should be stated that the canal across St. Clair flats was commenced in 1866 and opened for navigation in 1871.* During these operations a thirteen foot straight canal was excavated across shallows of six feet (*see* figure 26, Chapter XXVI.). This may have occasioned the temporary fall of Lake Huron, which in years corresponded to those of the principal dredgings. After 1886, and completed by 1902, the canal was further deepened to eighteen feet, and since then to twenty or twenty-one feet. But on turning to the tables, we find the most remarkable lowering of the other lakes as having occurred just after 1889 and continuing to the present time.

LOWERING OF LAKE HURON.

If the mean annual differences be taken in place of the quinquennial, as in this chapter (*see* Appendix V.), the remarkable lowering of Lake Huron is seen to have commenced in 1889, reaching almost its maximum in 1890; in 1891 the lake rose somewhat with subsequent minor fluctuations, but the general effect has been to lower it 0·66 of a foot more than Lake Erie. On the other hand, from 1894 to 1905 inclusive, Lake Superior had risen over 0·41 of a foot when compared with the previous elevations between 1860 and 1893.

This lowering of Huron was shown by Mr. Russell, to whose writings I am indebted. He says:—'The mean of 1873-1892 indicates an increase of 11,355 cubic feet per second in the datum discharge of St. Clair river. The change in discharge in one foot of rise in the surface of the river is 14,217 cubic feet per second. A lowering of the body of the river by almost 0·80 of a foot is therefore indicated since 1893 as compared with the twenty years preceding' (page 4118, 1904). On turning to the rainfall tables in Appendix IV., it will be

* Appendix OO., Rept. of Engineers, U.S.A., 1905, pp. 598.

seen that the mean annual rainfall of Huron-Michigan basin has diminished by more than 1·5 inches during the years 1891-1905, when compared with the period from 1882-1890; while the rainfall of both Superior and Erie has increased. This will not account for the fall in the Huron basin, but as the period under consideration embraces a number of years its effect on Lake Erie would have produced proportional results during most of the time. Even considering the fluctuations it is impossible to account for the differential subsiding of Huron other than by a lowering of the outlet, probably somewhat affected by the excavation of St. Clair canal, and to some degree by the Chicago drainage canal, but mostly by scouring at the bottom of the channel. A closer analysis might show a further slight deepening of the St. Clair outlet. My calculations amounting to 0·66 of a foot include the years 1904 and 1905 of higher water, not entering into Mr. Russell's calculation (0·80 of a foot lowered). Doubtless this difference and even more occurs where the data do not permit of more precise calculations. This does not cover the full amount of lowering of the lake, but to this must be added that of Lake Erie. (*See* next chapter.)

DRAINAGE BY CHICAGO CANAL.

In this connexion it should be stated that the full allowance of the canal (10,000 cubic feet per second) should theoretically lower Lake Huron 0·521 of a foot; Lake St. Clair 0·455 of a foot; and Lake Erie 0·379 of a foot, requiring 4·86 years to effect nine-tenths of this change. The canal was opened January, 1900. During 1901 the average flow was 4,270 cubic feet. During 1905 the canal withdrew about 5,000 cubic feet per second.

CHANGES IN THE HURON LEVEL AFFECTING THAT OF ERIE.

The rise of the lakes is not simultaneous, and if this amounts to one foot in Lake Huron it would eventually raise

Lake Erie by 0·727 of a foot. It would require seventy-two days to accomplish five-tenths of this rise in Lake Erie, and for nine-tenths it would take 239 days.† A rise of one foot in Huron corresponds to 0·602 of a foot in St. Clair. A rise of one foot in Erie produces 0·346 of a foot of back water effects in Lake Huron. From these facts it will be seen that a comparison of the lake levels for single years might produce large errors, and only observations extending over several years can be relied upon.

In former times the enormous changes of level in the Ontario basin have played a fundamental part in the recession of Niagara falls. Some of the later changes occur from the cutting down or scouring of the outlets. These have a measurable amount.

FLUCTUATIONS OF ERIE AND ONTARIO COMPARED.

The changes of Niagara river closely correspond to those of the levels of Lake Erie. The surface of the river above the First cascade of the Upper rapids is about fourteen feet lower than the lake. The differential changes of level between Lake Erie and Lake Ontario are shown in the following table.

MEAN QUINQUENNIAL FLUCTUATIONS OF ERIE AND ONTARIO.

Fluctuations.	Lake Erie at Pt. Colborne.	Lake Ontario at Toronto.	Ontario, below Erie.
1854-60	573·23	246·78	– 326·45
1861-65	573·25	246·55	– 326·70
1866-70	572·60	246·10	– 326·50
1871-75	572·28	245·40	– 326·88
1876-80	572·75	245·93	– 326·82
1881-85	572·92	246·22	– 326·70
1886-90	572·80	246·41	– 326·39
1891-95	571·66	245·06	– 326·60
1896-00	571·57	244·68	– 326·89
1900-05	571·76	245·49	– 326·27
1854-90	572·83	246·24	– 326·59
1891-05	571·66	245·07	– 326·59
1855-05	572·48	245·86	– 326·62

† Thomas Russell, in Appendix EEE., Rept. Lake Survey, U.S. Engineers, 1904, p. 4131.

While the mean elevation of Lake Ontario during fifty years is given, that of 1891 to 1905 is now the more accurate, as it allows for the lowering of the outlet after 1890.

MEAN QUINQUENNIAL FLUCTUATIONS OF ONTARIO.

Daily records of lake level have been kept at Toronto, Oswego, and Charlotte for periods of over fifty years. At other points the information is more fragmentary, and it is to be regretted that the data over a long period cannot be obtained at the outlet of the lake itself. Important conclusions as to fluctuations can be arrived at by an analysis of the records of the three points named, and at the head of the first of the Saint Lawrence canals, sixty-six miles below the outlet of the lake, where the river surface is lowered a little more than one foot only. This last point will be discussed in a succeeding paragraph.

QUINQUENNIAL† FLUCTUATIONS AT TORONTO, OSWEGO AND CHARLOTTE *.

Years.	Toronto.	Oswego above Toronto.	Oswego.*	Charlotte.*	Charlotte above Toronto.
1856-60	246·89	+ ·28	247·17	247·23	+ ·34
1861-65	246·55	+ ·75	247·30	247·24	+ ·69
1866-70	246·10	+ ·51	246·61	246·88	+ ·78
1871-75	245·40	+ ·43	245·83	245·91	+ ·57
1876-80	245·93	+ ·46	246·39	246·56	+ ·63
1881-85	246·22	+ ·44	246·66	246·69	+ ·47
1886-90	246·41	+ ·42	246·83	246·74	+ ·33
1891-95	245·06	+ ·53	245·59	245·61	+ ·55
1896-00	244·68	+ ·45	245·13	245·14	+ ·46
1901-05	245·49	......	......	245·80	+ ·39
1855-05	245·86	......	......	246·38	+ ·52
1854-90	246·24	......	......	......	......
1856-00	......	+ ·47	......	......	......
1891-05	245·07	......	......	245·52	+ ·45

† Mean annual fluctuations will appear in Appendix V. Table 5.

* The correction by precise levelling to Greenbush, N.Y., has been applied to Toronto levels, but not to those of Oswego and Charlotte, which would reduce them by 0·33 of a foot, thus diminishing the unavoidable difference in determining the heights at different stations.

The variability of levels between Toronto and Oswego is remarkably small. Since 1866 the maximum quinquennial amount has been only 0·11 of a foot, though some mean annual fluctuations are greater. The mean difference of the reading in these years is 0·47.

With the difference for the quinquennial period ending in 1870 at +·51, and that of 1900 at +·45, if there be any change at all it would suggest that Oswego had moved very slightly in one direction; while on the other hand if the former period be compared with that ending in 1895 (+53), the opposite movement might be inferred. Thus only one conclusion can be arrived at, namely: that the small variation found in the levels at the two points is within the range of mean arithmetical error and is of no value. It is remarkable how small the variations are found to be when spread over any considerable period. Comparing the levels at Charlotte with the other two points the fluctuations are found to be slightly greater; but this station is situated at the mouth of the Genesee river, which might give rise to temporary higher water.

On observing the fluctuations of the periods ending in 1860 and in 1865, the variations from the average (+·47) are found to be exaggerated on both sides. Whether this arises from wind, less perfect observations, or other conditions, has not been determined. Finally, the mean fluctuation of Lake Ontario at the different points mentioned may be taken as a remarkably constant figure.

FLUCTUATIONS OF LAKE ONTARIO AND SAINT LAWRENCE RIVER COMPARED.

Having found the constancy in the fluctuation at points on Lake Ontario, the question arises, first, what is the ratio in the fluctuation between Lake Ontario and Galops rapids, sixty-six miles beyond the outlet of the lake, at a point above that where the river begins to descend. Records of the fluctuations have here been kept at old Lock No. 27 of St. Lawrence canals.

A comparison of these points should throw light on the question of changes of level of land.

Application of these data will be found in Chapters XIX., XX., XXI. and XXX.

From this table it may be seen that the Galops rapids can be taken as another point for comparing the fluctuations of Lake Ontario. The period of observation is here shorter, covering only thirty years, and the mean fall is 1·10 feet.

MEAN QUINQUENNIAL FLUCTUATIONS AT TORONTO, LOCK 27 GALOPS RAPIDS, LOCK 15 CORNWALL, AND LOCK 14 VALLEYFIELD.

Years.	Lake at Toronto	Lock 27.	Lock 27 below Ontario.	Lock 15.	Lock 15 below Ontario.	Lock 14.	Lock 14 below Ontario.
1861–'65	246·55	....	....	....	....	155·08	−91·47
1866–'70	246·10	....	....	....	....	154·44	−91·66
1871–'75	245·40	....	....	157·53	−87·82	153·97	−91·23
1876–'80	245·93	244·35	−1·58	157·06	−88·87	154·26	−91·67
1881–'85	246·22	244·86	−1·36	157·25	−88·97	154·27	−91·95
1886–'90	246·41	245·10	−1·31	157·69	−88·72	154·48	−91·93
1891–'95	245·06	243·89	−1·17	156·61	−88·45	153·91	−91·15
1896–'00	244·68	243·53	−1·15	155·92	−88·76	153·38	−91·30
1901–'05	245·49	244·21	−1·28	....	....	153·56	−91·93
1861-75	246·02	....	....	....	....	154·50	....
1876–'90	246·18	244·77	−1·41	157·33	−88·85	154·33	−91·85
1891–05	245·08	243·88	−1·20	....	....	153·62	−91·46
1891–'00	244·87	243·88	−1·16	156·26	−88·6	153·47	−91·40
1861–'90	246·10	....	....	....	....	154·42	−91·68

CHAPTER XIX.

LOWERING OF THE LAKE OUTLETS.

Stability of the outlet of Lake Superior.
Table of mean annual fluctuations of Erie, Huron and Superior.
Lowering of the Huron outlet.
Table of mean annual fluctuations of Erie and Ontario.
Lowering of the Erie outlet at the same rate as that of Ontario.
Lowering of the outlet of Ontario.
Effects of lowering of Ontario on higher lakes.
Effects of the lowering of the lakes on the canals and harbours.
Corrected elevations of the Great lakes.

STABILITY OF THE OUTLET OF LAKE SUPERIOR.

Tables of the quinquennial fluctuations of the lakes have been given, but in order to further investigate the question of the lowering of the outlets the mean annual fluctuations of the lakes are found in the following table,—for Superior at Sault Ste. Marie, for Lake Huron at Sand Beach near the outlet of the lake, and for Lake Erie at Cleveland.

The fluctuations of Lake Superior since 1893 show an average increased height amounting to 0·41 of a foot as compared with the years 1860-'93. This is an absolute rise of the water surface, in excess of any lowering of the outlet over the crystalline rocks, the data for determining which are not at hand, if indeed it be measurable. The rise is in conformity with the mean rainfall, which increased by 1·7 inches, between 1891-1905, compared with the mean of the period of 1882-'90.

Of itself this evidence is not conclusive as to the present constancy of the outlet of Lake Superior, but it sufficiently separates the question from that concerning the lowering of the Huron outlet, so that the scouring of the outlet of Lake Superior may be considered so slow as to be immeasurable.

TABLE OF MEAN ANNUAL FLUCTUATIONS OF ERIE, HURON AND SUPERIOR.

Years.	Lake Erie. Cleveland.	Sand Beach above Cleveland.	Lake Huron. Sand Beach.	Lake Superior. Sault Ste. Marie.
1855	573·10	8·68	581·78	
1856	572·88	9·07	581·95	
1857	573·32	9·23	582·55	
1858	574·22	8·87	583·09	
1859	574·26	9·02	583·28	
1860	573·49	9·37	582·86	602·53
1855-60	573·54	9·04	582 58	
1861	573·58	9·28	582·86	602·58
1862	573·69	9·07	582·76	602·30
1863	573·40	8·94	582·34	601·94
1864	572 79	9·05	581·84	601·62
1865	572·44	9·00	581·44	602·03
1861-65	573·18	9·07	582·25	602·09
1866	572·58	8·54	581·12	602·02
1867	572·60	8·96	581·56	602·24
1868	572·23	8·84	581·07	602·05
1869	572·65	8·54	581·19	602·38
1870	573·28	8·82	582·10	602·07
1866-70	572 66	8·75	581·41	602·15
1871	572 69	9·46	582·15	601·67
1872	571·73	9·37	581·10	601·78
1873	572·43	9·08	581·51	602·06
1874	572·94	8·97	581·91	602·07
1875	572·28	9·42	581·70	602·21
1871-75	572·41	9·26	581·67	601·96
1876	573·69	9·05	582·74	602·52
1877	572·87	9·58	582·45	602·09
1878	573·28	8·92	582·20	601·61
1879	572·52	8·80	581·32	600 96
1880	572·77	8·72	581·49	601·41
1876-80	573·02	9·02	582·04	601·72
1881	572·61	9·26	581·87	601·86
1882	573·48	8·73	582·21	601·82
1883	573·26	9·23	582·49	601·60
1884	573·33	9·37	582·70	601·42
1885	573·24	9·62	582·86	601·70
1881-85	573·18	9·24	582·42	601·68

TABLE OF MEAN ANNUAL FLUCTUATIONS OF ERIE, HURON AND SUPERIOR—*Concluded.*

Years.	Lake Erie. Cleveland.	Sand Beach above Cleveland.	Lake Huron. Sand Beach.	Lake Superior. Sault Ste. Marie.
1886	573·35	9·73	583·08	601·51
1887	573·29	9·13	582·42	601·44
1888	572·60	9·18	581·78	601·73
1889	572·37	8·91	581·28	601·77
1890	573·05	8·06	581·11	601·62
1886-90	572·93	9·00	581·93	601·61
1891	572·15	8·39	580·54	601·24
1892	572·13	8·24	580·37	601·19
1893	572·08	8·52	580·60	601·51
1894	572·09	8·67	580·76	602·14
1895	571·17	8·73	579·90	602·29
1891-95	571·92	8·51	580·43	601·67
1896	571·39	8·20	579·59	602·15
1897	571·96	8·24	580·20	602·20
1898	572·13	8·22	580·35	601·77
1899	571·90	8·46	580·36	602·26
1900	571·94	8·43	580·37	602·34
1896-1900	571·86	8·31	580·17	602·14
1901	571·38	9·25	580·63	602·37
1902	571·84	8·37	580·21	602·31
1903	572·37	7·99	580·36	602·49†
1904	572·45	8·39	580·84	602·71†
1905	572·16	8·60	580·95	602·34†
1901-05	572·04	8·50	580·59	602·44

† Marquette.

LOWERING OF THE OUTLET OF LAKE HURON.

The Huron outlet has been partly considered (page 227), with the apparent sudden fall of the lake surface, commencing in 1889, which has remained lower since that time. The average lower water of Huron subsequent to that date compared with the mean level before amounts to 1·66 feet. If, however, the subsidence of Huron waters be compared with the fluctuations at Cleveland it is found that the lake there has also fallen one foot. As this has been continuous over a period of fifteen years the mean difference, which amounts to 0·66 of a foot, is not a temporary oscillation of level such as may be observed when even individual years are compared.

From the evidence at hand, I, therefore, agree with Mr. Russell that this must be a permanent lowering of the Huron outlet. The records of fluctuations before 1855 are too incomplete to be able to form definite conclusions from them. Between January, 1846, and August, 1854, only a few scattered monthly records of the levels of Lake Erie are obtainable. Between January, 1846, and August, 1849, there is a full monthly record for Huron—the mean height during this time was 580·44 feet.

The Erie record for the first eight months of 1846 gives a mean elevation of 571·49 feet, while that of Lake Huron is 581·00 feet. Accordingly the difference of level between Erie and Huron was 9·51 feet, which is greater than the average of any quinquennial period since 1854. This fragmental record goes to show that, as far back as 1846, the level of Lake Huron had not fallen as compared with Lake Erie. Again, there is a record from May to October (inclusive) for the year 1840, but this shows a relatively lower level for Lake Huron, while during the high water of June and July, 1838, there was an increased differential height for the lake. So also a still further increased height for Huron is found in June, 1819, when the difference was 10·40 feet. Individual months or even seasons taken separately are of little value, for, as has already been shown, any considerable sudden rise in Lake Huron will require from months to even years to be equalized in Lake Erie.

From the incomplete records now obtainable back to 1819*, there is nothing to show that for any considerable period the low differential elevation of Huron had occurred prior to the period between 1890-1905.

* Compiled in Report of U. S. Engineers on the Lake Surveys.

Although the greater rise of Superior began in 1894, yet on account of the general subsidence of the other lakes occurring just after 1890, this latter date may be taken as the break in the records without involving any considerable error. Between 1861 and 1890 the mean height of Lake Superior was 601·67 feet above tide, while since that time its height has risen to 602·08 feet. At the same time Lake Huron fell from 581·95 feet to 580·38 feet (above sea level), or an absolute fall of 1·57 feet; and Lake Erie subsided from 572·90 to 571·94 feet, or 0·96 of a foot. During 1891-1905 the mean annual rainfall of Superior basin increased 1·75 inches, and that of the Erie basin rose 0·46 of an inch. On the other hand the rainfall of the Huron-Michigan basin diminished by 1·57 inches.

So far as the discharges of the rivers are concerned the recorded diminution of the Michigan-Huron rainfall is more than half compensated for by the greater outflow from Lake Superior and the slight rise in the Erie basin. Consequently the reduced overflow of Lake Huron, due to the change of rainfall, should come within the limits of 1,400 to 1,800 cubic feet per second; which would also affect the discharge of Lake Erie.

Evidences of the differential lowering of Lake Huron have been given (page 227). This is now further confirmed by showing the small effects produced by the changes of rainfall, as also by comparison of the outlet of Lake Superior. Changes due to evaporation are not determinable from the data, in which no important modifications are recognizable. The fluctuations show that the principal lowering of the outlet of Lake Huron occurred between 1889 and 1902,—measurable to the extent of 0·6 to 0·66, or even 0·80 of a foot according to the years used in the calculations. But further slight changes might also be found in more detailed studies of other years. In addition to the differential lowering of Lake Huron whatever subsidence has occurred in Lake Erie must be added to that of Lake Huron. About one foot is found to have obtained there in the same years. A small portion of this lowering only is attributable to meteorological changes. (*See* lowering of the Ontario level.)

As the positions of the gauges for recording the lake levels are stationary, a fall in the gauge readings might indicate a rise of the land and not a lowering of the outlet. In the case of the Huron outlet the materials composed of silt or sand would be immediately scoured out by any increased height of the water, or the same materials would be deposited at the bottom of the channel by a slight lowering of the river level. On the other hand, the outlet of Lake Erie can be affected in a twofold manner. The great rim which determines its level is the limestone ledge at the First cataract of the Upper rapids. But at the outlet of Lake Erie there is a slightly higher barrier which has continued to exist, retarding the waters in the upper river. This feature is well shown between Fort Erie and Black Rock. While at the western end of the International bridge the barrier is composed of rock, yet in the centre and at the eastern end such is replaced by clay deposits. Accordingly a lowering of the lake could take place here in a similar manner to that due to a scouring of the outlet of Lake Huron. At a mile and a half southward, however, a rocky barrier seems to cross the river at a depth of seventeen to twenty-four feet, so that this is at the same plane as the rim above the Upper rapids. In chapter xxx., it will be shown that at the present time, compared with fifty years ago, there has been absolutely no change in the water level due to earth movements, so that the fall of Lake Erie is mainly due to a lowering of the outlet.

TABLE OF MEAN ANNUAL FLUCTUATIONS OF ERIE AND ONTARIO.

Years.	Toronto.	Pt. Colborne.	Toronto below Pt. Colborne.
1856	246·56	572·57	326·01
1857	247·07	573·06	325·99
1858	247·40	573·91	326·51
1859	247·14	573·95	326·81
1860	246·31	573·52	327·21
	246·89	573·40	326·51
1861	247·05	573·56	326·51
1862	246·92	573·71	326·79
1863	246·50	573·50	327·00
1864	246·29	573·07	326·78
1865	246·03	572·41	326·38
	246·55	573·25	326·70
1866	245·62	572·72	327·10
1867	246·44	572·44	326·00
1868	245·17	572·23	327·06
1869	246·06	572·49	326·43
1870	247·20	573·13	325·93
	246·10	572·60	326·50
1871	245·84	572·60	326·76
1872	244·41	571·64	327·23
1873	245·53	572·25	326·72
1874	246·28	572·71	326·43
1875	244·96	572·21	327·25
	245·40	572·28	326·88
1876	246·76	573·59	326·83
1877	245·58	572·52	326·94
1878	246·10	572·94	326·84
1879	245·70	572·25	326·55
1880	245·51	572·45	326·94
	245·93	572·75	326·82
1881	245·14	572·21	327·07
1882	246·13	573·10	326·97
1883	246·31	573·11	326·80
1884	246·96	573·12	326·16
1885	246·59	573·09	326·50
	246·22	572·92	326·70
1886	247·31	573·46	326·15
1887	246·77	573·16	326·39
1888	245·56	572·38	326·82
1889	245·67	572·16	326·49
1890	246·73	572·80	326·07
	246·41	572·79	326·38

TABLE OF MEAN ANNUAL FLUCTUATIONS OF ERIE AND ONTARIO
—*Concluded.*

Years.	At Toronto.	At Pt. Colborne.	Toronto below Pt. Colborne.
1891	245·77	571·88	326·11
1892	244·93	571·88	326·85
1893	245·49	571·85	326·36
1894	245·31	571·80	326·59
1895	243·81	570·93	327·12
	245·06	571·66	326·60
1896	244·06	571·08	327·02
1897	244·44	571·66	327·22
1898	245·03	571·88	326·85
1899	244·97	571·63	326·66
1900	244·91	571·63	326·72
	244·68	571·57	326·89
1901	244·73	571·05	326·32
1902	245·01	571·70	326·69
1903	245·54	572·02	326·48
1904	246·29	572·21	325·92
1905	245·91	571·84	325·93
	245·49	571·76	325·27

LOWERING OF THE OUTLET OF ERIE AT THE SAME RATE AS THAT OF ONTARIO.

To ascertain whether the deepening of Niagara channel is measurable or not it is necessary to compare the levels of Erie and Ontario. The records at Port Colborne on Lake Erie (datum of which is slightly different from that of Cleveland) are here compared with those of Lake Ontario at Toronto, as shown in the accompanying table and in the quinquennial table, Chapter XVIII., page 229. The great drop of Erie occurred in 1891 and a sudden lowering of Lake Ontario took place at nearly the same time.

The mean level of Erie at Port Colborne between 1854 and 1890, see p. 229, was 572·83 feet above sea level, and between 1891 and 1905 it was 571·66 feet; thus showing a sinking of Lake Erie amounting to 1·17 feet. The mean height of Lake Ontario between 1854 and 1890 was 246·24, and between 1891 and 1905 it was 245·07; also showing a difference of 1·17 feet. Thus it will be seen that there has been no change (in the mean of many years) of lake fluctuations. The conclusion is that the lowering of the Erie outlet is at the same rate as at the St. Lawrence outlet of Lake Ontario. At Niagara falls, and at Galops rapids of the St. Lawrence, the two rivers flow over limestone which mostly determined the rims of the lake basins above these points; although a limited amount of drift affects the St. Lawrence as well as the outlet of Erie as above mentioned. While silts have seggregated around the piers of the International bridge, yet in channels between some of them, the river has deepened its bed. Thus in the channel of the fourth span, some thirty years ago, the depth was forty-two feet, while it has since scoured to a depth of fifty-three feet.

At Galops rapids the depth to the rocky rim does not exceed thirteen feet, which in June, 1902, reached 2·09 feet or 1·25 feet below Ogdensburg, a few miles above (page 2793, Rep. Eng., 1902). There the bed of the river is composed of clay. While the rocky rims are the principal barriers to the lakes, limiting the power of the rivers in the scouring of the clay beds, yet part of the lowering of the lakes appears to be due to changes in the clayey sections, and it is not surprising to find that the amount of lowering of the two lakes has been the same.

The wear of the rocky floor of the river, adjacent to the head of Goat island seems at first insignificant; but after passing the First cascade between two and six feet of rock have been removed by the modern river, which has acted upon the rapids only since the falls receded from 1,000 feet south of Hubbard point, or 7,000 feet from the present crest of the falls; that is after the falls had begun to remove the drift from the buried Falls-Chippawa valley, with the appearance of the Upper rapids themselves. This occurred less than fifteen hundred years ago, and shows that the lowering of the river, through the rocky barrier, has been very slow, and accomplished at irregular intervals.

LOWERING OF THE OUTLET OF LAKE ONTARIO.

From the table of the quinquennial fluctuations of Lake Ontario and the St. Lawrence river already given (Chapter XVIII.) and the annual fluctuations (Chapter XXXI.), the following table has been computed.

Years.	Lake at Toronto.	Lock 27.	Lock 27 below Lake at Toronto.	Lock 15	Lock 15 below Lake at Toronto.	Lock 14.	Lock 14 below Lake at Toronto.
1876–1890...........	246·18	244 77	1·41	157·33	88·85	154·33	91·85
1891–1900...........	244·87	243·71	1 16	156·26	88·61	153·47	91·40
1901–1905...........	245·49	244·21	1·28	....	....	153·56	91·93

Although this table is not complete for all the years of observation at the four stations, yet it is sufficient to show that it would be only slightly changed by the addition of the averages of fifteen years preceding that of 1876. From the quinquennial table (page 232), it is found that the level of Lake Ontario at Toronto between 1861 and 1890 is only 0·08 of a foot higher than the average of the later fifteen years, so also Lock 14 shows that the mean of thirty years from 1861 to 1890 exceeds that of fifteen years ending with 1890 by only 0·08. Consequently the earlier records at other points are unnecessary. On analyzing the table here given it is found that the mean water surface fell between the periods ending 1891 and 1900: at Toronto, 1·31; at Lock 27, 1·00; at Lock 15, 1·07, and at Lock 14, 0·86 feet. After 1900 the water rose again at Toronto, 0·62; at Lock 27, 0·50; and at Lock 14, 0·09 of a foot. With this rise of the broad surface of Lake Ontario, amounting to more than half a foot, the rise of the river level should have been commensurate in place of an insignificant quantity. The conclusion is that the bed of the St. Lawrence rapids channel adjacent to Lock 14 was reduced 0·62 less 0·09, or 0·53 of a foot at least. The level of the lake fell 0·45 of a foot during the decade 1891-1900 more than the river at Lock 14. These results added give the permanent lowering of the lake outlet at and above Lock 14 at 0·98 of a foot, although on account of the increased rainfall (1901-'05) the actual present subsidence in the lake surface has been reduced to only 0·69 of a foot (1·31—0·62) lower than between 1876 and 1890.

Turning now to the discharge of the St. Lawrence river (page 248 and Appendix VI., Table 3) the mean volume between 1876 and 1890 was 260,700 cubic feet per second, but from 1891 to 1905 it was reduced to 234,000 cubic feet—a difference of 26,400 cubic feet per second. As a fall of one foot of the lake level corresponds to a diminution of discharge amounting to 25,761 cubic feet per second, the actual measurement shows an amount corresponding to the lowering of lake level by slightly more than one foot. As this was not due to decreased rainfall, for in late years the precipitation has increased, it was evidently caused by a lowering of the channel, thereby permanently reducing the surface of the lake to a lower level. The lake level during 1891-1905 was 1·10 feet lower than in the years 1876-'90, while the lowering determined by the discharge is shown to be approximately 1·05 feet, the mean of fifteen years. The increased rainfall during 1901-'05 has apparently counteracted this lowering to 0·69 of a foot, thus reducing it from 0·98 of a foot—a condition which cannot be expected to continue.

EFFECT OF LOWERING OF ONTARIO ON HIGHER LAKES.

The mean annual fluctuations given in table accompanying Chapter XXXI. show that this sudden subsidence of the water occurred between 1890 and 1902, with the subsequent fluctuations which are fairly expressed by taking the mean of several years. Changeable winds prevailing over several years may to some extent give rise to variations; so also groupings of different years, but the results are all in the same direction—showing a lowering of the lake outlets, though now partly counterbalanced by the present excessive rainfall.

The mean height of the water during thirty years until 1890 shows no extraordinary changes, while immediately following there was a sudden lowering at all the lakes except Superior. The slope between Toronto and Lock 27 being only slightly more than one foot, and most of this situated within twelve miles of the Lock, it may be considered that the whole distance belongs to the lake level. Between Locks 27 and 15 the rapids descend nearly eighty-nine feet to the expansion of Lake St. Francis. Between Locks 15 and 14, which last is beyond the lower end of this lake, there is only a slight fall. Beauharnois canal, with Lock 14 at its head, extends (alongside Coteau, Cedar, Split Rock and Cascade rapids) to Lake St. Louis, which is more than eighty feet below Lake St. Francis. Some streams from the northern side of the Adirondack mountains enter the St. Lawrence above Lock 15, yet in the mean averages here, no effects appear, as it is seen that the lowering of the water is the same as that at Lock 27. Lake St. Louis receives the large and variable Ottawa river, producing very great fluctuations of ten feet or more. Such changes increase or reduce the head of the waters on these rapids, which would theoretically retard the outflow above Lock 14 at times of high water in the Ottawa river, if the amount were not too small for consideration on account of the great descent of the rapids.

Turning now to the other lakes as well, the cause of this general low stage of water, also prevailing in the Erie and Huron basins, cannot be attributable to any great extent to the inferior rainfall throughout the whole period; for after some years of reduced precipitation (1891-1900) the mean rainfall for the following five years increased in the whole lake region, so that the precipitation was greater than that which prevailed not merely during the years of low water (1890-1900), but also during higher water preceding 1891. Yet it has not raised the lakes to their former stages; and with the next cycle of low rainfall the reduced levels will become more apparent. Accordingly with the evidence before me there seems no other sufficient explanation for this lowering of the lakes than that due to the scouring of the outlets, making itself manifest by the sudden sinking of the water, particularly within a period of two years (1890-92). In the meanwhile the oulet of Lake Superior has not been measurably reduced, and the increased rainfall has raised its level.

The rise of about 0·62 of a foot in Lake Ontario during 1901-'05 does not appear in Lake Erie, where the change is only 0·15 of a foot, while the height of Lake Huron is raised by 0·24 of a foot, although the increase in rainfall should have affected the level of Lake Erie rather than that of Huron.

This inferior rise of Lake Erie in contrast to that of all the other lakes is doubtless attributable to the artificial diversion of the waters of the river, already begun to a small extent. (*See* Chapter XXI., Part II.) A uniform rate of lowering could not be expected. The impact occurring on the various strata would weaken their resistance and cause them to give way at irregular times. When the next lowering of the outlets will occur cannot be foreseen, but the forces are always at work wearing down the rocky barriers of the lake.

As has been shown the amount of lowering in the lake is about one foot. On referring to the discharge tables it will be found that the mean Erie overflow, as given, between 1860 and 1890, was 21,800 cubic feet per second more than during the period 1891-1905. This is equal to about 0·95 of a foot. This includes the slight rise caused by increased rainfall for the last five years.

For the absolute sinking of Lake Huron one foot must be added to 0·66, or 1·66 feet as the total amount of lowering of Lakes Huron-Michigan which has occurred. The shoaling is very noticeable in the shallow channels among the islands.

EFFECTS OF THE LOWERING OF THE LAKES UPON CANALS AND HARBOURS.

About 1893 much concern was occasioned by the shoaling of the harbours, the cause of which was not explained at that time. Low water was characteristic of the decade ending 1900. Since that time the water levels have been higher with the increased rainfall which is partly counteracting the effects of the lowered outlets. With the return of normal diminished rainfall the lowering of the lakes will be more apparent, in the relationship of their levels to the harbours and canals. The sudden shoaling of the canals by one foot, when they were made for even fourteen feet draught, is a serious problem which must enter into the engineering features of the future, and also the shoaling of the harbours, the effects of which are variable with the oscillations of rainfall.

Added to this shoaling of the harbours and canals will be the future lowering of Lake Erie, due to the diversion of the waters for power purposes. (*See* Chapter XXI., Part II.)

CORRECTED ELEVATIONS OF THE GREAT LAKES.

As the outlets of the lakes have been lowered since 1890, the mean elevations that should be adopted are those between 1891 and 1905 inclusive, thus making:—

	Feet above mean sea level at New York.
Lake Ontario	245·08
Lake Erie	571·66
Lake Huron	580·09
Lake Superior	601·94

(This elevation of Superior is the mean during 1861-1905.)

CHAPTER XX.

DISCHARGE OF NIAGARA AND OTHER RIVERS OF ST. LAWRENCE DRAINAGE.

NOTES ON DISCHARGE.

In the earlier investigations of Niagara river* the only available measurements of the discharge of the St. Clair and Niagara rivers were extremely fragmentary, and those obtainable were made in 1868.† Very much more satisfactory information is now at hand, as extensive determinations have been made for different stages of the lakes, and published in reports for the years from 1900 to 1905,‡ so that the discharge of any day since the fluctuations of the lakes were first recorded some fifty years ago can be calculated. The discharges for the Niagara river are given in the report for 1903. The mean monthly and annual discharges have been transcribed to Appendix v. of the present report.

While the fluctuations of the lakes involve many problems bearing on the lake history, discharges of Lakes Huron and Erie only produce a direct modification of the recession of Niagara falls. The present conditions have not always prevailed. Thus, in 1888, it was first discovered that Lake Huron did not

* 'Duration of Niagara falls,' J. W. Spencer, Am. Jour. Sci., Vol. XLVIII., p. 461, 1894.

† Report of Chief of Engineers in 1869, p. 582.

‡ Ib. 1900-'5.

empty into the Niagara drainage until a recent date, consequently it was necessary to ascertain the difference of volume of discharge of the St. Clair and Niagara rivers.

As the surveys of Niagara falls were made in 1875, 1890, and 1905, the periods of discharge in the following table have been chosen so as to correspond with the years of the surveys. From the table it will be seen that there was a sudden shrinkage of the water after 1890. The discharge of Niagara in 1890 was given at 228,974 cubic feet per second, while in 1891 the amount was only 208,908 cubic feet. The lowering of the water of the St. Clair river began to appear in 1889, but only in 1891 did it attain the present low level.

MEAN QUINQUENNIAL DISCHARGE OF ST. MARY, ST. CLAIR, NIAGARA, AND ST. LAWRENCE RIVERS.

Years.	St. Mary.	St. Clair.	Niagara.	St. Lawrence.
1860–1865	84,238	215,290	233,182	277,608
1866–1870	83,985	194,773	220,483	260,629
1871–1875	80,531	203,623	214,819	240,694
1860–1875	....	205,232	223,476	260,767
1876–1880	75,550	208,341	228,644	254,866
1881–1885	74,844	215,865	232.124	261,802
1886–1890	68,299	206.249	226,554	265,195
1876–1890	....	210,152	229,107	260,621
1891–1895	65,922	173,832	203,832	234,691
1896–1900	80,391	168,891	202,480	222,989
1901–1905	....	173,665 (*a*)	206,167	244,428
1891–1905	....	....	204,167	234,036
1891–1902	....	171,746	202,185	....
1860–1892	....	197,603	219,499	251,930
1860–1890	....	207,357	225,967	260,694
1860–1905	....	*	218,859*	....

(*a*) for 1901–02 only.

* The discharge of Niagara river given in the 1904 report (p. 4058), is 215,200 cubic feet per second as the mean from 1860 to 1903, and for the St. Clair river 205,400 cubic feet. As will at once be seen the difference of these discharges is entirely too small and could not have been used in determining the relative physical features of Niagara river.

The tables are adapted from the Engineers' Report of 1903, based upon the mean measurements at an open section of the Niagara river and at the International bridge, two miles within the river.

VARIATIONS IN DISCHARGE OF NIAGARA RIVER.

The change in discharge for one foot of fluctuation of Lake Erie is (for datum discharge) equal to 23,205 cubic feet per second. This includes 1,200 cubic feet per second discharge for the Erie canal, and 1,100 feet per second for the Welland canal. (Thomas Russell, p. 4116, 1894.) The equation for the variation of the river stands thus:—

Discharge in cubic feet per second (s-f) equals 158,500 +22,462 (C—570). C is the elevation of Lake Erie at Cleveland. (s. f. is cubic feet per second.)

In the discharge tables the volumes of the various years are based upon the fluctuations of the lakes. The meter determinations for various stages were made during some of the years between 1898 and 1902. Thus it will be seen that the measurements were only taken after the lowering of the lake outlet, which feature was not recognized in computing the discharge prior to 1891. This omission accounts for the larger volume of the river between 1860 and 1890 compared with that of subsequent years, giving an excessive discharge between 21,000 and 23,000 cubic feet per second.

If the Niagara channel has been uniformly deepened to the equivalent of one foot since 1890, one foot should have been taken from the lake levels in calculating all discharges prior to the lowering of the outlet; which has not been done, but in the tables, the discharges are given as if the outlets were as high as when the lake-levels were recorded prior to 1891, although the water-meter determinations were made since the lowering of the outlets. By comparing the mean discharges from 1860 to 1890 with that from 1891 to 1905, the volume of the Niagara river for the two periods is reduced from 225,967 to 204,164 cubic feet per second, a difference of 21,803 cubic feet, or a lowering of about 0·95 of a foot. Transposing the case, with the bed of the channel as formerly nearly a foot higher, the mean discharge before and after 1890 would be approximately the same. Thus is explained the extraordinary discrepancy that demanded investigation, as the meteorological variations were entirely unable to account for it. In short, the discharge of Niagara river in the future can only be taken as that of the mean since 1890, which further re-determinations may slightly correct. Accordingly the mean volume is taken at about 204,000 cubic feet in place of 219,000 for the whole period from 1860 to 1905. This materially reduces the estimate of the power of Niagara falls. The Lake Survey has lately reduced their estimate to 215,200 cubic feet (their method being unpublished), but nowhere have they corrected the discharges for the lowering of the outlets as mentioned. With my correction applied, the mean discharge would be further reduced to 200,000 cubic feet per second.

VARIATION IN DISCHARGE OF ST. CLAIR RIVER.

A change of discharge in Saint Clair river for one foot of fall of Lake Huron is 19,238 cubic feet* per second (page 4120). While the formula for the discharge is simple yet it was instrumentally determined for only a limited range of height, as in the case of Niagara river, after the lowering of the St. Clair outlet. Consequently, similar corrections in the discharge tables must be applied for the years preceding 1891. Again, ice action on which observations have been made during only three winters, is not fully understood; thus results are less satisfactory than at Niagara river.

* Report of U. S. Engineers, page 4120, 1904.

The table (page 248) gives the mean discharge of Lake Huron from 1860 to 1890 at 207,357 cubic feet per second, and that from 1891 to 1902 at 171,746 cubic feet. As has been shown (Chapters XVIII. and XIX.), the Huron outlet has been lowered by 0·66 of a foot more than the surface of Lake Erie, to which one foot must be added. Applying this correction to the mean discharge given before 1891, the result shows 176,957 cubic feet per second, or about 5,000 cubic feet per second more than the mean discharge of the twelve years 1891-1902. This excess would be reduced by including the discharge of the last three years; and further allowing for the imperfections of observation, the discrepancy of calculation before 1891 compared with determinations since that date is greatly reduced.

Thus it becomes apparent that the differences between the discharges of the two periods is due to the omission in considering the former higher bed of the St. Clair river. This analysis confirms the conclusion as to the recent lowering of the Huron outlet, and the necessity of adopting the discharge values since 1890 as the standard.

VARIATIONS IN THE DISCHARGE OF THE ST. LAWRENCE RIVER.

A formula has been found for extending the discharge calculations, and it may be added here, along with those of the other rivers. The meter measurements were taken in 1900-'02, at the narrowest part of the river below Cardinal (that is below Lock 27).

The discharge in cubic feet per second = 94683 + 25761 (level of Lake Ontario at Oswego —240); or, in other words, the variation of one foot changes the volume by nearly 25,761 feet. Fluctuations of level of one foot at the Lock 27 represent nearly 26,787 cubic feet, in the discharge measurements.

VARIATIONS IN THE DISCHARGE OF ST. MARY RIVER.

The formula for the variations of the discharge of Lake Superior may be applied in the study of the relative fluctuations of that lake and Lake Huron. The pier bridge across the St. Mary has increased the velocity, but the formula since 1898 is:—

Discharge in cubic feet per second = 48,235 + 17,656 (level of Lake Superior —600).

PROPORTIONAL DRAINAGE OF THE ERIE BASIN.

A special object in studying the discharge of the Huron basin is to determine the differences between the outflow of the Huron and Erie basins. Tables given in the Reports of Engineers for 1903 and 1904 vary the mean discharge of the rivers by a small percentage, which when reduced to the differential discharge of the Erie basin makes the apparent discrepancy here very much greater than is permissible. Concerning Erie alone, Mr. Russell shows that of the Niagara discharge, when it reaches 222,400 cubic feet per second, 31,100 cubic feet per second should come from the Erie basin, if the rainfall of the region were proportional to the respective areas —that is the Niagara discharge would exceed the St. Clair by this amount. But the calculation from the discharge formula as given in the 1903 report shows only 21,300 cubic feet per second as the average between the years 1860 and 1892 inclusive. This is ten per cent of the total overflow of the Erie basin. In the report of 1904 this percentage was reduced so much indeed that Mr. Russell says: 'It would require a very great and totally inadmissible evaporation from the lake to have the differences as small as observations indicated (page 4125).' 'The most that can be done then with the water heights, discharge, and rainfall is to see what a reasonable value of the land run-off and the lake evaporation will give for the difference of the Detroit and Niagara rivers.'

By taking the run-off of the year at six-tenths, and the evaporation of Lake Erie at three feet in a year, Mr. Russell finds the Erie discharge would correspond to 37,255 c. f. per second. Combining the result with that from the Niagara river he shows it would raise the lake surface by 1·61 feet more than without it. He concludes by saying that the evaporation indicates that the winter run-off is probably more than six-tenths of the rainfall, and the summer run-off somewhat less. This would make the proportional overflow from the Erie basin to be 16·7 per cent of the total discharge of Niagara river.

For the Huron-Michigan basin the run-off from the land is taken at six-tenths of the rainfall, and the evaporation from the lake surface alone may be taken at thirty-three inches for the year; while in Lake Superior region, with the same run-off from the land, the evaporation from the water is less than eighteen inches.

Considering the discrepancies between the meteorological and the gauge determinations, Mr. Russell says: 'The adopted datum discharge for the St. Clair and Detroit rivers is possibly too large, and the discharge of Niagara too small by a very considerable quantity; 10,000 cubic feet per second or more' (page 4130). In the Report of the Engineers attention is also called to the fact that the gauge readings were taken during years of low water.

In the above, great discrepancies appeared between the mean discharge of the Erie basin and the total volume of the Niagara river, when comparing the tables with other evidence bearing upon the subject; for from the table the mean run-off from the Erie basin appears to be only 10 per cent of the total discharge of all the Upper lakes, while the drainage areas and the meteorological phenomena indicated much larger proportions.

From the corrected discharges it is found that the run-off of the Erie basin is 15 per cent of the total discharge of Niagara river.

This amount of 15 per cent as derived from the discharge values is close to that obtained from the meteorological calculation, which is 17·7 per cent (page 221); and from the proportional part of the drainage area of 16 per cent. The discharge value is probably the most correct on account of the variable rainfall in the different lake basins. There will be other meteorological variations, such as a greater velocity of wind in the Erie than in the Superior basin, a higher temperature in Erie than in the other basins, as well as a greater evaporation. Finally, the adoption of 15 per cent as the proportional part of the Niagara discharge derived from the Erie basin may be used in the variable recession of Niagara falls during the period of changing volume. This problem involved one of the most complex questions in the present work, as the approximately correct determinations of the age of Niagara falls hinged upon this investigation.

CHAPTER XXI.

POWER OF NIAGARA—PART ONE.

Variable discharge and present shrinkage.
Range of horse-power of the falls.
Available power in recession.
Net mechanical horse-power.
Ratio of Canadian and American channels and falls.
Franchises.
Limitations of use.
Power of Niagara river below the falls.

VARIABLE DISCHARGE AND PRESENT SHRINKAGE.

The descent of the Niagara river from the First cascade of the Upper rapids to Lake Ontario is 312 feet. The surface of the river below the falls may be taken at 100 feet. Thus the power of Niagara represents the product of a fall of 212 feet and the variable discharge volume of any particular day.

		Cubic feet per second.	Corrected cubic feet per second.
Average discharge	1860-1890	*226,000	204,000
"	1891-1905	204,000	204,000
"	1860-1905	*219,000	204,000
"	1858 (October 7)	314,000	292,000
"	1862 (for the year)	243,000	221,000
"	1862 (month of June)	260,000	238,000
"	1895 (for the year)	187,000	187,000
"	1902 (month of February)	175,000	175,000
"	1902 (Feb'y. 28th)	158,500†	158,500†

Reducing these figures to horse power the following results are obtained:—

RANGE OF HORSE-POWER OF THE FALLS.

Average			Corrected
gross horse power	1860-1890	5,444,000 H.P.	4,914,000 H.P.
"	1891-1905	4,915,000 "	4,915,000 "
"	1860-1905	5,276,000 "	4,748,000 "
"	1858 (October 7)	7,563,000 "	7,033,000 "
"	1862 (for the year)	5,854,000 "	5,326,000 "
"	1862 (for month of June)	6,264,000 "	5,736,000 "
"	1895 (for the year)	4,505,000 "	4,505,000 "
"	1902 (month of February)	4,216,000 "	4,216,000 "
"	1902 (Feb'y, 28th)	†3,818,000 "	3,818,000 "

From these figures it may be seen that the work of Niagara varies enormously.

* These are averages taken from the discharge tables, but on account of the lowering of the lake outlets, not allowed for here, the correct mean discharge is that of the period of 1891-1905.

† Water at Port Colborne only 569·58 above the sea.

AVAILABLE POWER IN THE RECESSION.

From the standpoint of the recession of the falls the whole of this horse power, whether large or small, comes into operation. The greatest force of the river is at the apex. This condition has obtained for some time, as our recent survey has found that the deepest channel is close under the American falls, and near Goat island shelf. It is seen, both from the soundings and the present discharge over the falls, that the force at work is unequally distributed.

It is only reasonable to suppose that the principal work of new excavation is effected during periods of high water, when the rock formations are the most weakened. The apparent modern reduction in the discharge of the river has been explained, but the diminished rate of recession of the falls during the last fifteen years to less than half that of the annual amount during the forty-eight preceding years (page 41) is not due to the reduction of discharge. This slower recession now in progress is largely attributable to a change of rock structure, owing to the falls now crossing the site of the ancient Falls-Chippawa valley in place of following along its course (page 166).

The above brief consideration of the work of Niagara falls shows simply the natural retreat of the great cataract; but now artificial conditions are beginning, and henceforth these will be greatly extended.

NET MECHANICAL HORSE POWER.

A change of one foot in the height of Lake Erie will increase or diminish the discharge by 23,205 cubic feet per second, which is equivalent to 569,000 horse power. When it comes to the question of the artificial application of power, if water be taken from the river below the First cascade, the obtainable horse power will be much less than if taken above. On the average of all the companies, the available amount will be reduced by from 30 to 35 per cent,* owing to the loss in height, in the waste weir tunnels, and at the bottom of the shafts, etc. This will reduce the available horse power for a foot of fall in the lake to 400,000 or less. Where the water is taken at a considerable distance below the head of the rapids, from forty to fifty feet lower down, the available amount will be still further decreased. Accordingly, the net mean water power of the falls if entirely diverted for artificial purposes would fall to 3,200,000 horse power, and the low water discharge to 2,600,000. On the basis of 7 per cent, the available horse-power of the American falls is 350,000 for mean stages, or nearly 250,000 for low water.

The preservation of Niagara falls is now a question before both countries. Where water power franchises are given they are granted in quantities irrespective of the stages of the river, or, in other words, they withdraw the water from the minimum discharge. Thus when the mean volume was reduced to the stage of February, 1902, it was about 30,000 cubic feet per second less than the mean annual discharge. This produced the lowering of the river above the rapids by over two feet below mean stage.

RATIO OF THE VOLUME OF THE CANADIAN AND AMERICAN CHANNELS AND FALLS.

The mean depth of the water at the American falls does not exceed 1·5 feet, though some channels are deeper. These falls, including Luna island, have a breadth of nearly one thousand feet. The barrier whose height determines the discharge is situated near the head of Goat island, where the river is reduced to a breadth of about 340 feet. The First cas-

* Power companies' heads: Canadian Niagara, 136. Electrical Development, 136. Ontario Power Company, 180. Niagara Falls Power Company, New York, 136. Niagara Falls Hydraulic Company, 210. Chicago canal, 32 feet. See Report of Queen Victoria Niagara Falls Park, by James Wilson, 1905, p. 7. These figures show the great loss of power head in transmitting the water through the tunnels.

cade between Goat island and the Canadian side forms a rim of nearly 3,400 feet, as the river cascades over the rock ledges which control the discharge of the Canadian falls. Accordingly, in breadth the American channel is only nine per cent of the whole. As mentioned in Chapter v., there is an almost horizontal ledge of limestone extending across the river which is covered in many parts by only a thin sheet of water, as on the eastern half. Thus for 400 feet from Goat island, during the present average water already lowered, the sheet has a depth of less than one foot. Then for a distance beyond, beginning above the outermost Sister islands, the depth of water appears to be from two to three feet, where it descends six or seven feet. This continues for a few hundred feet, beyond which the ledge of rock is very thinly covered with water, reaching perhaps more than half way across the river. Beyond is the deep part of the Niagara river, extending to near the Canadian shore, where I have estimated the depth from discharge values as averaging eight to nine feet, although Mr. Wilson does not think that it is so great. At the First cascade of the American channel the average depth scarcely exceeds three feet; and being very much smaller than the deeper section of the Canadian channel, the volume of discharge is reduced considerably below nine per cent, perhaps as low as six per cent, though probably the range may be between this and eight per cent. At seven per cent the volume is about 14,000 cubic feet per second. Indeed, the shallowness at the head of Goat island was shown during low water as in 1904, when, owing to the backing of the river due to wind, a wide expanse of rocks was laid bare above the Sister islands. Kalm records that four Indians forded from Goat island to the New York shore.

Some idea of the character of these rapids is shown in Plates xii. a and b, and xxxi. a and b.

From Goat island to the International Boundary Line, on the First cascade, is a distance of about thirteen hundred feet, where the depth is shallow as just described. From this Line to the Canadian side is twenty-one hundred feet, including the deepest portion of the river, where the water is not less than three times the depth of that to the east. Accordingly, not over 13 per cent of the discharge is on the eastern side of the Boundary Line. This, together with, say, seven per cent in the American channel, would allow 20 per cent of the volume of the river to be upon the New York side and 80 per cent on the Canadian. A mile above, the soundings give a good cross section on each side of the Boundary Line, and by Chézy's formula it is found that 75 per cent of the water flows on the Canadian side; while at the First cascade, owing to the position of the Line and the shoaler water, on the eastern side, a smaller amount passes.

At the brink of the American falls themselves the volume of the cascade, as given above, is approximately seven per cent, while the stream of water over the end of Goat island shelf, from a breadth of less than 300 feet, is so inconsiderable that it is almost inappreciable. Above this end the whole great cataract lies within Canadian territory.

FRANCHISES.

The question of franchises now presents itself. These have been granted on the Canadian side of the river to:—

Canadian-Niagara Power Company....	8,600	cubic feet per second ;	100,000	H.P.
Ontario Power Company	11,700	" "	180,000	"
Electrical Development Company....	10,750	" "	125,000	"
Electrical Railway Company..........	400	" "		
	31,450			
On the New York side:				
Niagara Falls Hydraulic Company....	10,000	cubic feet per second ;	100,000	H.P.
Niagara Falls Power Company......	17,200	" "	200,000	"
	27,200			
Chicago Drainage canal.............	10,000	" "		
Welland canal (including Hamilton Cataract Company)...........	1,100	" "		
Erie canal..........................	1,200	" "		
	12,300	" "		
Total..............................	70,950	" "		

Of the franchised diversion, the two companies on the New York side, and the Ontario company on the Canadian, take their water from or above the First cascade, and consequently affect the river common to both countries. The intakes of the Canadian Niagara and the Electrical Development Companies are from the deeper part of the river, far lower than the First cascade, and they will not use the water from the shallower part of the river near Goat island side. Nor will they lower it in the basin above the First cascade or Lake Erie to any appreciable extent. As a power question alone, below the First cascade, almost all the water passing down the Canadian falls, belongs to Canada.

It is the diversion of the water from above the rim of the First cascade which will further shrink Niagara falls. Already, the crest has been curtailed by 415 feet, on the western side, owing to the artificial embankments. (*See* pp. 267-8.)

Besides these there are ten other franchises, mostly old, some of which have been cancelled. Several are in unlimited amounts, so that the whole volume of the river might have been given away, but none of these last are under construction.

At the time of writing (winter of 1906) the Chicago drainage canal is taking 5,000 cubic feet per second; the Canadian companies, 3,000; and the New York companies 9,000 cubic feet, in all 17,000 feet, besides the Welland and Erie canals. This is equal to the lowering of the water in Lake Erie by three-quarters of a foot. The figures include a liberal loss in conversion, and they should be compared with the discharge at a time of low water. Passing by the minimum daily overflow, occurring in these later years, but adopting the mean low volume of February, 1902, which was 175,000 cubic feet per second, the above franchises, including canals, represent 40 per cent of the total low water discharge.

LIMITATIONS OF USE.

Since writing the above, the report of the International Waterways Commission has appeared. They recommend the limitation of the power on the Canadian side to 36,000 cubic feet per second, and on the New York side to 18,500 cubic feet per second; in addition to which is the discharge of 10,000 cubic feet for the Chicago canal;—in all 64,500 cubic feet, including the Welland and Erie canals, or nearly 37 per cent of the low water discharge. This amount will lower the river, producing effects on the falls only a little less than the diversion of the full franchise volume mentioned. So, also, it will most seriously impair navigation on the Upper lakes as will be explained in next chapter.

POWER OF NIAGARA BELOW THE FALLS.

The question of the power of Niagara does not end here. There is the same volume of water descending about another hundred feet before reaching the mouth of the gorge. Here is nearly fifty per cent of the power of Niagara falls themselves. Various schemes have been proposed to utilize it—for instance a tunnel on the Canadian side, adjacent to the Whirlpool rapids, where there is a descent of 51·5 feet. On the New York side it has been proposed to build a retaining wall beside the rapids which would eventually reach a height of fifty feet, and then cut down the natural slope of the side of the cañon so as to build a canal between the retaining wall and the side of the gorge, now made perpendicular. On the embankment the Gorge railway would run, while the power house would be situated on the rocks at the outlet of the Whirlpool.

At Foster flats a fall of twenty feet is available. Finally, the last proposal is to dam the mouth of the river to a height of 100 feet, and thus at once obtain a million and a quarter of available horse power. This would flood Foster flats, drown the Whirlpool, submerge Whirlpool rapids, and form a great mill pond. Such a proposition disregards the various considerations of the destruction of all these features and ignores international questions. The engineering difficulties of opposing a force of 3,000,000 horse-power, which might be hurled against the works, at any time during a great flood, seem insurmountable, and not to have been taken into account; also, the fact that the dam would require to reach more than 180 feet below the surface of the river.

In this chapter I have set forth the power of the river as a natural agent, and have pointed out the capabilities for supplying power. Another proposition has been brought forward, namely, to divert the water from the main river into the New York channel and to save the American falls. But to pay for this expense a million more horse power is to be abstracted from the greater falls, which are Canadian. This is an insidious proposition for obtaining more water, in fact more than a third of the total available power of the river.

Before making these investigations I had no appreciation of the magnitude of the changes which the proposed use of power is likely to produce. It is only by applying measurements to the falls that the comprehension of the effects of diversion can be understood. These will be shown in chapter xxi., Part Two.

The result of lowering the river in the basin above the Upper rapids by the equivalent of three-quarters of a foot in Lake Huron can be seen in Plate vii, photographed on a day when the lake level was exactly the mean of the last five years, but subsequent to the lowering of the water on the rapids, to an apparent extent.

PLATE XXXI. A.

View of east end First Cascade at Goat Island and bared rock at Sister Island. (Sept., 1906).

PLATE XXXI. B.

View of First Cascade above the outermost of the Sister Islands. This rim determines distribution of river flow. (Sept., 1906).

CHAPTER XXI., PART TWO.

SHRINKAGE OF FALLS AND LOWERING OF LAKES BY POWER DIVERSION,

Effects on Niagara Falls by use of power.

Lowering of lakes and canals, by use of power at the Falls.

EFFECTS ON NIAGARA FALLS BY USE OF POWER.

A fall of one foot in the level of Lake Erie reduces the discharge by 23,000 cubic feet per second. This amount divided into the franchise allowances of about 70,000 cubic feet per second represents the equivalent lowering by three feet if the water were taken directly from the lake itself. For each additional foot of the subsidence the outflow diminishes, so that the franchise amount would represent a sinking of the lake by a qualified factor. The outlet of Lake Erie at the International bridge is reduced to a breadth of 1,850 feet, and a mean depth of 22·5 feet, with a sectional area of 42,000 square feet. As most of the water will be withdrawn from below here the effect upon the lake will be through an increased velocity, until equilibrium becomes re-established by a lowering of the lake. This question will be considered immediately after the present one.

Below Grand island the two branches of the river unite and form a basin, which, just below the creek entrance at Chippawa, is 5,050 feet across, with soundings, so that the area of the section can be determined. This is 83,000 square feet. The mean depth is sixteen feet. The discharge, is that of Lake Erie, with only a small increase from the creeks at Chippawa and Tonawanda. It took fifteen to twenty minutes for floats to cover the distance from the line of soundings, where the area is measured, to the First cascade, at the end of which is situated the Forebay of the Ontario Power Company (*see* Plate XII. A), showing the small descent of the river. From this basin or above it the power franchises allow the withdrawal of about 41,200 cubic feet per second, which represents 20 per cent of the mean discharge, or 24 per cent of the low water flow. Accordingly, the proportional diversion represents an unmodified lowering of this basin to the extent of four feet for low water stages, or 3·2 feet for average water. To this must be added 10,000 feet for the Chicago canal, thus making a total of 51,200 cubic feet, or 25 per cent for mean water, and 30 per cent for low water. This total diversion at or above the First cascade should be modified to an undetermined amount from confining the river to a narrower channel, after the shallower rim will have been mostly drained.

If the proposed limitation be carried out, then from the 64,500 cubic feet must be deducted the Canadian franchises of 19,750 cubic feet taken at points below the First cascade, leaving 44,750 cubic feet to be withdrawn from above it. This would make the theoretical lowering of the basin, without corrections, amount to more than 3·5 feet for even mean water, or over four feet for low water.

The withdrawal of the water behind the rim of the First cascade has the same effect as the deepening of the outlet. It increases the velocity of the river above, which for a time lessens the amount of the subsidence in the basin, until the Erie level is adjusted to the new conditions. Even now the rim of the First cascade for many hundred feet from Goat island is covered by only from one-half to one and a half feet of water. These observations were made after there had been a considerable diversion of the river, and on a day when the lake was at its mean quinquennial level. The deeper the water upon the rim at present, provided it be eventually drawn off, the more would be the lowering of the surface behind it, due to the diversion through artificial orifices; while if there be less water on the rim the discharge would be diverted into the narrower and deeper channel, causing some retardation of the current in the basin. There is nothing to lead me to expect that the lowering will be less than three feet for mean water and more for low. (*See* p. 272.)

The diversion already at the rim of the basin has reached a foot. This has lowered the water on Goat island shelf (as shown in Plate XXXVIII. A), where formerly fewer blocks appeared, to beyond the International Boundary Line at the cataract, and also near the Goat island walk (*see* Plate II.). In the meanwhile the diversion is laying bare the shallow river bottom above the upper end of Goat island and about the Sister islands. The effect upon the falls is also increasing. With the lowering of even two feet the crest line from Goat island will be drained round the angle of the shelf to a distance of about 800 feet (*see* Plates II. and VII.), thus cutting off this magnificent sheet of the falls. This will be the first part of Niagara falls to disappear, as the shallowest part of the water is on the rim above.

The next shrinkage will be in the American falls, which will be reduced from a sheet of about a thousand feet wide to a few narrow streams coursing down the deeper channels, as may be determined from the rim above the rapids.

At the same time the main falls will have the depth of water reduced two or three feet. This change is arising from the diversion of the water above the rim of the First cascade; while that from fifty feet below the First cascade, will scarcely affect the discharge at the rim above. After the loss of 20 to 25 per cent of the water, above the rim, the power drawn from below it will divert about one-eighth of the remainder of the discharge (for mean stage) from the deeper channel. This will further lower the water here by less than one foot. The lowering of the river above the falls in this deeper channel may contract their breadth on the Canadian side, by 200 feet more, as already 415 feet have been taken owing to the artificial embankment. As as stated on the previous page, the shrinkage in progress on the western side of the falls will amount to 800 feet.

Niagara falls reached their supreme magnificence by 1900, when the perimeter of the Canadian falls was 2,950 feet and the American 1,000 feet. The whole is now reduced by encroachment to about 3,500 feet. With the use of the full franchises the entire width of the falls will be reduced to 1,500 or 1,600 feet, and then they will lie wholly in Canadian territory, except small streams coursing down the ancient river bed over the Goat island shelf and the present route of the American channel and falls. But occasional glimpses of the ancient grandeur of the falls will be seen during exceptionally high water.

LOWERING OF LAKES AND CANALS BY POWER DIVERSION AT NIAGARA RIVER.

If the subject be considered at all, there seems to be an impression that the diversion of the water at Niagara will not affect the higher lakes. If the water were all taken from below the Greens or the First cascade, at nearly fifty feet down the rapids, the affect on the upper river would be unappreciable. But most of the water under the franchises will be taken from or above the rim, which forms the barrier to the basin of the Upper rapids.

In the narrow part of the outlet of Lake Erie, at the International bridge, the mean depth is twenty-two and a half feet, but the deepest part of the channel reaches to fifty-three feet. At 1·25 miles above, the rocky beds appear at seventeen to twenty-four feet. Many parts of the river below are thirty feet deep to a point just above the basin mentioned, which is nearly fourteen feet below the level of Lake Erie. The sandbars in the river are mobile and deposited by a slight diminution of the

View of western end of Canadian Falls, before curtailment of 415 feet.

current, the same would be removed, with an equally small increase of velocity. Thus, if the velocity be doubled, the transporting power is increased sixty-four times. This shows that the bars are as unstable as the river, the whole course of which may be considered to have a depth of between thirty and fifty-three feet. As the depth upon a great part of the rim is less than three feet, and as probably the deepest channel does not average more than eight or nine feet, the floor of the river everywhere, to near Lake Erie, is practically at as low a plane as the bed of the channel across the rim. Accordingly, it is not entirely the river bed that gives the slope, but it is largely the constriction at the narrow outlet of the lake, whereby the surface of the river is here piled up and flow out with more rapid currents.

At Fort Erie town is a broad terrace five to eight feet above the river extending to a high river bank. At the upper end, it is underlaid by rock, once a floor extending across the river. At the crib of the Buffalo Waterworks the depth of channel is seventeen feet. But immediately above and below is a large channel to twenty-four feet or more, so that the deeper part of the seventeen-foot channel may now be refilled with clay. Here the velocity of the river reaches eight miles an hour, although the width is about 1,850 feet. As the deeper channel is about 1,000 feet wide, with its limitation, by a depth of twelve feet or less, I find here the original outlet of the little Erie drainage; so that all the channel less than twelve feet deep has been only recently overflowed (*see* Chapter XXVII.) by the late increase of the river discharge. At the time of the augmented volume the river flooded the rocky floor of Fort Erie to a depth of about twelve feet, since which time the lake has been lowered perhaps twenty feet by the scouring out of the clay and rocky barrier, during the recent part of the history of the river.

It is thus easily seen that if the slope of the river be increased, its velocity at the outlet mentioned, which is now five to eight miles an hour, must be increased also, and that the principal acceleration due to the lowering in the basin above the Upper rapids will be concentrated at the narrow outlet of the lake. At the Upper basin the velocity is less than two miles an hour, but this is two and a half times the width of the lake outlet.

A change of level of Lake Huron by one foot will raise or lower Lake Erie 0·727 of a foot; also a rise of one foot in Lake Erie will cause a backwater of 0·346 of a foot in Lake Huron. The distance is sixty miles, and the fall of the river eight and a half feet. At Niagara I have determined the fluctuations in the basin from Port Day levels, and find that a change of one foot in Lake Erie produces a fluctuation of 0·45 of a foot in the Upper basin, about five hours later The distance is nineteen miles, with a fall of nearly fourteen feet. Under these circumstances it is easily seen that a lowering of the water in the basin above the Upper rapids must considerably increase the velocity at the outlet of Lake Erie.

The result of the withdrawal of the water behind the First cascade, as has been already shown (page 266), is to lower the water in the basin. As the water is being drawn off, it is partly compensated by the increased velocity of the river above. So long as any water runs over the thinly covered rim, the artificial diversion from behind will have the same effect as if the channel were depeened. Once it shrinks below the higher part into the narrower deeper channel a new component will be introduced, when the result will approach that of simply a change of outlet. This, however, cannot occur until the level has fallen considerably for ordinary stages of water. If it were not for the contraction of the channel, the greatest lowering would exceed the amount mentioned (page 267).

With the gradual lowering of the basin, a difference of one foot in the slope of the river should increase the velocity at the outlet of Lake Erie by about three per cent, which in the course of a year and a half would lower Lake Erie nearly a foot,* with the complete effect shown sometime afterwards. While some as yet unmeasured factors may somewhat retard the velocity and increase the time, the ultimate effect must be the same. After that the equilibrium should be restored at a lower level of the lake. Subsequently comes in the lowering of another and still another foot, or more, so that I cannot see, even in this preliminary study, how that in a few years at most, from the time of the complete use of the franchise power, Lake Erie will not be lowered by three feet, or more for prevailing low water—not taking into account the effect of the further deepening of the outlet of the lake which may recur at any time. This last statement introduces a new feature. The tendency of the river is always to scour and lower the bed of the outlet of the lake, as actually occurred to the extent of one foot immediately after 1890. Now, with the increased velocity occasioned by the slope of the river, augmented from fourteen to seventeen feet, the deepening of the outlet must be accelerated at the bridge section, and on the more rocky rim at Fort Erie town. While the full amount cannot be precisely stated, it presents a serious problem from the economic side of the question, which cannot be avoided even if overlooked. With the lowering of Lake Erie, the same effects will follow, and Lakes Huron and Michigan in their turn will be lowered a little later.

So much for the physics of the river as the question appears to me. But has not the diversion of water already in use produced an appreciable effect?

The five thousand cubic feet per second taken by the Chicago canal has an effect of lowering Lakes Michigan and Huron by 0·26 of a foot or over three inches. The volume of the Chicago canal increased to ten thousand cubic feet per second will double this amount, or lower Lake Huron by somewhat more than six inches. This Chicago diversion of five thousand cubic

* Chézy formula is : $v = c\sqrt{R. S.}$, where v represents velocity; c constant requirement of river to be determined (which in large river does not differ greatly for small changes) ; R, the radius or depth ; S, slope or fall.

feet affects the level of Lake Erie by 0·22 of a foot,† and Lake Ontario by 0·19 of a foot, which in each case will be doubled with the increased discharge by the Chicago canal.

A marked increase in the rainfall has occurred since 1900, as compared with the mean rainfall during the decade ending with that year. On examining the tables of the fluctuations of level and rainfall, and taking into account the effects of the Chicago canal upon different basins, I find from both the results that Lake Erie should have risen 0·46 of a foot more than it actually has done, when compared with both Lake Ontario* and Lake Huron. What is the cause of this failure to raise the level of the Erie basin, where the rainfall has increased not only over the amount of the previous period, but also in excess of that of the other basins. Certainly there is but one explanation, namely, the excess has been diverted by the power uses from above the rim of Upper rapids during the five years ending with 1905, over the mean of that of the ten preceding years of low water. Adding to this the effect of the Chicago drainage canal, the fall which the lake has experienced from the artificial diversion amounts to 0·68 of a foot in height, or about eight inches. At the close of 1905 the total diversion of water was equivalent to the lowering of Lake Erie by about nine inches. Here then is direct evidence that the diversion of water has lowered Lake Erie, to more than eight inches, while as yet not over one-quarter of the franchise power has been brought into use.

But the superficial observer would not see the change on account of the increased rainfall, by which the actual present

† U. S. engineers give this at 0·19 foot.

* This figure is found thus: with the increased rainfall, Lake Ontario has risen 0·62 foot, to which must be added 0·19, the effect of the Chicago canal, or 0·81. As the lowering of Erie and Ontario are found to have been nearly equal, Erie should have been correspondingly raised (0·62 foot for increased rainfall and 0·22 for Chicago canal diversion, or 0·84). This last 0·22 and the actual observed rise of 0·15, is all that can be accounted for, leaving 0·47 foot as the amount of lowering of Lake Erie by the diversion of water at Niagara falls from above the First cascade. From the changes of the rainfall, the result was found to be 0·45.

level of Lake Erie is not lowered below that of previous years. Had not the diversion occurred, while a corresponding rise actually took place in Lake Ontario and Lake Huron, Lake Erie would have been raised 0·68 of a foot (0·46 at Niagara and 0·22 at Chicago).

While it is more difficult to recognize small fluctuations than large ones, all must be taken over a considerable length of time, for neither a day, nor even a year, is sufficient, yet this demonstration of the effect upon Lake Erie of the changes brought about by the power diversion, confirms the estimated effects on the same. A lowering of the higher lakes (Huron and Michigan) must also occur when the change in the Erie basin is completed. This lowering of Lake Erie, during years of mean stage of water, and still more during periods of unusual lowness, will produce serious effects on the canals and harbours, for which provision must be made.

CHAPTER XXII.

CHANGES OF ONTARIO LEVELS SHOWN IN IROQUOIS BEACH.

Early observations concerning the Iroquois beach.
Characteristics of Iroquois beach.
Tilting of the land recorded by Iroquois beach.
Lower beach and increased descent of the Niagara.
Sudden changes of level.

EARLY OBSERVATIONS CONCERNING THE IROQUOIS BEACH.

Mention has been made in Chapter xv. of the higher stages of water at the mouth of the Niagara gorge shown in the now elevated beaches. The most perfectly developed, and also most carefully studied one, is the Iroquois beach, and its importance lies not merely in its height at the Niagara, but in its now upward tilting on proceeding northeastward, so that it becomes one of the standards of late terrestrial movement.

Narrow gravel ridges traversing an otherwise clayey plain, running in directions more or less parallel to the lake shore, were made use of as Indian trails. These were adopted by the original settlers of the country as the main thoroughfare, and constitute what are called the Ridge roads. Fragments of such occur about all the lakes. Those south of Lake Ontario, from Lewiston on the Niagara river to Rochester, were described so long ago as 1811 by DeWitt Clinton.* The character of the roads so nearly resembles that of the present lake beaches that many early writers regarded them as of such origin. But they are not horizontal.

In discussing the disturbed levels of the roads between Rochester and Lewiston with Prof. Desor in 1851,† Prof. Stoddard said: 'The unequal elevation of the different parts

* Journal of the New York Historical Soc., p. 68, 1811.
† Proc. Boston Soc. Nat. Hist., Vol. III., p. 358, 1851.

of the Ridge road was not incompatible with the theory of there having been a beach, if it were supposed to have been raised to its present position. The elevation of so extensive a tract to a height of 500 to 600 feet' (an incorrect reference to sea level) 'could hardly have occurred without having produced inequalities at different places as great as are found of some thirty or forty feet.' This is the earliest clearly expressed idea known to the writer, of the deformation of the land being recorded in the raised beaches, which was necessary to account for their origin. A fragment of the beach west of Toronto was described by Mr. (now Sir Sandford) Fleming, in 1859.* In 1863,† Prof. Robert Bell correlated the Davenport beach near Toronto with that at Lewiston, thereby suggesting a greater rise of land in the vicinity of Toronto than at Niagara river. The details of this same beach through Hamilton and elsewhere at the head of Lake Ontario were described in the Geology of Canada, and later by myself in 1882.‡

At the eastern end of Lake Ontario Mr. William Dewey, in 1836,** proposed to locate the Rome and Watertown railway, but found that this beach rose too rapidly. Thus the atmosphere was full of the idea of the differential rise of this old shore line. In 1842 Prof. Hall recognized that the beach was of unequal height, but did not give prominence to the deformation. In 1885 Mr. G. K. Gilbert§ made further exploration from the Niagara river to North Adams, south of Watertown, where he terminated the beach, and gave the measurements at several points. In 1887 I continued the exploration of the beach from North Adams to Prospect farm, four miles beyond Watertown.|| In that year, and subsequently, I made further

* Canadian Journal, Toronto, 1859.

† Geology of Canada, 1863.

‡ 'Geology of the Region about the Western end of Lake Ontario,' J. W. Spencer. Canadian Naturalist, Vol. X., 1882.

** Quoted by Dr. Hough in History of Jefferson Co., N.Y.

§ Science, Vol. VI., p. 222, 1885.

|| 'The Iroquois beach, a chapter in the Geological History of Lake Ontario,' Trans. Royal Soc. Can., Vol. VII., Sec. IV. pp. 121-134, 1889. Abstract in Science, Vol. XI., p. 49, 1888.

surveys of the delta deposits on the northern side of the Adirondacks, and correlated a chain of them as the plane of this beach. In 1887 I carried the survey round the Canadian side of the lake to near Belleville, about 150 miles from the head of the lake. In that region it passes round a spur of high land into the Trent valley. Additional surveys were made in 1888, 1893, and 1895.

My paper on the Iroquois beach was first read before the Philosophical Society, Washington, D.C., in 1888 (*see* Science, vol. XI., p. 49), but the first map of the beach and this extending round both sides of the lake was published in the Transactions of the Royal Society of Canada, volume VII., pages 121-134, 1889. The paper was subsequently revised in the American Journal of Science in 1890.* The name 'Iroquois' was given by me, upon conferring with Dr. Gilbert who had made the survey on the New York side of the lake.

From the survey round the lake, with a determination of the heights at various points, those by myself being instrumentally measured, the amount of rise (mentioned by Stoddard) was determined as well as the direction. These could only be ascertained after the beach had been measured on both sides of the lake and afforded means of determining lines of equal rise. Interesting additional details, with the local sinuosities and an extension in the Trent valley beyond my published survey, have lately been completed by Prof. A. P. Coleman† on the Canadian side. The local details on the New York side have been further surveyed by Prof. H. L. Fairchilds, whose map marks some of the separated ridgelets at the eastern end of the lake. On this and other beaches Prof. Fairchilds has done most detailed work, as well as Prof. Coleman on the Canadian side.

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* 'Deformation of Iroquois beach,' Am. Jour. Sci. III., Vol. XL., pp. 443-451.

† Iroquois beach in Ontario, by A. P. Coleman, Rept. of Bur. of Mines for Ontario, pp. 225-244, 1894.

CHARACTERISTICS OF IROQUOIS BEACH.

At the western end of the lake the characteristics of this beach are shown in a sand and gravel ridge which may be 300 to 500 feet wide rising fifteen or twenty feet or even more above the sloping plain in front, which becomes more clayey on receding from the sand ridge. In front of the large old valleys great barriers have been built up, such as the Burlington Heights at Hamilton (*see* Figure 25), and Davenport

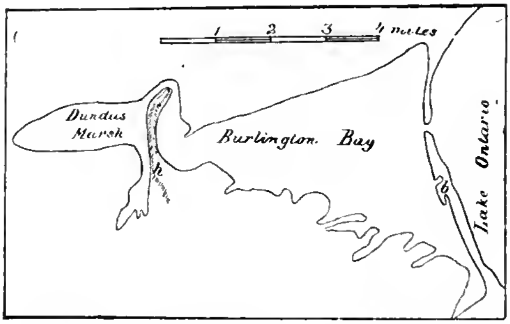


Fig. 25. Map of head of Lake Ontario showing a lower modern lake beach, and the raised Iroquois beach, locally known as Burlington Heights.

ridge west of Toronto. A common characteristic is the occurrence of shallow depressions which once formed lagoons behind the barriers. The Iroquois beach is generally found to be cut out of drift material furnishing the pebbles which have become water-worn by the waves of Iroquois lake. At certain points, as west of the Niagara river, the supply of gravel-making material being limited, or the waves encroaching upon the rocky shore, only cut-terraces were produced. In its western extension the beach may be occasionally seen as constituted of three separated beachlets having an amplitude of twenty to twenty-five feet. On proceeding eastward this feature of ridgelets with greater amplitude becomes more striking both on the Canadian and New York sides of the lake. In a recent paper* Prof. Fair-

* Pleistocene Geology of New York, 20th Rept. State Geologist, p. 107, et seq., 1902.

childs has marked five or six of these subridges at the eastern end of the lake; but there are also lower shore lines.

Having worked out the valley-like character of the Ontario basin† I was unable to account for the barrier to the lake in the St. Lawrence region until sufficient tilting of the land, subsequent to the Iroquois epoch, was found to account for the obstruction to the basin.‡ This enabled me to complete the explanation of the origin of the Lake Ontario basin.* (*See* Plate XXXIII.)

The Iroquois beach is of further importance in showing that for a long time the water stood much higher than now at the outlet of Niagara gorge. The deformation of the beach also shows the amount of warping of the earth's crust in this region since the waters were at this height.

TILTING OF LAND RECORDED BY IROQUOIS BEACH.

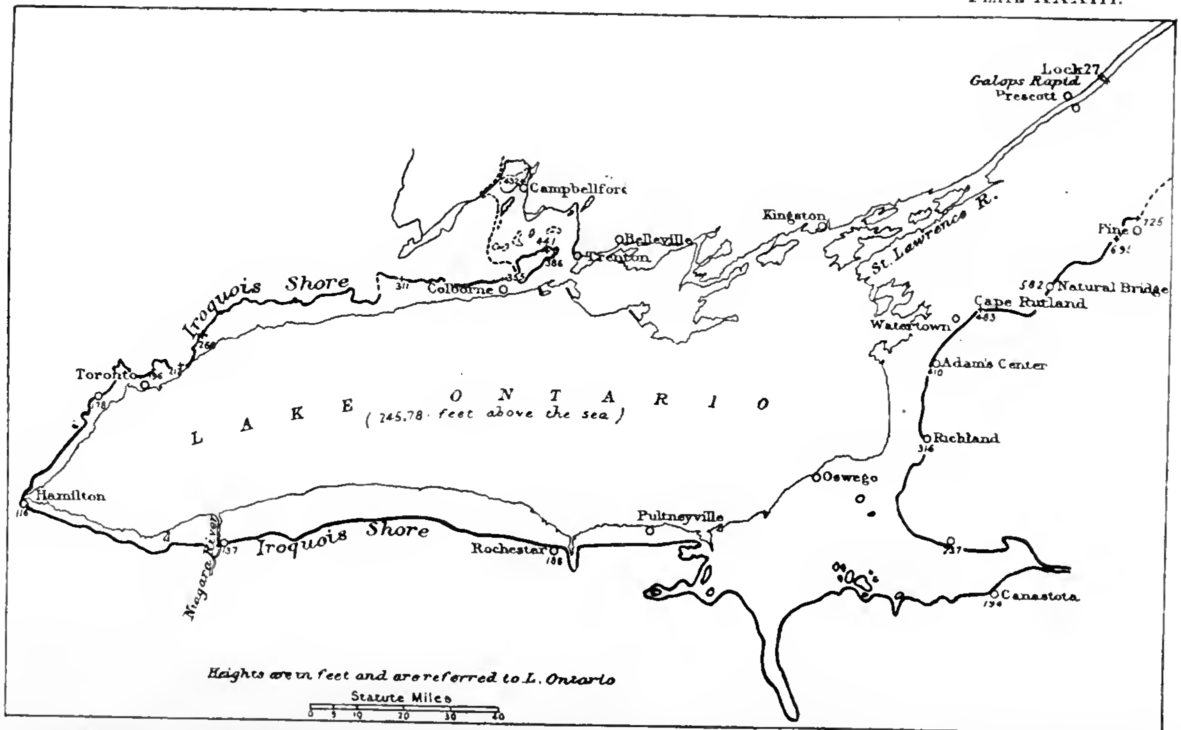
At the head of Lake Ontario the Iroquois beach is 116 feet above the lake; at Niagara river 137 feet (Spencer); at Rochester 189 feet; at Canastota, southeast of Lake Ontario, 194 feet; and at Adams Centre 410 feet (Gilbert); at Prospect farm, four miles east of Watertown, 483 feet (Spencer). The deltas which are regarded as showing the interrupted extension of this same shore plane north of the Adirondacks have a height of 582 feet at Natural bridge; near East Pitcairn 695 feet; and at Fine 725 feet. On the northern side of the lake the beach rises from Hamilton at 116 feet (Spencer), to north of Carlton station west of Toronto at 178 feet* (Coleman). At Kingston Road, twelve miles east of

† Discovery of Pre-glacial Outlet of Erie basin into that of Lake Ontario. With notes on Origin of Great lakes. Proc. Am. Phil. Soc. XIX., pp. 300-337, 1881. Also Proc. Amer. Ass. Adv. Sci., Vol. XXX., pp. 131-146, 1881.

‡ Transactions Royal Society, Canada, loc. cit.

* 'Origin of Basins of Great lakes.' J. W. Spencer, Quar. Jour. Geol. Soc., Vol. XLVI., pp. 523-533, 1890. Also Am. Geologist, 1890.

PLATE XXXIII.



Map of Iroquois beach, from original one by J. W. Spencer, including observations of G. K. Gilbert, (Trans. Royal Society, Canada, vol. vii., part iv., p. 123, 1889); with subsequent additions by A. P. Coleman on the northern side of the lake and H. L. Fairchilds on the southern side. (Loc. cit.)

Toronto, it reaches 212 feet (Spencer); north of Port Hope 311 feet (Coleman); north of Colborne 355 feet; and two miles and a half north of Trenton the beach is now elevated to 386 feet. (Spencer).

The upper terrace at 436 feet, with a front shore line above, is probably the representative of the Bell terrace south of Lake Ontario, which has a height of forty feet or more above the Iroquois plain. Prof. Coleman recognized here a lower bar at 374 feet, and recalls attention to the fine boulder pavement at the rear of the terrace at 339 feet. I regarded the series from the boulder to the top of the gravel beach (forty-seven feet) as the amplitude of the Iroquois beach, which, nearer the head of the lake, is often faced with boulder pavements; but the range there is only twenty or twenty-five feet.

The recent publication on the extended Iroquois shore in the Trent valley, is due to Prof. Coleman, who finds that at Campbellford and near Madoc Junction the upper beach has a height of 475 feet. He also recognizes the smaller amount of tilting in the lower beaches. In this region the deformation of the lower shore line is four feet or less per mile, while in the upper beach it is five feet per mile. From these measurements it is found that the beach at the western end of Lake Ontario rises about two feet per mile in a direction N. 25° E. (corrected.) This is the triangle which affects the Niagara district. The rise increases so that at the northeastern end of Lake Ontario (between Trenton, Richland, and Prospect Farm, New York) the average rate is five feet per mile N. 16° E. This tilting calculated for Kingston at the outlet of the lake indicates the uplift of the lake region from the head of the lake to be 400 feet, and if computed to the first rapids of the St. Lawrence (Galops rapids), sixty-six miles directly beyond, the rise should amount to 650 feet in all. (*See* Chapter XXIX.) In the region of

* 'The Iroquois beach in Ontario,' Prof. A. P. Coleman. Rept. of Bur. of Mines of Ontario, pp. 225-244, 1904.

Watertown the rise is somewhat greater, so that the total amount of differential rise might be taken to be 750 feet.

These measurements show a remarkable land tilting at a very recent date, as this old shore line was horizontal when it was formed ages after the birth of Niagara falls. It must be remembered that this beach line was a water level when the present barrier to Lake Ontario at Galops rapids was reduced to 500 feet or more below sea level, and the lake was lowered by the amount of its present elevation of 246 feet. If, however, the continental region were sufficiently high, the Niagara river could have descended even to what is now the deepest part of the floor of the basin of Lake Ontario. In either case it is not surprising to find the deep Niagara River channel excavated after the withdrawal of the Ontario waters subsequent to the Iroquois episode, with the later backing of the lake to its present level.

If the Iroquois plane of the Ontario basin be brought into comparison with that of Forest beach of the Erie basin, the rise, from its lowest point west of the head of Lake Erie to a point east of Sheridan, N.Y., is found to be 240 feet. Accordingly the Iroquois plane is thus proved to have been at least so much nearer sea level than its lowest point now is. Higher beaches of the Upper lakes indicate an even lower plane than the one mentioned, possibly even to that of present sea level. If the whole great lake region stood higher the relative elevations of the beaches remain as shown. However, it is not intended here to go into the question of oscillation of the earth's crust since the commencement of the beach-making period, but only to state such facts as bear upon the changes affecting Niagara river.

LOWER BEACH AND INCREASED DESCENT OF THE NIAGARA.

It was mentioned that the Iroquois beach was characterized by beachlets throughout the range of some twenty-five feet at the western end of the lake. At the northeastern end, on both sides, the range of beachlets is considerably more. There are lower beaches. Near Watertown is one at 288 feet above the lake, which descends nearly to water level in the vicinity of Oswego, (Gilbert). Passing under the water to the head of the lake I regarded its position as that which determined the present formation of Burlington beach (Figure 25) at the end of Lake Ontario, when the lake there was nearly seventy-eight feet lower. This beach increased in height from the bottom of the lake as the water gradually rose to the present level, upon the reflooding of the basin and drowned the deeper Niagara channel. The outer part of the drowned delta of the Niagara river owes its position to the same water line.

The lowering of the lake increased the descent of the river from the Iroquois shore line to the deepest channel of the Niagara, far below the present level, thus causing the increase in the height of the falls, although later they were again lowered.

SUDDEN CHANGE OF LEVEL.

Other beaches are mentioned as occurring about the outlet of Niagara river. Each of these marks a period of rest in the lowering of lake levels. Formerly I had regarded the subsiding of the lakes as being secularly regular, so that a general average of the time might be taken. The idea of general uniformity must be abandoned. The changes occurred almost per saltum, with intermittent pauses; long epochs of stability, then rapid changes, until the next water line was established, but with greater amplitude of movement in the northeastern than in the southwestern direction. This deformation was not the result of drawing off the water which had left the horizontal beaches, but it was due to an unequal rising of the land, from some internal earth movement.

CHAPTER XXIII.

EFFECTS OF TILTED SHORES OF WARREN WATER ON THE NIAGARA DISTRICT.

NOTES ON THE STUDY OF LAKE WARREN.

During an earlier post-glacial epoch than that of the Iroquois beach all the Upper lakes were more or less united into one sheet of water, which I named Warren lake or water, after the late General G. K. Warren, who had first described the shrunken Lake Winnipeg in the Red River valley, which lake in justice should have been named after him.* The shores of Warren water were first studied on the Canadian side as well as in Michigan by myself, but since that time Mr. F. B. Taylor has given much attention to the subject.†

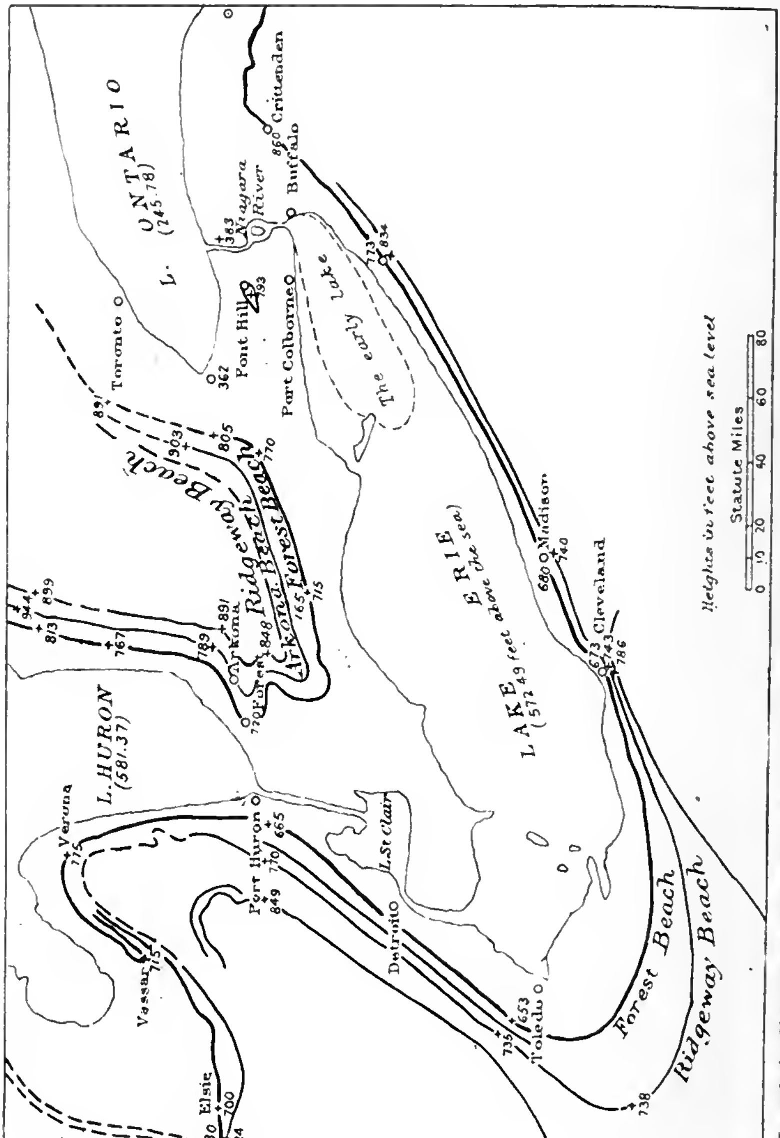
Earlier work had been done on fragments of this shore in Southern Michigan and Ohio, as the beach feature had been long recognized. But these were not correlated into the plane of a lake shore recognisable on both sides of the lake until my work appeared.

The Ridge roads about Lake Erie were old recognized features like those in New York state. In 1885 Mr. G. K. Gilbert

* 'The Iroquois beach ; a chapter in the Geological History of Lake Ontario,' by J. W. Spencer. Trans. Roy. Soc., Canada, Vol. VII., Sec. IV., p. 122, 1889. Advanced abstract in Science, 1888. Although Gen. Warren had described the extended Lake Winnipeg and the channel connecting it with the Upper Mississippi, Dr. Warren Upham named it Glacial Lake Agassiz, against which both Prof. J. D. Dana and myself protested, as the honours of the discovery belonged to Gen. Warren, whilst Prof. Agassiz had nothing to do with it. This was following an arbitrary rule 'that discoveries should not be named after living authors,' which certain people unjustly attempted to establish. However, Warren's name attached to the Greater lakes is vindication.

† The Second Lake Algonquin, by F. B. Taylor, and Am. Geol., Vol. XV., 1895, and other papers.

PLATE XXXIV.



Map of the Forest beach after dismemberment of Warren water. (Height of lakes given refer to mean level of 1860-1905.)

measured the deformation of some of the beaches at the eastern end of Lake Erie.‡ The lowest of them he traced to Crittenden, N.Y., but this name he did not give to the beach. Subsequently, I extended this beach to near Batavia, and again Prof. Fairchilds took up the subject and mapped the old shore line some thirty-five miles beyond.§ He found it occurring as far as the Genesee valley, and fragmental equivalents of it to the head of Seneca lake.

The deformation or tilting of the shore lines has an important bearing on the physics of Niagara river. When the lake existed the sheet of water extended from Lake Huron high over Lake Erie into the Ontario basin. There were earlier stages of the lake when it formed higher beaches, but the most important of these though not the strongest, was the last of the series. After its survey upon the Canadian side, and upon their correlation on both sides of the lake, I named the lowest shore line of Warren water, the Forest beach, as it had not been previously worked out. (*See* map Plate XXXIV.)

ELEVATION OF FOREST BEACH.

Southeast of Lake Huron it is strongly marked near Forest, with its lowest point standing at 715 feet above the sea. I surveyed the beach eastward and parallel with Lake Erie, to the meridian of the western end of Lake Ontario, where it has an elevation of 770 feet. It then turns northeastward and rises still more rapidly. It frequently cuts across the spurs of drift ridges. The Niagara peninsula has too low an elevation for the occurrence of this beach except at one point. From twelve to fourteen miles west of the Niagara river, is Font hill, an unusual ridge of drift which attains an elevation of over 300 feet above Lake Erie, rising out of a plain which is only thirty or forty feet above the lake. Around this hill is a

‡ Science, Vol. VI., p. 222, 1885.

§ 'Lake Warren Shore-lines in West N.Y.,' by H. L. Fairchilds, Bull. Geol. Soc. Amer., Vol. VIII., pp. 269-286, 1897.

strongly cut terrace with a fine gravel floor at an altitude of 793 feet above sea level (measured). Northward of Forest I surveyed the old shore line to the base of Indian peninsula where it bends eastward. In this direction it has no special bearing on Niagara falls.

On the New York side this beach is 680 feet in height (bar.) at Madison, which is forty miles east of Cleveland. Here the elevation is 673 feet (bar.). The beach continues to increase in height toward the east, so that at Sheridan, N.Y., its elevation is 773 feet (Gilbert) and at Crittenden 860 feet. Beyond this it rises to Indian falls and again slightly descends as it trends to the southeastward, as established by Prof. Fairchilds. Westward of Cleveland the tilting is reduced to a very small amount, as beyond Toledo its height is 653 feet. Again it rises very slowly west of St. Clair river, and on approaching the latitude of Port Huron its height is 665 feet (Spencer).

However, here appears a strong eastern equivalent in the uplift, for near Forest, twenty-five miles across the former strait, its elevation is 715 feet above sea level. From this point the old shore line extends northeastward as shown on the map XXXIV.

A word may be repeated with regard to the survey of the beaches. Where they form bars or ridges, with depressions or lagoons behind them, I adopted the highest line of wave action, which would be from three to five feet above the water surface. This method was pursued on account of the crest being the most constant feature. On the other hand, where the waves were cutting terraces, the most accurate point determinable at the junction of the plain with the bluff behind would be below water level. The same is true where the beach is represented by sand plains. Consequently, when the shore line changes its character a personal equation appears. It was thus on the western side of the Huron strait, the measurement being low:

while on the eastern, where the ridge was strongly marked, it was slightly above the water plane.*

TILTING OF LAND AT EASTERN END OF LAKE ERIE.*

The Forest beach has particular importance in connexion with Niagara, in showing that the earth movements about the western part of Lake Erie were very small, while the rise of land at the eastern end of the lake was considerable. Between Madison, Font hill (Brown's nurseries), and Sheridan, the average rise in this large triangle is almost one foot per mile in direction N. 45° E. If the more eastern triangle between Font hill, Sheridan, and Crittenden be taken, and this embraces the outlet of Erie, the average rise is one and a half feet per mile in direction N. 60° E. As already noted (page 283), the deformation at the western end of Lake Ontario is two feet per mile N. 25° E., as recorded in the warping of the Iroquois beach. Slightly greater movements are shown in higher beaches.

From these measurements on the Forest beach it is found that there has been a rise in the Niagara district of 135 feet more than southwestward at Madison. With this deformation straightened out, Lake Erie was reduced to a small lakelet. (*See* page 296.)

This former tilting of the Niagara district would suggest the continuance of the movement so that it might be supposed that the Niagara river would be raised to a higher point, which would send the waters into the Mississippi. But from the present survey it is found that the stability of the region now prevails (*see* Chapter xxx.), without any indication of the direction which recurring movements may take.

* High level shores in the region of the Great lakes, and their Deformation, by J. W. Spencer. Am. Jour. Sci., Vol. XLI., pp. 201-211, 1891.

ELEVATION OF FOREST PLANE ABOVE THE IROQUOIS.

In the earth movements that have occurred the general direction is northeastward, but there are local variations as the rise is always increasing toward the northeast; so that, by adopting different triangles for the determination of the mean rise in each, variation will be found. Combining the deformation recorded in the Forest beach at the eastern end of Lake Erie with the mean rise in the western triangle of Lake Ontario, a corrected determination shows that the plane of the Forest beach was between 400 and 450 feet above that of the Iroquois beach; but it is probable (*see* Chapter XXX.), that the deformation of both planes occurred at the same time, subsequent to Lake Ontario falling below the Iroquois level.

WARPING AFTER A LONG RECESSION OF NIAGARA FALLS.

The deformation of the Forest plane did not take place to any considerable amount until the time when the Iroquois plane of Lake Ontario became warped; consequently the warping affecting the Niagara district did not occur until Niagara falls were very old. (*See* Chapter XXX.)

CHAPTER XXIV.

SEPARATION OF ERIE AND HURON ON THE DISMEMBERMENT OF WARREN WATER—SHRINKAGE OF LAKE ERIE.

Dismemberment of Warren water.
Separation of Huron and Erie drainage
Original discovery of the diversion of the Huron drainage.
Shrinkage of Lake Erie.

DISMEMBERMENT OF WARREN WATER—SEPARATION OF HURON AND ERIE DRAINAGE.

In the last chapter different shore lines extending about the Upper lakes were mentioned, showing that open water extended from Lake Huron to the Ontario basin. As the waters were lowered the successive beaches appeared—the Forest shore being the last or lowest one extending from the Huron basin to the Ontario drainage area. But at last the waters withdrew from even this lowest beach, below the level of the present higher land belt between Lake Huron and Lake Erie—the immediate result being the formation of three lakes, one including more or less of the basins of Huron, Michigan, and Superior, a small Lake Erie, and the Ontario water at substantially the same height as the shrunken Erie. The united upper three lakes I named the Algonquin. That it was separated from Lake Erie was shown by my survey of the Algonquin beach, which proved that the waters of this upper lake had a northeastern outlet in place of the present southern one into the St. Clair river. So far as Niagara falls is concerned it established the fact that throughout long ages they received only the Erie waters and thus were of small volume.

ORIGINAL DISCOVERY OF DIVERSION OF HURON DRAINAGE.

The first announcement of this diversion was made by the present writer before the Cleveland meeting of the American Association for the Advancement of Science, in 1888, with a short abstract in the proceedings for that year.*

This abstract of my survey (then just made) of the raised shore lines, extending for hundreds of miles from the outlet of Lake Huron, throughout their windings to the northeast, formed the caveat of my discovery that the Niagara river only recently received the drainage of the higher lakes; and on account of its importance in establishing priority it is reproduced in Appendix VII. In it this statement appears: 'Lake Warren became dismembered, and Huron, Michigan, and Superior formed one lake; the Erie basin was lifted out of the bed of Lake Warren and became drained . . . the outlet of the upper lake was southeast of Georgian bay . . . with the continued continental uplift to the northeast . . . the waters were backed southward and overflowed into the Erie basin, thus making the Erie outlet of the Upper lakes of recent date. This is proven by the fact that the beach which marked the old surface plane of the upper Great lake descends to the present water level at the southern end of Lake Huron. The Erie basin is very shallow and upon the dismemberment of Lake Warren was drained by the newly constructed Niagara river (except perhaps a small lakelet southeast of Long point). Subsequently the northeastern warping . . . eventually lifted up a rocky barrier . . . thus making the Erie the youngest of all the lakes' (page 188-9).

This announcement immediately attracted the attention of Mr. G. K. Gilbert,† with whom I discussed the matter freely in further detail, mentioning positions and heights of the Algonquin beach at various points.

* Proc. Am. Ass. Ad. Sci., Vol. XXXVII., pp. 197-8-9, 1888.

† 6th Rept. Commis. State Res. Niag., p. 71-73, for 1890.

Upon this data, in advance of my detailed paper and maps, he presented an essay the following year wherein my recent discoveries formed the prominent feature. Alluding to the diversion of the Huron drainage from the Niagara river, he begins thus: 'To illustrate the effects of the earlier system of land slopes upon the distribution of water in the region of the Great lakes I have constructed the map in Plate 4 . . . In the ancient system of drainage Georgian bay instead of being a dependency of Lake Huron is itself the principal lake receiving the overflow from Huron. Superior, Michigan, Huron, and Georgian constitute a lake system by themselves, independent of Erie and Ontario, and the channel of the Detroit river is dry. Lake Erie and Lake Ontario, both greatly reduced in size, constitute another chain, but their connecting link, the Niagara river, is comparatively a small stream.'

Even in his full statement there is no mention of data for his hypothesis of the diversion of the Huron drainage from Lake Erie, but farther on he says that I stated that there was another outlet (Trent) for the Huron basin, 'demonstrating that during the existence of that outlet also the Detroit river ran dry.' Thus this subsequent reference (with '*also*') appears as a collateral hypothesis, and not as the original data, which it was, of the diversion of Huron drainage and small Erie lake. This method of presenting the main discovery of the former diversion of the Huron waters, the greatest by far that has been made affecting the Niagara river, could not fail to leave the impression that it belonged to him, especially as he has since frequently referred to it without even any mention of the author. Furthermore, for his Plate 5, showing the Trent outlet, he had my own unpublished measurements without his statement of the fact, but the citation of my own abstract establishes the priority of discovery in 1888.

The great importance of the diversion of the Huron drainage lies in the fact that it enormously increased the longevity of Niagara falls, hitherto unsuspected. It also removes the possibility of an enlarged volume in the river from a melting ice sheet on the Canadian highlands, as Dr. Gilbert had formerly supposed.

Other beaches were also found requiring a lower outlet than the one by the Trent valley. This was provided for by the Nipissing trench. Along this former outlet of Lake Huron the Indians frequented it as highway, and led the early French explorers from the Ottawa river, by way of Trout lake over the low divide only three miles across to Lake Nipissing, and thence down the French river to Lake Huron. Indeed, as early as 1615, Champlain followed this route, returning with the Hurons, by way of the Algonquin overflow past Lake Simcoe and Balsam lake and down the Trent river. While the Nipissing outlet was mentioned theoretically by Dr. Gilbert, after my discovery of the northeastern diversion of the Huron drainage from the Erie basin, Prof. G. F. Wright* was the first to observe definite traces of the shore lines in connexion with it, though earlier explorations of Dr. R. Bell showed the occurrence of beaches there. These have since been further explored by Mr. F. B. Taylor, who has established more fully the Nipissing outlet by direct observation.† As to the point, to which I found that the falls had receded before the addition of the Huron drainage, *see* page 194.

SHRINKAGE OF LAKE ERIE.

Upon the dismemberment of Warren water a barrier existed between Lake Huron and the head of Lake Erie. As the land was not yet tilted toward the northeast, the eastern end of Lake Erie basin was much lower, so that the present outlet at Buffalo s ood relatively 150 feet below the level at the western end of the lake. Accordingly, Erie was drained except a small basin

* Bull. Geol. Soc., Vol. IV., pp. 423-5, 1893.
† Bull. Geol. Soc. Am., Vol. V., pp. 620-6, 1894.

of 1,000 to 1,500 miles in area, in place of 10,000 square miles as to-day. For the relative size of Lake Erie *see* map p. 300, Plate XXXIV. The evaporation from the water surface would be reduced on account of the small area of the lake compared with that of the present time, as only a river and tributaries traversed the now filled lake basin. The area of Erie has subsequently been increased owing to the tilting of the land which has caused the backing of the waters.

CHAPTER XXV.

NORTHEASTERN OUTLET OF ALGONQUIN LAKE (THE THREE UPPER LAKES).

NORTHEASTERN HURON DRAINAGE AND DIVERSION FROM NIAGARA RIVER.

The barrier between the Huron and Erie basins will be described in the next chapter. I surveyed the winding Algonquin beach for hundreds of miles in 1887-88. It was formed after Huron had shrunk into its own basin and its level was too low for the lake to overflow the St. Clair divide. In this beach was the first suggestion that the Huron drainage had formerly been diverted by a northeastern overflow from Niagara falls as mentioned in Chapter XXIV.

NORTHEASTERN RISE OF ALGONQUIN BEACH.

At Grand Bend, on Ausable river, a few miles east of the present outlet of Lake Huron, the height of Algonquin beach is eighteen feet above the lake. Fourteen miles farther on it is thirty-six feet high, at Southampton 132 feet. Beyond it skirts the Indian peninsula, which was then a chain of islands on which the beach is preserved. This raised shore was surveyed at Owen Sound on Georgian bay, and has a height of 167 feet. At Clarksburg it is 191 feet. Four miles west of Collingwood its height is 187 feet; near Caldwell 170 feet. Again the beach turns northward, approaching nearer the shore of Georgian bay at Elmsvale, 220 feet; and east of Wyebridge its elevation is

260 feet. Swinging round a high drift ridge southward, to Orillia, it circles the basin of Lake Simcoe, eastward of which the height attained is 293 feet above Lake Huron. Between this place and Balsam lake the old shore line indicates a former outlet with the water at one time twenty-six feet deep. These details are taken from my paper on 'The Deformation of the Algonquin beach and Birth of Lake Huron.' *

The Algonquin beach is often broken up into ridgelets throughout a range of twenty-eight feet in height, so that the overflow of Balsam lake would not account for the occurrence of the lower beachlets. This raised shore line is shown on map Plate xxxv. There are also lower beaches and terraces much below the Algonquin plain and Balsam lake outlet, such as those at Clarksburg from eighty-one feet above the lake to lower levels.

Remnants of the Algonquin beach in the broken country to the north are difficult of recognition, while the Nipissing beach of Mr. Taylor passes below the lake level at a considerable distance from the southern end of Lake Huron. For this beach on the western side of the lake reference must be made to Mr. Taylor's papers. Northward of my farthest surveyed point Mr. Taylor carried his observations confirming the occurrence of the shore line.†

The Algonquin beach lies in the region of Lake Nipissing at a theoretical altitude of 600 feet above Lake Huron. Here Mr. Taylor found the highest and best developed beach at 558 feet, overlooking the divide, between Lake Nipissing and the Ottawa river, which is 112 feet above Lake Huron.

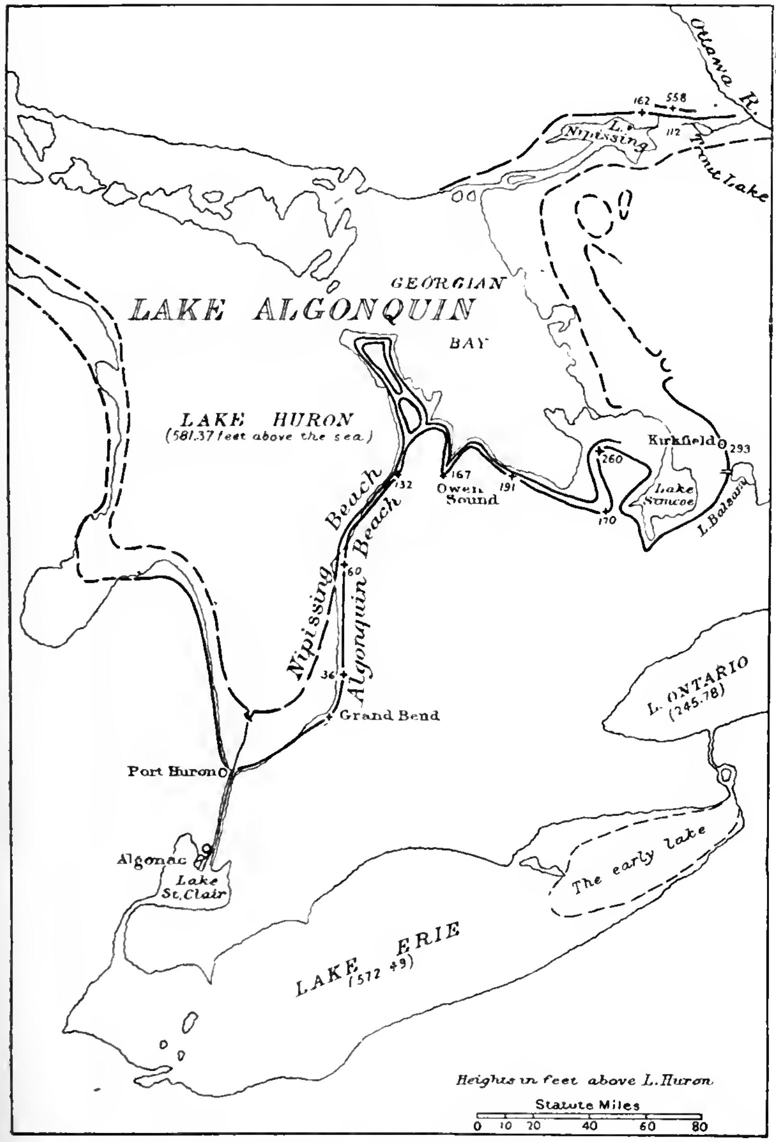
AMOUNT OF TILTING SHOWN IN THE BEACH.

From this survey it was found that the Algonquin beach is now tilted and rising from the southern end of Lake Huron from one and one-third, increasing to two feet or more per mile

* Amer. Jour. of Sci., cited before.

† 'Second Lake Algonquin,' Amer. Geol., Vol. XV., 1895, and other papers.

PLATE XXXV.



Map of Algonquin and Nipissing beaches and northeastern outlet of the Huron drainage.*

* Height of lakes here given refer to mean of 1860-1905, including that before lowering of outlets.

on proceeding northward. After skirting Georgian bay the rise is found to be three feet per mile in a direction N. 20° E., and farther on it is 4·1 feet per mile N. 25° E. The deformation will be further considered when discussing the Nipissing outlet. In the lower beaches a smaller amount of tilting was found.

The great valley in which Lake Nipissing lies is much lower than the temporary overflow by way of Balsam lake and Trent valley. Below the Iroquois plain fragments of the lower shore lines have been observed. In 1891 I stated that 'with the continued original uplift, the waters of the Algonquin were lowered as shown by numerous beaches, until the lake was dismembered and Superior, Michigan, Huron, and Georgia had their birth and drained through the last at the level of Nipissing outlet only, by a river flowing through the Ottawa valley.' But the direct observations were not established until made by Prof. Wright and more fully by Mr. Taylor, who connected a lower beach with the Nipissing overflow.*

It may be said that if all the warping shown in the various lake basins were levelled off, the region would be much lower than now. On the other hand, if glacial conditions were due to increased altitude the continental region would have been relatively high.

BARRIER TO ALGONQUIN LAKE.

Such being the ease, the question arises what held the waters at the higher level of the Algonquin plane? Some thought there was a glacial dam. My working hypothesis was sea level. Mr. Taylor was led to consider the Nipissing depression as

* The Ancient strait at Nipissing, Bull. Geol. Soc. Am., Vol., V., 1893.

Of Mr. Taylor's papers *see* 'Ancient Strait of Nipissing,' Ib. vol. 1, pp. 621-626, 1903. 'The Limit of Pre-glacial Submergence in the Highlands east of Georgian bay,' Am. Geol., vol. xiv., pp. 273-289, 1894. 'Second Algonquin and Nipissing beaches,' Ib. vol. xvii., pp. 397-400,1896. 'The Nipissing and and Mattawa rivers, the Outlet of the Nipissing Great lakes,' Ib. vol. xx., pp. 65-66, 1897.

Prof. Wright's paper was cited in the previous chapter. *See* Bull. Geol. Am., vol. iv., pp. 423-425, 1893.

being a strait, though later he thought that a glacial dam obtained at a point beyond his observations.

At the southern end of Lake Huron beaches rise to twenty-five feet, which might be considered as the continuation of the Algonquin shore line, but this may include constructional planes of the rising waters of the lake. The Algonquin beach skirts the end of the lake and does not turn into the St. Clair river, which cuts directly crosswise of it. East of the river the shore line is often characterized by sand dunes, but the ridge, reaching to a height of eighteen feet above the lake, or eight feet above the ground either side, forms a spit which at one time separated a lagoon from the river. (*See* next chapter.)

CHAPTER XXVI.

HEAD OF THE ST. CLAIR TRIBUTARIES OF ALGONQUIN LAKE.

Terraces about Lake St. Clair.
Depth of drift about the St. Clair outlet.
Head of St. Clair tributaries.
Date of drowned St. Clair valley.

TERRACES ABOUT LAKE ST. CLAIR.

On examining the banks of the river and the shores of Lake St. Clair low terraces and sand plains, with some gravel ridges, occur to heights of ten to fifteen feet or more above Lake Huron. These are cut out of drift material prevailing everywhere to a great depth. Southward of the lake, at a distance of fourteen miles, before reaching Marine city, the higher watershed of the country approaches the river with a height of forty-five or fifty feet above the lake. Here the St. Clair river has its minimum breadth and adjacent to it is a cut terrace or raised bottom thirty-five feet (bar.) above the water, with the banks rising ten or fifteen feet higher. This point is fifteen to sixteen miles from Lake Huron. A terrace on the western side is from 100 to 300 feet wide, but less conspicuous on the eastern side. It occurs for a length of over a mile.

That this was a barrier when the waters of Lake Warren were settling into the Erie and Huron basins there seems no doubt but the streams, afterwards descending rapidly to the north robbed the opposite drainage so that the real divide crept southward to the present surface of Lake St. Clair.

DEPTH OF DRIFT ABOUT THE ST. CLAIR OUTLET.

At the Fibre Works in Port Huron a well showed washed lake sand to a depth of seventy-eight feet, below which occurred blue clay twenty-four feet, rounded gravel five feet, clay with glaciated stones eighty feet, or 187 feet in all, reaching to a point 162 feet below lake level. This character is repeated on the eastern side of the river; and at a point eight miles distant a well was sunk to 160 feet before reaching rock. This represents a depth of 130 feet below lake level.

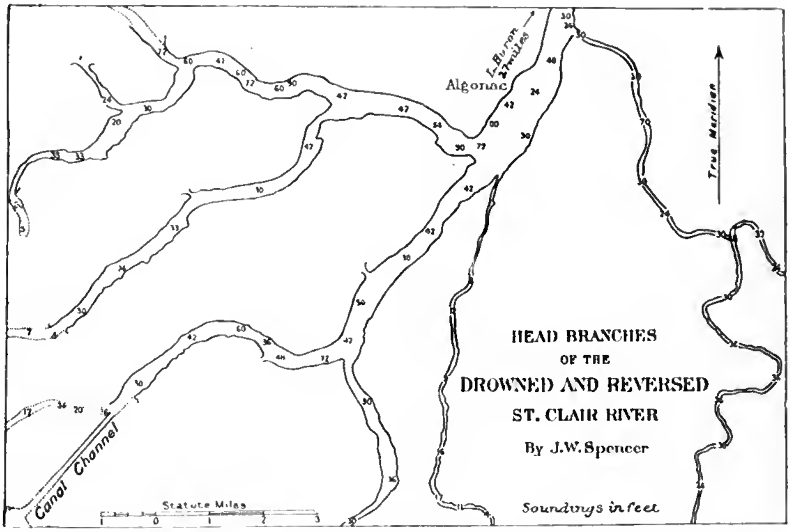


Fig. 26. Map of the head branches of the drowned St. Clair river, establishing a separation of the Huron and Erie drainage and former northern discharge of the Huron waters.

HEAD OF ST. CLAIR TRIBUTARIES.

The soundings of Lake St. Clair and the channels among the St. Clair flats proved exceedingly interesting. On observing the chart the first impression produced is what appears to be a delta as the St. Clair river enters the lake. However, the river carries no sediment except the washes of its own banks. The apparent delta is low ground shading off into marshes, but among these marshes, with a depth of one to five feet through the flats barely rising above the surface of the water, the channels are found to have a great depth, reaching to forty, sixty, seventy-two, and even ninety feet below lake surface. These channels appear in several branches, converging and enlarging as they approach the trunk which now forms St. Clair river, near the village of Algonac, *see* Figure 26.

The occurrence of this system of drainage heading in the shallow waters of Lake St. Clair, and reaching to a depth of ninety feet, establishes conclusively that the St. Clair river lately drained to the northeast through a very deep channel, at least more than ninety feet below the level of Lake Huron, as did also the tributaries from an amphitheatre at its head. At that time the waters of Lake Huron receded somewhat beyond the line of Kettle point, or seventeen miles north of Point Edward. Of itself this reversed drainage system would have established the former northeastern outlet of the lake, with a plane about 110 feet below the Algonquin beach, had it not been previously proved by lower beaches of the Huron basin.

Within two or three miles of the head of the drowned St. Clair, the lake has nowhere a depth of more than seventeen feet, but beyond the contours show a drainage southward into the Detroit river, even before reaching the river itself.

The drowned St. Clair has been partly refilled by the deposit of current-worn sand; and it can only be supposed that the lake sand shown at the Fibre Works is the refilling of the channel as the lake waves were building up the flats on the return of the waters of Lake Huron when they overflowed into Lake Erie.

DATE OF THE DROWNED ST. CLAIR VALLEY.

These channels of the drowned St. Clair were a late postglacial feature formed after the dismembering of Lake Warren, after the shrinkage of the Huron waters from the Algonquin plane, but before the tilting of the Nipissing outlet which turned the Huron drainage into Lake Erie and the Niagara river. This new observation is interesting evidence showing how recently it is since Lake Erie was receiving the waters of the Upper lakes.

In this chapter an important observation of Mr. Taylor's was almost overlooked.* He had found that several streams tributary to both the river and the Lake Saint Clair showed clearly the drowning effects, and that their channels were formed while the river was a tributary of the shrunken Huron lake. Now they have a depth of ten feet or more and are navigable to some distance above their mouth. He concluded that the channels were cut when the base level was twenty-five to thirty feet below the present, and that they were drowned upon the diversion of the Huron waters to the south. This confirmed the idea of the northeastern outlet of the Huron basin.

These tributaries observed by Mr. Taylor are not the ones brought forward by the writer, which now head beneath the surface of Lake Saint Clair coming from the amphitheatre at the watershed between the then Huron and Erie basins, showing a much greater depth than he found. The principle involved is the same.

* Proc. Am. Ass. Ad. Sci., Vol. XLVI., p. 202, 1897.

CHAPTER XXVII.

AUGMENTATION OF NIAGARA DISCHARGE BY ACCESSION OF ALGONQUIN WATERS—THAT IS HURON DRAINAGE.

Nipissing—Ottawa outlet.
Amount of terrestrial tilting and additiou of Huron waters to Lake Erie.
Origin of Lake St. Clair.

NIPISSING—OTTAWA OUTLET.

In the surveys of the high level shores about Lake Huron, beaches at lower levels than the Algonquin were found at many points. These necessitated a lower outlet than that of the Algonquin shore line. In the original surveys I did not anticipate beyond the points actually observed; nor had at that time any data been found directly connecting the beaches with the well-known Nipissing depression. But it was self-evident that a lower outlet in that direction was needed.

Trout lake on the present Ottawa drainage is only three miles from Lake Nipissing, and at its head, on the northern side, is a strongly marked terrace covered with a boulder pavement fifty to sixty-five feet above it (eighty-five feet above Lake Nipissing), this being above the divide by twenty feet or more.

In this direction Mr. Taylor has made the fullest explorations. He has connected this shore with the occurrence of beaches farther south,* and has appropriately named it the Nipissing beach. It was only this which was needed to explain the outlet of the lake during the epoch of low shore-lines. The Nipissing strand is now from 162 to 175 feet (the inner margin)

* Bull. Geol. Soc. cited before.

above Lake Huron. Between this and the higher shore line at 558 feet Mr. Taylor† found remains of other shore lines, but it is the Nipissing beach which is the most important feature.

Only after the floor of the channel had been raised was the last drainage to the northeast entirely closed. During the time of the Nipissing plane the waters of Lake Huron were very much withdrawn from the southern end of the lake, see Plate xxxv. In the last chapter the depths of the then tributaries have been shown to have reached ninety feet or more below the present lake surface.

AMOUNT OF TERRESTRIAL TILTING—ADDITION OF HURON WATERS TO LAKE ERIE.

The floor of the Nipissing-Ottawa outlet rises to 112 feet above the lake. However, there are some narrow stream valleys crossing the divide which are only ninety-seven feet above Lake Huron (A. St. Laurent). The amount of tilting since the Algonquin waters were at the Nipissing plane amounts to somewhat more than 112 feet and fifty feet, the height of the beach, to which must be added ninety feet, or to whatever additional depth the Nipissing beach at the southern end of Lake Huron is submerged,—in all about 250 feet, to determine the tilting since the Nipissing episode. But of this amount a warping of only 112 feet less about 22 feet for the now trenched St. Clair barrier was required to turn the Algonquin waters from the Huron basin into Lake Erie.

At the time when the waters of the Huron basin were withdrawn so far from the St. Clair divide, Lake Erie, represented by only a small sheet of water, was at a plane of about 150 feet below the present St. Clair level.

The period of the northeastern drainage of the Huron basin was one of long duration, as shown both by the strength of the Nipissing shore line and the depth of the St. Clair drainage

† 'The Nipissing strait' cited before.

valleys. The story of the recession of Niagara falls confirms this, and here a computation may be made of the date when the rim of the basin near Lake Nipissing rose so high as to send the Huron waters over the St. Clair divide into the Erie basin.

I regard the date of the warping of the earth's crust which raised the Nipissing rim to have been substantially synchronous with the rise of the land at the outlet of Lake Erie, which caused the backing of the waters to the extent of the present lake.

ORIGIN OF LAKE ST. CLAIR.

This shallow lake excavated out of drift material may be regarded as the lowered col between the drowned St. Clair and Detroit rivers, where the atmospheric agents had produced a shallow amphitheatre at the head of both streams. Subsequently, upon this district being flooded, Lake St. Clair was produced, though modified by its own lake waves acting upon the low shore.

CHAPTER XXVIII.

RECENT CHICAGO OVERFLOW.

Old beaches about Saginaw bay show the tilting of the deserted shore lines. West of Port Huron I have found the height of the Forest beach to be 665 feet; northwestward at Verona Mills Mr. Taylor's measurement is 765 feet; and at Elsie southward 770 feet; and reduced to approximately 680 at Maple Rapids. This was near the Pewamo col to the southern part of the Michigan basin, and it would permit of the existence of a moderate amount of warping between this point and the Chicago outlet, with the suggestion that the Algonquin plane should pass below the water surface at the southern end of Lake Michigan. But the relationship of these old tilted shore lines, and those more recent about the head of Lake Erie, has not been fully determined; so that it is not possible to state precisely what overflow has occurred into the Mississippi valley from the Algonquin basin. Some years ago I suggested a temporary overflow of part of the Niagara drainage.

Dr. Edmund Andrews,† and later Mr. Frank Leverett,* have made contributions on the Chicago outlet. Omitting the height of the upper Michigan beach, which has an elevation at Homewood of seventy-four feet above the lake, and of lower ones, though of the higher series, there is a lower beach. Here the channel did not exceed seven feet in depth according to Mr. Leverett, the divide being eight feet above the lake. Beneath this level of eight feet there are lake sands superimposed upon

† Trans. Chicago Acad. Sci., Vol. II., pp. 1-23, 1870.

* Bull. Chicago Acad. Sci.; Geol. and Nat. Hist. Survey, No. 11, 1897.

drift, showing the higher lake stages. Again, in part, the summit is marshy with beaches at ten to twelve feet. Mr. Leverett says that these shore lines 'seem to have been formed after the southeastern outlet of the lake was abandoned' (p. 74). And again he says: 'These beaches are to be referred to the action of the present lake' (p. 78).

This manifestly recent lake level of Michigan can only be accounted for by the superior height of the Saint Clair outlet. The position of the Chicago outlet is shown in Figure 27, from a map furnished some time ago by Dr. Andrews.

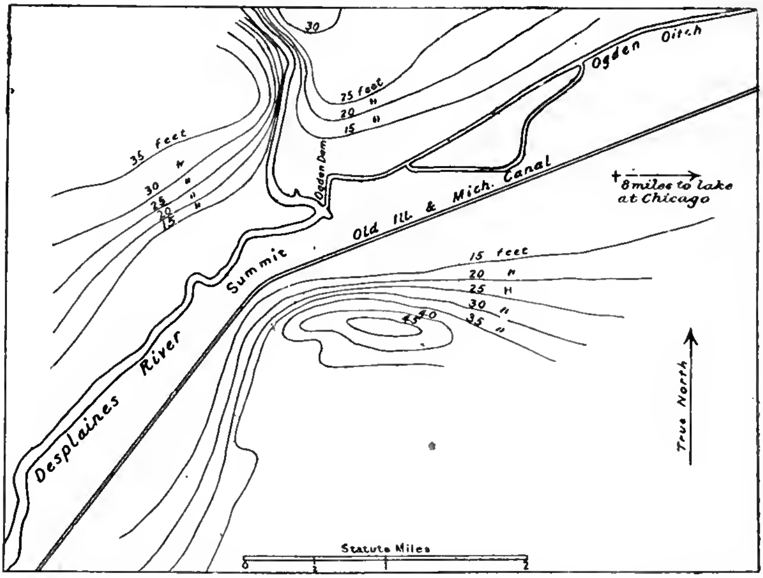


Fig. 27. Map of the low summit between Chicago creek and Des Plaines river which is only eight feet above the lake, with a trough a mile wide.

A counterpart of this condition is seen about Lake St. Clair where there are sand plains cr, in one case, a gravel ridge rising to twelve or fifteen feet above Lake Huron. The St. Clair has lately been lowered 1·66 feet by the scour of the incoherent materials of its bed, so it can hardly be doubted that at a very late date, there may have been a shallow temporary overflow in the direction of the Mississippi, as previously suggested.

The Chicago outlet has often been associated with earlier glacial conditions. Be this as it may, the recent investigations point to a subsequent temporary overflow in that direction; possibly to the extent of the channel which Mr. Leverett thinks had a depth of seven feet.

This relationship between the Chicago and St. Clair outlets now throws light on the lake history, and the contraction of the gorge, which at the Whirlpool rapids, is due to a partial diversion of the lake waters over the Chicago divide. The hypothesis of the future diversion of the Niagara to the Mississippi, with the submergence of Chicago, will have to be abandoned as there has been discovered a cessation of earth movements (Chapter XXXI.) which would bring about such a change; and in the course of some centuries, upon Niagara falls retreating a half mile or a little more, the channel of the river will be rapidly deepened in the drift of the basin above the falls. This will further postpone such a western diversion, if the future tilting of the land should occur.

CHAPTER XXIX.

ST. LAWRENCE CHANNEL WITHOUT HURON DRAINAGE

Smaller channel of St. Lawrence.
Terrestrial deformation shown in the rapids.
Ancient Niagara and present Ottawa rivers compared.

SMALLER CHANNEL OF THE ST. LAWRENCE.

The history of Niagara river is only the expression of that of the lake region in all its complicated parts. The investigatión of one feature inperceptibly leads us afield until we pass the boundaries of our original topic; thus it is here. But the new observations react and more fully explain the phenomena. The tributaries of the reversed St. Clair confirm the proof of the former northern outlet of Lake Huron, with the diversion of the Upper Lake waters from the Niagara river. On the other side, the St. Lawrence river itself furnishes proof of its correspondingly small channel before Lake Huron was turned into the Niagara river.

An investigation of the St. Lawrence would doubtless bring to light much new interesting material, but only one or two points will here be touched upon. From the outlet of Lake Ontario to the foot of the rapids at Cornwall the direct distance is 110 miles. Then the river broadens out into an expansion from two and a half to four miles wide, extending as far as Valleyfield, a distance of thirty-three miles. This is called Lake St. Francis. There is a small descent from the foot of Lock No. 15 to the lake, and again from the lake to the head of Lock No. 14, at Valleyfield. These, together with the slope (?)

in the lake amount to about three feet. Throughout the wider part of the lake but little of this descent can obtain, and consequently the current is very much reduced.

Cornwall is below the foot of rapids, extending from which into the lake is a narrow deep channel, having a breadth of three-eighths of a mile in places, with a depth of sixty-seven feet. The channel is bounded by broad flats submerged to ten feet. The river-like character of this channel is unquestionably shown for twenty miles, beyond which the lake has been sounded at only a few points. As the older channel is filled to overflowing its size is not sufficient for the present St. Lawrence. On the other hand, the sharply defined banks of this channel, with a great depth, show that it was made by a stream with a strong current, though now bars obstruct it at places.

Two things become apparent. First, the channel was made by a smaller river; and secondly, this reach of the river has subsequently been filled to overflowing. The flooding of the river banks might occur from a rising barrier at the outlet of the lake, but the trench is too small for the river of the present capacity. The small inner channel is excavated more or less out of drift material, at the foot of rapids descending over a rocky bed. It is such a one as should be expected when Lake Huron emptied by way of the Nipissing and the Ottawa in place of by the Niagara and the St. Lawrence. A few miles below Valleyfield, the river again widens out into Lake St. Louis, in which the features of the drowned channel are repeated. These channels now mentioned in this connexion confirm the diversion of the upper lake waters from the Niagara in a manner gratifying to one who first discovered these changes in the physics of the river.

I have also found that a small channel at the outlet of Lake Erie obtained, which has recently become flooded in the same manner as the plains of Lake St. Francis. Thus there is everywhere proof of the change of drainage.

TERRESTRIAL DEFORMATION SHOWN IN THE RAPIDS.

The depth of the St. Francis channel, compared with that of the rapids below, indicates that it could not have been formed after the barrier to the lake had obtained its present height, or that the valley of the lake was flooded, by merely the increased volume of the St. Lawrence, without either a raised barrier, or a diversion from the course of the pre-glacial drainage.

Upon the side of the Adirondack mountains the deltas show an extension of the Iroquois plane with a mean rise of about six feet per mile, along a line nearly parallel with the St. Lawrence. How much of the rocky barrier at Valleyfield has been raised to blockade the lake has not been determined; but a small proportion of the movement since the Iroquois epoch would be sufficient to drown this deeper channel flooded by the increased volume of the St. Lawrence river.

At the Galops rapids the rocky floor of the channel is from ten to thirteen feet below the surface of the river; yet above the rapids the river has a depth of seventy-five feet. So, also, the rocks at intermediate rapids are found to obstruct deeper parts of the channel above them. Here I am simply calling attention to these phenomena which are worthy of the same detailed study as has been made on Niagara river.

While various questions arise from such a structure these barriers show a recent elevation of the earth's crust in this region. The proof of the elevation has been established along the Adirondacks to the south, but direct evidence adjacent to the St. Lawrence has not been previously suggested. Accordingly, the former assumption of the continuation of the deformation to the St. Lawrence river is sustained, though the precise amount has not yet been actually measured at this locality.

A few miles below Lake St. Francis, the Ottawa river joins the St. Lawrence, forming Lake St. Louis. It was down the Ottawa that the northern drainage of Huron came. While it is interesting to observe the characteristics of the former and inferior St. Lawrence river compared with those of the present, it might be equally so to observe the relationship of the present shrunken Ottawa with its recently greater channel which received the Upper Lake waters.

ANCIENT NIAGARA AND PRESENT OTTAWA RIVERS COMPARED.

The basin of the Ottawa river has an area of 56,700 square miles, while the Erie basin has 40,000. The Ottawa rainfall is supposed to be less than the Erie, being given at between thirty and thirty-five inches a year; but much of this country is underlaid by rock surfaces, not to speak of the wooded character, so that the rainfall, which runs off, is relatively large. The fluctuations of the Ottawa are liable to great extremes* not occurring at the Niagara, yet in the mean stages of the former river may be seen to-day a stream a little larger than the Erie stage of the Niagara. On the other hand the Ottawa river, at that time was as large or somewhat larger than the present St. Lawrence above its union with the modern Ottawa.

* In 1870, the extreme high water at Sainte Anne was 86,500 cubic feet per second; ordinary high water, 41,400 cubic feet; very low water, 1906, 5,820 cubic feet. (A. St. Laurent.)

CHAPTER XXX.

TIME OF WARPING OR TILTING OF LAKE REGION.

Post-Iroquois warping shown in that beach.
Post-Iroquois warping in Niagara district.
Warping of Algonquin beach.
Tilting of Nipissing beach affecting Niagara falls.
Effects of post-Iroquois uplift on Niagara river.
Chicago overflow.
Cause of earth movements—Fisher's theory.

POST-IROQUOIS WARPING SHOWN IN THAT BEACH.

· The Iroquois beach is directly connected with the history of Niagara falls. From the head of Lake Ontario to Prospect farm, east of Watertown (*see* map Plate XXXIII.) is a direct distance of 206 miles with a rise of 367 feet; or, to Trenton, 125 miles, the rise is 270 feet. At the eastern end of this district the rise is more than five feet per mile; beyond these points deltas of rivers show the extension of the Iroquois plane, on the northern side of the Adirondacks to a point 245 miles from the head of the lake, having been uplifted by 609 feet. There are terraces in the higher valleys which I have observed, but not written upon, and they may throw more light upon the phenomena in this region. However, the limitation of the Iroquois plane, whether formerly blocked by ice or not, is unknown.

As shown long ago the component beachlets diverge more towards the east and north than in the opposite direction, showing a greater amplitude of movement between the intermediate pauses than at the west. So, also, the warping is more exaggerated in the older beaches than in the newer and lower ones. This shows a decadence in earth movements. The great extent of the Iroquois shore line, which was a water level, proves that it could only have been disturbed after its completion, and no glaciers could have occupied the lake basin while the beaches were being formed—an epoch of repose lasting for a long time.

POST-IROQUOIS WARPING IN NIAGARA DISTRICT.

At the head of Lake Ontario, including the Niagara district adjacent to it, the tilting movement amounts to two feet per mile. On the southern side of the Niagara district the Forest plane has been warped to the extent of a foot and a half. A higher beach indicates a slightly greater uplift. But farther westward and round the head of Lake Erie the differential movements have been small. The tilting about the head of Lake Ontario is in such close accord with that at the eastern end of Lake Erie that it is seen to be one continuous feature.

The conclusion, therefore, is that almost the entire amount of deformation shown in the Forest beach occurred after the construction of the Iroquois, and at the same time that the latter beach was uplifted. Had the earth movements been uniform and not intermittent these strong and distinct beach lines would not have been formed.

WARPING OF ALGONQUIN BEACH.

The Algonquin beach was formed subsequently to the Forest, but it cannot be asserted that it was synchronous with the Iroquois. As in the Ontario basin considerable time must have elapsed during the construction of the Bell and other terraces. The Algonquin beach was, however, confined to a separate lake basin, where different conditions as to outlet formerly prevailed; but, like the Iroquois, the Algonquin plane was several hundred feet above the lowest rim of its basin in the Nipissing region. The rate of its deformation at the southern end of Lake Huron is only about a foot and a quarter per mile, increasing to four feet per mile, with a direction east of north, but pointing to the foci of uplift occurring north of the Ontario basin. Whether synchronous or not with the Iroquois its bearing upon the Niagara river is of secondary importance after having established through it the fact that the Huron waters did not then overflow into Lake Erie. Still, the lowering of the waters from the Algonquin plane was like that in the Ontario basin.

TILTING OF THE NIPISSING BEACH AFFECTING NIAGARA FALLS.

In the Huron basin the waters were lowered to the Nipissing plane,—160 to 170 feet above the lake in the vicinity of Lake Nipissing; while at the southern end of Lake Huron they were more than ninety feet below the present level. Upon the further subsidence of fifty feet the waters fell to the floor of the Nipissing-Ottawa divide. With the renewed deformation of the land the waters backed and flowed over the St. Clair divide into the Erie drainage.

EFFECTS OF POST-IROQUOIS UPLIFT ON NIAGARA RIVER.

This terrestrial movement was extended to and increased at the outlet of Lake Ontario, and eventually raised the barrier there so as to drown the Niagara channel by the backing of the waters into it. The warping also caused the overflow of the Huron waters by way of the St. Clair river. The rise of the Ontario rim so as to flood the Niagara channel was not completed for a considerable time subsequent to the overflow of the Huron waters into the Niagara drainage.

CHICAGO OVERFLOW.

During the rise of the waters in the Huron basin a temporary overflow by way of Chicago played a subordinate part, but the only effects upon the recession of Niagara falls were to partly reduce the volume of the river, when the falls were passing the Whirlpool rapids.

CAUSE OF EARTH MOVEMENTS—FISHER'S THEORY.

Some have supposed that the lowering of the waters was occasioned by the withdrawal of ice dams, still if such were the case their presence left large sheets of water forming great beaches at one level. The withdrawal of the water could lower the level but not tilt the land. The tilting is an earth movement. One stage of the earth movement carried the land unquestionaly below sea level, for at Montreal the marine deposits, with sub-arctic shells, occur at 530 feet. The minor oscillations, such as are found adjacent to the coast, are not a subject of this paper, and much is here left unwritten.

As to the cause of the warping some have supposed it to be the consequence of an isostatic return to equilibrium upon the withdrawal of an ice sheet. But any ice sheet was far removed to beyond the limit of the observed shore lines, so that the withdrawal of the ice had taken place not simultaneously with the warping, but long anterior to it. In the evidence before me this explanation seems to be at least largely without physical support. Even an isostatic return to equilibrium necessitates interior terrestrial movements.

As to the cause of this quiet rising and sinking of the land without apparent crumbling or dislocation of the strata only a suggestion can be offered. For a working hypothesis, one enunciated by the Rev. Osmond Fisher, author of 'Physics of the Earth's Crust,' offers at least a plausible explanation. The phenomena in the lake region indicate only one general form of earth movement, affecting, however, in a different degree, all parts of the Lake regions (Lake Superior excepted as not having been brought here under careful analytical investigation as in the case of the other lakes).

The foci of greatest rise are on the Laurentian highlands, a considerable distance northward of the outlet of Lake Ontario, which may be calculated from data given in this work. From these foci the radiating movements diminish to nearly zero at the head of Lake Erie. Accordingly, it is again necessary to emphasize the fact that the changes which affected Huron were the same as those operating upon Lake Ontario—a case of a rising node of the earth's interior.

Mr. Fisher explains such changes on the hypothesis that there is a liquid substratum in which convexion currents exist. 'Somewhere a column of fluid would begin to ascend and flow away horizontally at the surface. The waste in the lower parts of the ascending column would be supplied by the inflow of the surrounding liquid, which would depress the isotherms in it, and the whole region affected will become cooler . . . and therefore more dense than the average of the general mass, and eventually gravity and friction will cause it to descend, when the processes of the ascending will recur elsewhere. These occur in cycles. The surface above an ascending column would become elevated, and above a descending one depressed (p. 216).* 'If . . . . an upward convexion current were to occur beneath the continent, the change of level would be local and would affect the superincumbent area. This would cause the kind of uplift which is found in plateau regions without much crumbling of the strata' (page 218).

* 'A suggested cause of changes of level in the earth's crust,' by Rev. Osmond Fisher, Am. Jour. Sc., Vol. XI., pp. 216-220, 1906.

CHAPTER XXXI.

NO PRESENT EARTH MOVEMENTS—OR STABILITY OF THE LAKE REGION.

OBSERVATIONS ABOUT LAKE ERIE.

In preceding chapters late earth movements are shown to have occurred, so that it was only natural to conclude that such might still be in progress. A successful effort has now been made to compare the lake levels in their relation to the present topic. In the latter part of this chapter a statement of the earlier studies and conclusions will be given.

The raised shore lines westward of Cleveland indicate scarcely any changes of level, while between Cleveland and Pt. Colborne, the late rise amounts to nearly 120 feet. Therefore it is in this section that modern fluctuations should be looked for. At the entrance lock of the Welland canal, situated at Port Colborne, the daily fluctuations have been kept continuously, and those since 1849 have been investigated. The Cleveland record is continuous since 1854. These two points are located 156 miles apart.

In the record personal equations appear. The readings at Port Colborne were taken by the lockmasters who recorded only the nearest inch, consequently some men might favour the larger while others the smaller readings, and others might be careless. But in the thousands of records the error will become nearly eliminated by the law of averages. Not so, however, if only levels, taken by different observers, during short periods, be compared.

A very small tide exists, and with only one daily reading at a constant hour another source of error will appear during short times of observation, which would be eliminated if longer studies were made; but this is subordinate to records reading only to the nearest inch. The intensity and effect of the winds produce the greatest variation, but even this error is reduced when the observations extend over a long period.

As the sill of the lock is taken for the Port Colborne datum, there is little probability of any alteration occurring in its position at many feet below frost action. The bench at Cleveland has been changed, but with corrections as close as possible, by the Engineers of the Lake Survey. When taking long periods there is no apparent reason for going behind the data thus furnished.

The table on the following pages gives the fluctuations for Lake Erie at Cleveland and Port Colborne for annual and quinquennial periods, also the difference between these two stations. It must be stated that in the correction of the levels south of the lakes, one amounting to 0·33 of a foot has not been made, while the change has been made in the Canadian levels. The error is retained so as to avoid confusion with records previously published. As this is constant the ratio of fluctuation is not affected.

FLUCTUATIONS OF PORT COLBORNE AND CLEVELAND COMPARED.

The first five years of continuous records are those of 1855 to 1859. In the table which is given the level of Port Colborne is shown lower than Cleveland. The bench marks are stationary, consequently if the table gives an increased minus quantity at Port Colborne it denotes a sinking of the land there more than at Cleveland. A movement in the opposite direction indicates a rising of the land. Thus the quinquennial period ending 1905 shows—0·28 of a foot, and for the same length of time ending 1859,—0·29. Indeed if a longer period from 1891 to 1905 be taken, it is also —0·28 of a foot. Thus it is seen that while there are personal errors the mean level at the two stations varies by only 0·01 of a foot, though a period of fifty years has elapsed. The variation is far within the limit of arithmetical error.

TABLE OF FLUCTUATIONS OF LAKE ERIE AT PORT COLBORNE AND CLEVELAND.

Years.	Lake Erie at Pt. Colborne.	Pt. Colborne below Cleveland.	Lake Erie at Cleveland.
1850	572·12		
1851	572·81		
1852	573·12		
1853	572·82		
1854	572·51*		572·82*
1855	572·80	—·30	573·10
1850–1855	572·73	.....	.....
1856	572·57	—·31	572·88
1857	573·06	—·26	573·32
1858	573·91	—·31	574·22
1859	573·95	—·31	574·26
1860	573·52	+·03	573·49
1856–1860	573·40	—·23	573·63
1861	573·56	—·02	573·58
1862	573·71	—·02	573·69
1863	573·50	—·10	573·40
1864	573·07	+·28	572·79
1865	572·41	—·03	573·44
1861–1865	573·25	+·07	572·18
1866	572·72	+·14	572·58
1867	572·44	—·16	572·60
1868	572·23	·00	572·23
1869	572·49	—·16	572·65
1870	572·13	—15	573·28
1866–1870	572·60	—·06	572·66
1871	572·60	—·09	572·69
1872	571·61	—·11	571·73
1873	572·25	—·18	572·43
1874	572·71	—·23	572·94
1875	572·21	—·07	572·28
1871–1875	572·28	—·13	572·41

* 5 months.

TABLE OF FLUCTUATIONS OF LAKE ERIE, &c.—*Concluded.*

Years.	Lake Erie at Pt. Colborne.	Pt. Colborne below Cleveland.	Lake Erie at Cleveland.
1876	573·59	—·10	573·69
1877	572·52	—·35	572·87
1878	572·94	—·34	573·28
1879	572·25	—·27	572·52
1880	572·45	—·32	572·77
1876–1880	572·75	— 27	573·02
1881	572·21	—·40	572·61
1882	573·10	—·38	573·48
1883	573·11	—·15	573·26
1884	573·12	— 21	573·33
1885	573·09	—·15	573·24
1881–1885	572·92	—·26	573·18
1886	573·46	+ ·11	573·35
1887	573·16	— 13	573·29
1888	572·38	—·22	572·60
1889	572·16	—·21	572·37
1890	572·85	—·20	573·05
1886–1890	572·80	—·13	572·93
1891	571 80	—·35	572·15
1892	571·88	—·25	572·13
1893	571·85	—·23	572·08
1894	571·85	—·24	572·09
1895	570·93	—·24	571·17
1891–1895	571·66	—·26	571·92
1896	571·08	—·31	571·39
1897	571·66	—·30	571·96
1898	571·88	—·25	572·13
1899	571·63	—·27	571·90
1900	571·63	—·31	571·94
1896–1900	571·57	—·29	571·86
1901	571·05	—·33	571·38
1902	571·70	—·14	571·84
1903	572·02	—·35	572·37
1904	572·21	—·24	572 45
1905	571·84	—·34	572·16
1901–1905	571·76	—·28	572·04
1855–1859	573·26	—·29	573·55
1860–1876	572·80	—·05	572·85
1877–1905	572·20	—·26	572·46
1855–1905	572·49	—·18	572·67
1861–1875	572·71	—·04	572·75
1876–1890	572·82	—·22	573·04
1891–1905	571 66	—·28	571·94
1901–1905	571·76	—·28	572·04

STABILITY OF EARTH'S CRUST IN ERIE BASIN SINCE FIFTY YEARS AGO.

If, instead of taking the average of a considerable number of years, that of two years be taken there will be equal propriety in selecting any pair whether near together or far apart. If the levels of 1858 or 1859 be compared (for they had the same elevation) with the height of water in 1860, Port Colborne would be found to be rising faster than Cleveland at 0·34 of a foot in one year. Such a sudden change—if an earth movement—would apparently give rise to earthquakes. On the other hand, if the year 1877 level be compared with that of 1876, the figures would show that Port Colborne was sinking faster than Cleveland at the rate of 0·25 of a foot a year, or twenty-five feet a century. By selecting the mean fluctuations covering a whole year most erratic results may be obtained showing either rise or fall; and if months or days be taken the results vary from zero to others most astounding. These, however, disappear to a great degree in taking the mean of a considerable number of years, with some remarkably uniform results establishing the stability of the earth's crust about Niagara falls, for the last fifty years. If, in place of comparing the levels of the last five or fifteen years with those of fifty years ago showing no difference, the lake levels of the last fifteen years be compared with the mean of the entire period of fifty years, the figures are on the side of sinking at Port Colborne, for in all this time the figures show only 0·10 of a foot, which is also so small as to be of no value whatever. This simply confirms the conclusion as to the stability of the region.

NO EARTH MOVEMENTS IN THE ONTARIO BASIN.

The height of the Iroquois beach nearest to that of the Lake station at Toronto is 188 feet; at Rochester 188 feet; at Canastota on the line of strike with Oswego, 194 feet above Lake Ontario. This includes the personal equation in their measurement. As such a small amount of deformation has occurred, if indeed any, since the Iroquois epoch, it is not to be expected that the fluctuations of the lakes between these stations should indicate differential changes of level. The uniformity of the lakes at these points has been discussed in Chapter XVIII., where it is seen that since 1865 the mean fluctuations have varied 0·05 of a foot or less on either side of the average, and back again to nearly zero; so that in this plane there has been no variation of earth movements recorded.

MEAN ANNUAL FLUCTUATIONS OF LAKE ONTARIO AND ST. LAWRENCE RIVER.*

Years.	Lake at Toronto	Lock 27 Galops rapids.	Lock 27 below Lake.	Lock 15	Lock 15 below Lake.	Lock 14	Lock 14 below Lake.
1861	247·05	....	....	....	....	155·26	91·79
1862	246·92	....	....	....	....	155.15	91·77
1863	246·50	....	....	....	....	154·80	91·70
1864	246·29	....	....	....	....	154·67	91·62
1865	246·03	....	....	....	....	155·55	90·48
	246·55	....	....	....	....	155·08	91·47
1866	245·62	....	....	....	....	154·34	91·28
1867	246·44	....	....	....	....	154 70	91·74
1868	245·17	....	....	....	....	153 79	91·38
1869	246·06	....	....	....	....	154·36	91·70
1870	247·20	....	....	158 74	88·46	155·00	92·20
	246·10	....	....	....	....	154 44	91·66
1871	245·84	....	....	157·62	88·22	154.26	91;58
1872	244.41	....	....	157 72	86·69	153.30	91.11
1873	245·53	....	....	156·56	88·97	154 09	91.44
1874	246·28	....	....	157 23	89·05	154·58	91·70
1875	244·96	242·76	2·20	157·62	87·34	153·64	91·32
	245·40	....	....	157·35	88·05	153 97	91·43
1876	246 76	245·50	1·26	158·43	88·33	154·73	92·03
1877	215·58	244·24	1·34	157·39	88·19	153·98	91·60
1878	246·10	244·04	2·06	156·09	90·01	154·38	91·72
1879	245·70	244·41	1·29	157·43	88·27	154.25	91·45
1880	245·51	243·55	1·96	155·96	89·55	153·97	91·54
	245·93	244·35	1·58	157 06	88·87	154 26	91·67

* Data furnished by Harbourmaster of Toronto and Superintendents of Canals.

†Sill at old Lock 27 is 234·82; at Lock 15 is 144·53; Lock 14 is 142·19 feet above mean tide (being 0·75 added for corrections). Recent slight corrections of sea level of the locks have been made, but these do no affect the variations or changes of level.

MEAN ANNUAL FLUCTUATIONS OF LAKE ONTARIO AND ST. LAWRENCE RIVER—*Concluded.*

Year.	Lake at Toronto	Lock 27 Galops rapids.	Lock 27 below Lake.	Lock 15.	Lock 15 below Lake.	Lock 14.	Lock 14 below Lake.
1881	245·14	243·76	1·38	156·09	89·05	153·65	91·49
1882	246·13	244·98	1·15	156·27	89·86	154·29	91·84
1883	246·31	244·88	1·43	156·86	89·45	154·37	91 94
1884	246·96	245·56	1·40	158·87	88·09	154·67	92·29
1885	246·59	245·15	1·44	158·20	88·39	154·36	92·23
	246·22	244·86	1·36	157·25	88·97	154·27	91·95
1886	247·31	246 02	1·29	159·11	88·20	154·92	92·39
1887	246·77	245·48	1·29	158·80	87·97	151·46	92·31
1888	245·56	244·21	1·35	157·50	88·06	153·90	91·66
1889	245·67	244·43	1·24	156·21	89·46	154·15	91·52
1890	246·73	245·36	1·37	156·86	89·87	154·99	91·74
	246·41	245·10	1·31	157·69	88·72	154·48	91·93
1891	245 77	244·47	1 30	157·83	87·94	154·43	91·34
1892	244·93	243 79	1·14	156·05	88·88	153·89	91·04
1893	245·49	244·26	1·23	157·71	87·78	154·19	91·30
1894	245·31	244·15	1·16	156·38	88·93	153·96	91·35
1895	243·81	242·81	1·00	155 12	88·69	153·10	90·71
	245·06	243·89	1·17	156·61	88·45	153·91	91·15
1896	244·06	243·24	0·82	156·09	87·97	153·20	90·86
1897	244·44	243·49	0·95	155·45	88·99	153·24	91·20
1898	245·03	243·68	1·35	155·43	89·60	153·52	91·51
1899	244·97	243·62	1·35	156·79	88·18	153·53	91·44
1900	244·91	243·61	1 30	155·85	89·06	153·44	91·47
	244·68	243·53	1·15	155·92	88.76	153 38	91·30
1901	244·73	243·44	1·29	155·97	88·76	153·33	91·40
1902	245·01	243·72	1·29	......	......	153·37	91·64
1903	245·54	244·62	0·92	......	......	153·56	91·98
1904	246·29	244·83	1·46	......	......	153·88	92·41
1905	245·91	244·48	1·43	......	......	153·65	92·26
	245·49	244 21	1·28	......	......	153·56	91·93
1861-'90	246·10	......	......	......	......	154·42	91·68
1891-'05	245·07	......	......	......	......	153·61	91·46
1861-'05	245·58	......	......	......	......	154·01	91·57

As the Iroquois beach shows a rapid rise (page 281) from Toronto northeastward it might be expected that the evidence of a modern elevation of the land should be found in the lake fluctuations. Eastward of Toronto there is no point where the lake levels have been continuously taken, until reaching old Lock No. 27 at the head of Galops rapids of the St. Lawrence sixty-six miles below the outlet of Lake Ontario. Throughout this distance the river is broad with a descent of only little over one foot, consequently it may be considered as part of the lake level. In the fluctuations of the lake, between here and Toronto, earth movements should be found if anywhere. While the records at Toronto and at Lock 14 farther down the St. Lawrence have been obtained for a period of forty-five years as shown in table page 332, those at Lock 27 cover a period of only thirty-one years. In the table abnormal changes are shown in the years 1875, 1878 and 1880. If these could be omitted the levels of the intervening years would indicate that at Lock 27 the water surface had a mean level of 1·30 feet below Toronto. However, without omitting these abnormal records, it is found that between 1881 and 1890 the mean water level at Lock 27 was 1·33 below the lake at Toronto; that of the next ten years 1·16 feet, and a return during the last five years to 1·28 feet—within the range of arithmetical error the level of the last five years and that of the decade ending in 1890 are substantially the same, showing that there has been no rise of land between Lock 27 and Toronto, 210 miles west of it. Lately one of the channels of the river has been artificially blocked, which may modify future readings.

The table also shows that Lock 14 has stood at 91·93 feet below the Ontario level from 1901 to 1905, while from 1881 to 1890 it was about the same or 91·94 feet. In the levels of the five year period, ending with 1905, it has been found that while there was a scouring of the outlet, the level was raised again owing to the increased rainfall,—the net deepening amounting to 0·53 of a foot (Chap. XIX., page 243), Accordingly this amount should be deducted from 91·93, leaving 91·40, which figure is lower than the mean difference of levels during forty-five years by only 0·17 of a foot. It is only

0·07 of a foot less than that of the quinquennial period ending in 1865, the result being on the side of sinking of the region, if any value could be placed upon the small difference, but the figures are so close that they give the idea of constancy at the end of forty-five years.

If the fluctuations of the last quinquennial period at Lock 14 (Valleyfield) be compared with those of the lake at Toronto, it may be observed that there was a considerable change during the decade ending with 1900, with figures on the side of a sudden rising of the land. But in the mean level of the last five years there has been a return to the same relationship that prevailed in the earlier years named. Consequently, from the lake levels, though fluctuating, there has been found a stability of the lake region. In the two decades which preceded the last mentioned the fluctuations were in the direction both of sinking and rising of the land with a return to normal conditions. This departure from, and return to, the normal differential levels between two distant points covers the case of oscillations of the earth's crust as seen in the fluctuations of the lakes, establishing a negative result, which is not confused with the question of the lowering of the outlets derived from the same data as discussed in Chapter XIX. Finally it cannot be emphasized too strongly that in the records of the changing lake levels the present stability of the earth's crust is established, although there are variations from the normal conditions of lake levels shown in some years.

ABSENCE OF EARTH MOVEMENTS ABOUT THE OUTLET OF LAKE HURON.

In Chapter XVIII. the recent lowering of Lake Huron has been described. On this account the evidence of earth movements might not be separable from that of the scouring of the river bed. In this region, as has been found about the head of Lake Erie, the post-glacial tilting is so small as to preclude any considerable amount of change at the present time, even if measurable.

Whether the lake region as a whole is now rising or sinking is a question outside of the present investigations which have to do with the differential movements or tilting affecting the outlets of the lakes, although there is now local stability where formerly there were great movements.

It should be mentioned that Lake Superior is not included in this study, and, accordingly, the generalizations do not apply to it either as to the rising or sinking of the region.

IMPORTANCE OF TERRESTRIAL STABILITY.

The present study of the lake fluctuations has brought to light the stability of the land in the lake region adjacent to the outlets of Erie and Ontario. It is one of the important problems solved by the present survey. If the earth's movements were causing a sinking of the land towards the outlets of the lakes it would facilitate the lowering of the water and a drainage from the heads of the basins. On the other hand, if the land were rising the waters would be submerging the low lands at the upper ends of the lake basins, and eventually Lake Erie would discharge into the Mississippi. No change of level whatever indicating such deformation has taken place during the last fifty years, although it obtained during a prior epoch when the deserted shore lines were tilted, and the Huron waters turned into the Erie. Indeed, the low flat at the mouth of Niagara river proves a recent lowering of the lake level, but this is due to the scouring or deepening of the outlet.

FORMER SUPPOSITION OF FUTURE DIVERSION OF NIAGARA TO THE MISSISSIPPI.

The late tilting of the beaches naturally suggested the continuance of the movement, the consequence of which would be the drainage of the Upper lakes into the Mississippi river. It was a logical conclusion with an interesting sensational aspect. In 1894, in connexion with studies on the Niagara, the rocky barrier near Hubbard point appeared so high, that unless it had been raised, since Niagara falls had receded past it, the waters would have been diverted into the Mississippi, thereby ending the life of the falls.* The measurements were taken from a topographic map of the Lake survey, which was lately found to be inaccurate. Upon commencing the present survey, and in making more careful measurements, the results led to the abandonment of the former conclusions; but it was some time before the present stability of the region was affirmed. On the former occasion the rate of the rise of the rocky barrier was estimated to be such that Niagara river should be drained, as far as Buffalo, with the Niagara waters diverted into the Mississippi in 5,000 years,—a time which would have been diminished to 3,560 years had the measurements been reduced to the standard of the rocky rim of the Upper rapids.

About two years after the above announcement by the writer, Dr. Gilbert† adopted the same idea of earth movements, but attempted to prove the question *de novo* from fluctuations of the lakes. Strange as it may seem his conclusions that Niagara falls would cease to exist in 3,500 years closely coincided with my own when reduced to the same datum.

He selected thirty-six irregularly chosen days between August 20 and October 30, 1858, and taking the levels on them he compared the height of the water at Cleveland and Port Colborne on thirty-three days also irregularly chosen between June 28 and August 18, 1895. Therefrom he concluded that Port Colborne had risen 0·239 of a foot, or at the rate of 0·65 of a foot per century more than Cleveland.

From his paper I infer that he chose the days of low levels

* 'Duration of Niagara falls,' by J. W. Spencer, pp. 471-2.

† 18th Annual Rept., U.S. Geological Survey, Part 2, p. 622, 1897.

when he thought the wind was blowing most gently. But the effect of this was that the levels taken from 1895 were only 0·03 of a foot below the mean of those of the three months from which he chose, while those adopted from 1858 proved to be much below the mean of the months from which they were selected. It does not appear why the averages in both cases were not taken, or why levels of autumn months, when the velocity of the wind is twenty-five per cent greater than in summer, were compared with those of months of gentler breezes. Had he compared the summer months in both cases by taking the mean levels, the difference would have been 0·04 in place of 0·239. In this case, however, had he taken the means of the whole months actually drawn from, the amount of rise would have equalled only 0·03 of a foot in thirty-seven years, or 0·08 of a foot per century: but no value can be placed on such small differences. Indeed he himself recognizes a probable error of plus or minus 0·057, which gives a range of more than a tenth of a foot. This choice of days and seasons, indicating an upward movement of the Niagara district, which if continued would divert the Niagara waters into the Mississippi in the not distant future, must give place to the analysis of the full data covering the mean levels of thousands of days fifty years apart, which establishes the stability of the lake region during that time. The data for comparing fluctuations are given in this chapter, while the monthly variations are found in Tables 1 and 2, Appendix v.

In the Ontario basin Dr. Gilbert compares the levels of only four days in all, taking them from August, September, and October, 1896, with thirty-four days irregularly chosen between April 17 and June 9, 1874, at Sackett harbour and Charlotte; concluding that Sackett harbour has risen 0·061 of a foot. As has been shown in the more extended analysis, this amount is a negligible quantity as well as the observations being too few. Even if not so the records of mean fluctuations for many years at Galops rapids shows there has not been any rise in the earth's crust during the last thirty years (this chapter, page 334). The same author computed the changes of Lake Michigan, comparing those for a few days in July and August, 1876, with a larger number between the end of July and the end of October, 1896. But this district lies outside the province of this paper and would not affect Niagara falls.

From the fuller evidence now brought forward it may again be repeated there is not the slightest indication of present earth movements which will divert the Niagara waters to the Mississippi, flooding Chicago. Nor can we predict whether future changes will be those of upward or downward movement.

Beyond the scope of this book, the question of terrestial stability established in the large lake region, of the interior of the continent, may prove of value in other problems of physical geology.

CHAPTER XXXII.

RECESSION OF NIAGARA FALLS.

PREFACE.

The many preceding chapters were a necessary preparation to this one, in elucidating the character of the recession of the Falls of Niagara, their changing history, their power, and the determination of their age. This chapter seems to be separated a long way from the one on the recession lines; but so complex has the history been that the work of the falls could not be understood until investigations had been made upon the various conditions and phenomena which have accelerated or retarded the retreat of the cataract.

In a general way the recession of the falls depends upon three factors—their height, their volume, and the character of the rock formations, which are being channelled by the stream. The falls have retreated across a very level country, underlaid by almost horizontal rock formations having a great degree of uniformity, as was noted even so long ago as 1789 (Ellicott).

Few people have supposed that the recession was not uniform; fewer still would think that the story had not all been told concerning a commonly known natural feature. The history had been partly anticipated in the discovery that the volume and descent of the water have not always been the same, and that some of the features have changed to a degree.

PRESENT RECESSION.

Although the form of the falls was sketched out in 1819, yet the actual retreat has only been measured between the years 1842 and 1905. During these sixty-three years, seven and three-quarter acres have disappeared. The width of the gorge at the falls is 1,200 feet, the excavation of which is due directly to the cataract. The mean recession during these years is found to be 4·2 feet per annum, while during the last fifteen years it was reduced to 2·2 feet; the previous fifteen years showed an annual mean rate of 4·54 feet (page 36, Chapter III.). It must be borne in mind that there are years of no appreciable falling away, succeeded by others when large areas collapse.

EFFECTIVE HEIGHT OF FALLS IN RECESSION.

The height of Niagara falls might be taken from the crest of Greens or First cascade of the Upper rapids, which is 312 feet above Lake Ontario, or 212 feet above the surface of the river in the cauldron below (as shown in longitudinal section figure 28). However, in the Upper rapids, the erosive work of the river is exceedingly slow, so that in comparison with that of the main cataract it is an almost negligible quantity. The accelerated velocity of the water adds something to the force of the descending column; but on account of the rising knobs and blocks in the bed of the rapids, the force is impeded, especially throughout a considerable portion of the breadth where the water is not deep. Accordingly, the theoretical gain in power by the descent of the water on the Upper

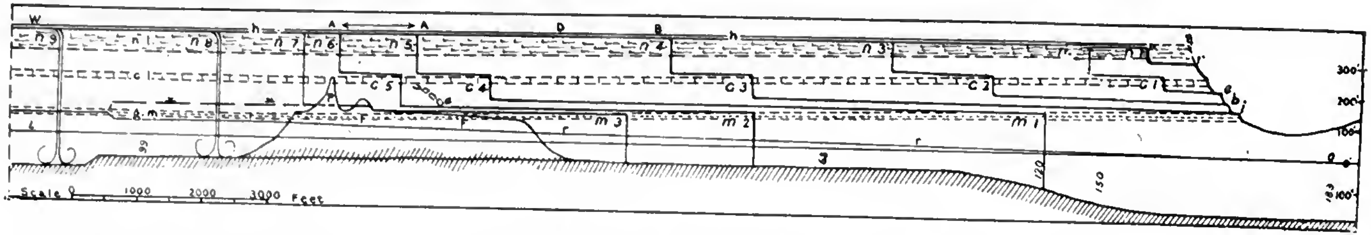


Fig. 28. Longitudinal section of the gorge of Niagara, showing recession of the falls. Fig. 22 illustrates the features from the Whirlpool as far up as Hubbard point. Fig. 3 and the cross section show the characteristics of the gorge. The durable, falls-making, hard beds shaded; Niagara limestone (n. l.); Clinton limestone (c. l.), and gray Medina sandstone (g. m.). E., end of gorge; B., bend of cañon below Devils Hole (D); W., Whirlpool; A—A., position of Wintergreen flat; F. F., Foster flats; P., Wilson point (where Niagara and Clinton cataracts united); d., spur of fallen Wilson terrace. On the Clinton band from P. to below c5 a remnant of the floor of the upper Niagara channel. r. r. r., present surface of river; L. O. level of Lake Ontario; h. h. h., original surface of river and Lake Ontario; r., Roy terrace; e., Eldridge flat; b. Bell terrace; i., Iroquois beach. Soundings below level of river.

Original falls thirty-five feet high receded to n1. Two cataracts established n2 and c1 (aggregate height 120 feet); receding to n3 c2 (total height 150 feet); receding to n4 c3 with river discharging into Iroquois lake; descent 190 feet. Mean height of Upper Falls in receding from n1 to n6 was 105 feet.

Lake greatly lowered with establishment of Medina falls (a third cataract, m. f.) at one time over 300 feet high receding rapidly through shale; n5 (Upper falls) cascading on a remnant of Wilson terrace from which the Clinton falls (c4) descended to the floor of Foster flats with the river farther down cascading over the Medina falls. (The lower part of the floor of the intermediate channel now removed below Foster flats). n6, c5, m2, the three cataracts receding, this being the last station of the Upper falls before its union with the second cataract. n7 Niagara and Clinton cataracts united (descent floor to floor, 240 feet) with Medina falls at or below m3.

n8, The river greatly augmented in volume, breaking through the floor of Foster flats and making a deep channel with surface of river at x x. n9, Falls scouring out Whirlpool; Foster flats now trenched by the third falls, thus lowering level of river and facilitating the deeper excavation from the Whirlpool upward.

The positions of n1, n6 and n7 closely established, so also m 1; intermediate points interpolated from the features of the gorge, terraces and elevation of the hard band. n8, located from the increased breadth and depth of the channel; n9, from the increased depth of the river requiring the trenching of Foster flats for the lowering of its surface. Between n1 and n6, Smeaton's ravine furnishes intermediate evidence of the height of the upper falls.

rapids is very much reduced. At the side of the Canadian falls the height is 158 feet, while in the centre of the apex it is 175 feet. The old floor of the Park is so nearly 180 feet above the river in the channel below, or 280 feet above Lake Ontario, that this height may be taken as effective in the excavation of the gorge with the river at present level, thus making allowance for its increased velocity.

This effective elevation of 280 feet above Lake Ontario applies for a distance of 7,000 feet north of the present site of the falls, while on rising to the col of Hubbard point, the river plane, extending to the mouth of the gorge was generally near 317 to 320 feet. However, the changes in the gorge have caused variations in the height of the falls. Then the height was increased, so that when they were at Hubbard point, the descent was 270-280 feet. South of this point the descent was 240 feet, before the damming of the Whirlpool rapids, after which the effective descent is taken at 180 feet.

The bed of the river, some distance below the falls consists of an outer channel, with effective depths respectively of 80 to 100 feet, and an inner channel to 192 feet. This double channel is not characteristic under the falls, but it is known from the angle of Goat island shelf for a distance of 2,800 feet to Carter cove (Plate XXXVIII. A), where is the end of a lower drowned platform. To what is this deeper channel due? It is situated in front of the American fall and onward.

As the erosion effects are proportional to the height and volume of the water on the same materials, and as the deeper channel is excavated out of only soft shales, the increased height of the falls above the Whirlpool rapids by sixty feet, before the rising of the river to this extent, is sufficient to account for the great depths of the river above this point. It may seem remarkable that the refilling of the Whirlpool rapids should have been so recently completed as the phenomena prove. But, on the other hand, if such were not the case the mechanical action and the slight solvent power of the water should have greatly reduced these obstructions. Moreover, as before pointed out, the collapse of the walls here is so recent that the stream called Muddy run has not yet made even an incipient gorge in the shales beside the Whirlpool Narrows. Strange as it may seem, Kalm stated in 1750 that 'this fall . . . has grown less and less,' referring to the height of the great Falls of Niagara.

The Upper rapids appeared only after the falls had passed Hubbard point, which on retreating southward, sank more and more within the Falls-Chippawa valley. In the early days of these rapids the depth of the water was much greater than now in the channel on the New York side of Goat island, as seen in deserted banks on that side. Also the deepening of the Canadian channel of the Upper rapids has been occasioned by the river creeping southwestward into and over the side of the buried Falls-Chippawa valley, and the consequent lowering of the water in the New York channel and adjacent to Goat island. Then, too, islands existed where now there are rapids (as shown by fragments still remaining in 1799 and 1842). Accordingly the course of the main falls was near the Goat island shelf. The water was concentrated in the line of the deep inner channel, observed in the soundings, with the augmented American falls cascading into the side of the same. The submerged terrace above Carter cove was largely formed by the wide lateral encroachment of the river upon the western side of the cañon. This has resulted in a deep embayment in the wall opposite the American falls. The widening occurred partly from the action of the water flowing onward over the western shelf (as it does at the present time over the Goat island shelf) after the backing of the waters in the gorge due to the blockading at the Whirlpool rapids.

At the Whirlpool rapids and Whirlpool outlet the descent is fifty-nine feet, and twenty feet more at Foster rapids. Below this section the descent of the river is nearly twenty feet more. The channel at Whirlpool rapids was in part refilled upon the recession of the falls above this section; but the final blockading, which has given rise to the rapids, has occurred at a very late date, by the falling of the precipitous cliffs overhanging the narrow gorge. Theoretically the depth of the Whirlpool outlet should be 100 feet, but this is probably lessened by a collar such as appears in the constriction of the cañon at this point. There is a counterpart to this supposed structure in the remains of the neck at Wilson point on Foster flats. But most of the barrier is probably formed of rocks which have fallen into the channel to a considerable depth, so diminishing the section of the river as to produce a fall of seven or eight feet at the mouth of the Whirlpool. From the Whirlpool to Foster, the great cataract fell 240 feet, with the river surface forty feet higher than now. The height of the Whirlpool would have been the same, had not the loose material been quickly scoured out with the formation of great rapids. At Foster flats the river is impeded, but here the masses come sufficiently near the surface to give rise to other rapids. The rise of Lake Ontario, reducing the current, has been favourable to their formation.

The effective height of the falls before they reached the head of Foster flats is given on 355 and following pages.

FORMER CHANGES IN THE HEIGHT OF NIAGARA FALLS.

The present descent from lake to lake is 326 feet. As the Erie level was about the same as to-day, the height of the falls from Hubbard point northward was from 260 to 280 feet, while the Whirlpool rapids were not yet raised to their present level. Indeed, the level of the river, except temporarily in the vicinity of the Whirlpool and above Hubbard point, has corresponded approximately to the elevation of Lake Erie since the birth of the falls. The changing height depended upon that of Lake Ontario. The inferior height of the water between Hubbard point and the falls was caused by the river taking possession of the deeper pre-glacial Falls-Chippawa channel, which was reopened when the falls had removed the obstructing rocky barriers at Hubbard point. Great changes have occurred in the Ontario levels, and these have produced variations in the descent of the different component cataracts of Niagara falls.

When the drainage from the Erie to the Ontario basin was first begun the river gradually worked its way among the irregular hills, and when it became fully established the two lakes were at almost the same level; but Ontario suddenly sunk a few feet. Fragments of the old river floor are found now forming terraces which were covered by two or perhaps four feet of water. The first of these terraces marking the subsidence of the Ontario waters was the Roy, terminating in the delta just below Brock's Monument, the terrace of which is 287 feet above Lake Ontario (page 199).

The next lowering of the Lake developed the Eldridge flat at 200 feet; another drop was to the Bell terrace 174 feet; then to the Iroquois beach 137 feet, afterwards another to about seventy-five feet; while one or two others occur at still lower planes above the present lake level. This subsidence of the Ontario waters continued even to below the present level, until eventually a channel 183 feet below the modern surface of Lake Ontario was produced (page 73). Then the descent from lake to lake was nearly 509 feet as now discovered; but the bottom of the deep channel is doubtless concealed by river deposits, so that the depth which would naturally be taken for the water in the channel may be quite provided for without greatly diminishing this height. But let us assume that the descent was 500 feet in place of 326 feet as to-day.

However, this increased height was added to the effective power of the third cataract only, and in the making of the extended channel below the end of the gorge for a distance of nearly twelve miles. It never produced any acceleration of the recession of the main cataract, for by the time the third cataract had receded a mile and a quarter within the gorge, the waters of the lake had risen and drowned the newly made deep channel, and this was long before the junction of the Medina cataract with the main falls. The amount of this rise is not absolutely determined for such would require the actual establishment of identity between the apparently corresponding terraces of the St. Lawrence and Niagara rivers. It is quite probable that the St. Lawrence terraces may dip and pass under the lake, in which case even the Lower Niagara terraces belong to the original subsiding of the river, except that one fringing the mouth of the river at a height of five feet more or less. This uncertainty is immaterial, however, as the recession of the falls can be determined from the upper cataract alone, although at one time or other, three falls existed in place of the great one of to-day. If it were not for this fact it might be hopeless to attempt to distinguish the work performed by the river during all the minor episodes of changing heights. However, the recession of Niagara falls during all the stages can now be determined.

VARIATION IN THE VOLUME OF THE WATER.

The approximate discharge of Niagara river is now known. The volume may vary by a large per cent; thus on October 7, 1858, it reached 292,000 cubic feet per second while on February 28, 1902, it fell to 158,500 cubic feet per second (page 255). So, also, there have been great variations between different years; while the average volume between 1891 and 1905 was 204,000 cubic feet.

While low water was observed in earlier fragmentary records between 1830 and 1854, on account of the lowering of the outlet there is no suggestion that the former levels will rise again, though they greatly vary. The mean rainfall for the years 1891 to 1905 was somewhat less than formerly, but for 1901 to 1905 it has increased again to beyond the earlier amount. From all possible conditions the mean discharge of 1891 to 1905 is the best measurement of the whole time.

It was previously stated that the volume of Niagara had been increased when there were glaciers on the Canadian highlands, which melted and carried waters from beyond the lake basins into the river.* But on finding that Huron did not empty into Erie until a late date, when there was no glacial discharge here, it has completely refuted this theoretical increase of water to the Niagara and establishes the fact that Niagara river was very much smaller than now (Chapters xiv. and xxvii.), on account of receiving only the Erie rainfall, which lasted from the birth of the falls until Huron drainage was finally turned into it, which was the Erie Stage.

Some time after the addition of the Huron waters, there was the slight diversion of the Michigan drainage by the Chicago overflow to the Mississippi. This partly reduced the width of the Niagara gorge from 1,200 feet so that the river sunk into the pre-glacial shallow depression at the Whirlpool rapids, and restricted the width of the cañon here to 800 feet or less, with very little water flowing over the adjacent floor of the river outside the gorge. Even if the relative width of the broader gorge be compared with that here, the diversion would be less than a third of the volume. But as the water was withdrawn only from the shallower part, the diminished volume could not have been so great. Indeed, this diversion alone would not have narrowed the cañon, (as a volume of only seven per cent of that of the whole river at the American falls shows now a breadth of a thousand feet).

From the volume of the Niagara river the history of the falls may well be divided into two epochs; the one when the Erie basin alone supplied the water, and that when all the Upper lakes emptied by way of the river.

*Proc. A.A.A.S. Vol. XXXV pp. 222-223, 1887.

DIFFERENTIAL DISCHARGE FROM THE ERIE BASIN.

The Erie stage was one of long duration. What then was the volume of the river? While the proportional area of the Erie basin is 16 per cent of that of the four Upper lakes, and the rainfall of the same is 17·7 per cent (page 221, Chapter XVII.) it might be concluded that the former volume of Niagara river could be taken at one of these figures. But there is greater evaporation here than in the Upper lakes, so that according to the rainfall measurements the differential volume should be slightly reduced. This question has been carefully considered both by Mr. Russell and myself (page 252). His conclusion is that the differential discharge of Lake Erie is approximately 16·7 per cent of the four Upper lakes. I have derived that of the Erie from fluctuations of the lakes during the years 1891-1905, and find that the Erie stage of the lake was only 15 per cent of the present overflow. This problem of determining the value of the Erie overflow has at last been satisfactorily solved in Chapter XX. Accordingly, in my computations, this discharge of the Erie basin will be taken as the percentage of that of the four Upper lakes. The question arises: What proportion of the gorge has been excavated during the Erie and modern periods?

LAWS OF EROSION.

According to mathematical laws, erosion is proportional to the height of the falls and the volume of the river, provided other conditions remain constant. The volume is apt to be greater at one point than at another; thus producing a deeper central channel which again may be widened by the falling in of the sides owing to undercutting. The débris may be so accumulated as to protect points of contact where the water impinges on the bed of the river, not to speak of the changing character of the foundations of the channel. This then leads to the examination of the nature of the formations through which the falls have excavated their trench.*

CHARACTER OF THE ORIGINAL RIVER CHANNEL.

Throughout the cañon section of the Niagara river, except at the Upper rapids, at Hubbard point, just below the Whirlpool, and above the end of the gorge, the course of the river is over a mantle of drift material. From the Upper rapids to Hubbard point the course is that of a pre-glacial channel filled with drift, which, upon the recession of the falls past that point, was removed so as to expose the underlying rock with the sloping side of the buried Falls-Chippawa valley, which valley became the floor of the Upper rapids only after they had passed Hubbard point, 8,000 feet below the present site of the falls. The rocky barrier at the outlet of the Whirlpool remained intact, causing the ancient Whirlpool channel, which was pre-glacial, to retain its drift filling material. But upon the falls breaking through the side of the pre-glacial gorge, the drift was gradually washed out.

Above, at the Whirlpool rapids, there was a shallow channel which deflected the currents into a narrow gorge, resulting in the present constriction of the chasm when the surplus water flowing over the lateral floor was lowered by the Chicago drainage. A very important result of the present survey is the establishment of the fact that the gorge at the Whirlpool rapids was excavated out of solid rock, and that the pre-glacial valley of great depth did not reach any nearer the falls, although it extended into the Whirlpool.

Below the Whirlpool, the river crossed a slightly elevated rocky barrier, and also another near the end of the gorge, between which was a pond-like expansion of the river, with a low island, to both of which features Smeaton ravine is due.

* The erosion varies with the mass and square of velocity ($M V^2$). $V^2 = 2 g h$ (gravity and height). As the gravity is cancelled out, the erosion is found to vary directly with the volume and height.

The effect of the topography was one generally favourable to a uniform recession from the end of the gorge to the mouth of the Whirlpool. From here to the middle of the gorge, at Sinclair point, 800 feet, there was only a drift-filling, so that the time of re-excavation was negligible. From Sinclair point to the head of the eddy the excavation by the falls, commencing in drift material, reached the mean breadth, but became restricted to a narrow channel wherein the force of the water was concentrated after the partial diversion by the Chicago overflow—a condition favourable to rapid deepening of the channel, but on the other hand its narrowness afforded greater resisting strength to the excavating forces. So it is improbable that any important change in the variation of rate can have occurred, as waters from only the lateral portion of the channel were diverted from the Niagara discharge. In the meanwhile the size of the outer channel, which in this section was fully as wide as that of the channel above and below, was nearly drained.

EFFECTS OF FALLS-CHIPPAWA VALLEY UPON THE RECESSION.

At Hubbard point the capping thickness of limestone was increased, but south of that point it was again reduced in thickness, on account of the superficial depression.

As the falls were receding southward from Hubbard point the channel was constantly being deepened as the drift was washed away, for the Falls-Chippawa valley has a gradient becoming lower on proceeding southward (page 165, Chapter XIII.). Thus it would seem that the work of the falls was somewhat accelerated. However they are now at the point where the reopened valley is becoming buried, with the crest line turning from its recent course and commencing to ascend the side of the ancient valley, thus giving rise to the Upper rapids in place of the advancing crest continuing in the preglacial valley.

Along this course the falls are constantly encountering a thicker layer of capping Niagara limestone, which at the same time, on account of its dip, is reducing the height to which the underlying shales rise. This gives a stronger and more resisting structure. A large part of the late reduction in the recession is probably due to this feature. So, also, in the future I should expect the rate of recession to be retarded until the falls shall have passed the line of the Greens or First cascade. After that the Upper rapids will gradually be lowered on the channel cutting through the hard rim.

RECESSION OF AMERICAN FALLS.

This is very slow, amounting to about 0·6 of a foot per annum. The volume is taken at only about seven per cent of that of the whole river, but this amount subtracted from the main cataract might be expected to somewhat reduce the rate of recession of the greater falls. The American falls descend on an accumulation of dislodged blocks, so that they are not deepening the channel.

EFFECTS OF THE ROCK STRUCTURE.

To some extent the recession of Niagara falls is accomplished by the wedging off of the upper layers along the margin of the crest (page 35). More than this the currents of the Upper rapids are producing but little effect except by dissolving out and opening up lines of joints, thus facilitating the attack of the powerful currents on the frontal masses of limestone rock. Otherwise the recession is accomplished by the undercutting in the soft shales which form the base of the walls of the gorge. As has been found from soundings, throughout a considerable portion of the breadth of the gorge, the present forces of the river are not breaking through the hard Medina sandstones which lie nearly ninety feet below the surface of the river. The soundings under the great cataract show that their excavating power does not exceed 80 to 100 feet. Below the Goat island shelf, the gray sandstone has been penetrated to a great depth. Where the forces of the falls were greatest they not merely pierced this hard Medina gray sandstone, but they reached to the deepest sounding, which, however, was only accomplished when the level of the river was lower. As great masses of rock have fallen on the higher shelf since the first surveys were made it is quite probable that some of these are still remaining and protecting the higher shelf beneath the eighty feet of water.

The formations have a remarkably uniform character throughout the gorge, but the Medina gray sandstone is still below the surface of the river until reaching to the mouth of the Whirlpool. The depth of the river above Cantilever bridge is 186 feet or far below the zone of the sandstone. In the Whirlpool rapids the channel reached an equal depth, though it has since been refilled by the rocks which have fallen from the sides of the gorge (page 149). The Whirlpool is also deep. Accordingly the river above this point has a channel uniformly extending to about ninety feet below the level of Lake Ontario, showing a very constant penetrating power for the falls, below the Goat island shelf, as far as the Whirlpool.

All these features concern the Niagara river during its modern history. The rock structure beyond this point does not affect the recent history, as all the harder beds lie at a considerable height above the river. While the limestone foundation of the upper river has been variable, on account of topographic features, it grows thinner at the end of the gorge.

HEIGHT AND VOLUME OF THE FALLS AT THEIR BIRTH.

Upon Lake Ontario subsiding below the level of Erie there was a sudden drop of about thirty-five feet. Then a terrace was formed which now has a length of 900 feet, extending upward along the river. The northern projecting end (450 to 500 feet), beyond the line of the 'mountain,' is covered by a delta deposit formed by the river accumulations covering the underlying beds, while the more southern 450 feet are cut out of rock formation as shown in Plate XXVIII. The falls then, at their birth, had a height of thirty-five feet, and the episode lasted sufficiently long, so that the incipient cañon commenced to be formed. Of the distance of 450 feet which might be assigned to it, a portion seems due to the older topographical depression in the edge of the escarpment. As the river was falling into the lake, wave action as well as river currents prevailed; accordingly the excavation due to the falls does ont equal the above amount, while the delta deposit extended the length of the terrace. Here the capping of the Niagara limestone was entirely removed, and the floor of the terrace was superimposed on Niagara shales. This water level was of considerable duration as the well-defined shore line west of the gorge proves (page 197). Upon the withdrawal of the lake waters, there seems to have been a short pause allowing for the structure of another subordinate terrace.

The breadth of the river may have reached 1,400 feet, though this width might have to be reduced before the subsequent falling of the walls on the eastern bank. The average depth of the water at the modern American falls is taken at 1·5 feet, and its volume does not exceed seven per cent of that of the whole river of to-day. The original river having a greater breadth than that of the American falls, and larger volume of water (fifteen per cent) the Niagara falls at their birth should have had a somewhat greater depth of water than the smaller American cataract of the present day.

The terrace showing height of Niagara falls at their birth is seen in Plate XXVIII., page 199. This being densely wooded, the terrace form is not seen so well as when examined on the ground.

This is the first time that the original falls have been described, although an uncorrected estimate of the volume of the river was announced in 1894.*

INCREASING HEIGHT OF NIAGARA FALLS AND ESTABLISHMENT OF A SECOND CATARACT.

The waters of the Ontario basin suddenly sunk to a level 200 feet above the present lake surface. This exposed above the river level the thick band of Clinton limestone, the height of which on the western side of the river is 240 feet above the modern lake level. Thus was established the second cataract with a height of forty-five feet. Then for a time the upper cataract descended upon the Niagara shales overlying the Clinton band until the shales were removed, so that the upper falls had a height of about eighty-five feet, cascading directly upon the hard bed of Clinton limestone (longitudinal section figure 27).

On account of the superior height of the upper falls, and the less resistant material of shales, they receded faster than the secondary cataract, and in this way became well established in advance of the Clinton falls before the Ontario level fell below the Eldridge flat.

When this upper falls had receded to Smeaton ravine, about 4,000 feet from end of gorge, a cross-falls was produced by the small stream passing behind the island in the river just above. But the main upper falls receded a long distance, probably 3,000 to 4,000 feet more, to the turn of the gorge, before the Smeaton stream was completely drained, when the cross gorge had reached a length of 500 feet. In the meanwhile the second cataract had reached to the Smeaton ravine, and it too was cut back in the Clinton beds beneath the present talus slope of the little cañon, for a length of about 200 feet, or about fifty feet within the line of the brow of Niagara gorge. It descended vertically upon the Medina red sandstones and shales about

* 'Duration of Niagara falls,' p. 464.

thirty-five feet and then the floor sloped, forming rapids in all to some fifty feet, showing that the secondary cañon was made while yet the level of Lake Ontario was at the Bell terrace (as all the lower beds to the Medina gray bands were easily eroded) or at most had only just sunken to the Iroquois level. Thus I have found preserved interesting records of the intermediate history of the upper falls, and of the recession of the second cataract, during the middle of the long Erie stage of the Niagara falls.

SUBSIDENCE OF WATERS TO THE BELL TERRACE.

This was a drop of only twenty-four feet to a level 174 feet above the lake, thus only slightly increasing the intensity of the secondary falls, which was still inferior to the upper one. The lake remained for a long time at this level, as a strongly marked shore line is seen in front of the Niagara escarpment (see map figure 24, page 198), and until the secondary falls had receded to Smeaton ravine, as above described. However, upon the characteristics of the upper falls alone, depends the determination of the work of the Erie stage.

IROQUOIS SHORE LEVEL.

Again a sudden subsidence lowered the lake to the Iroquois beach with the water surface 135 feet above the modern level. The Iroquois beach indicates an episode of long duration, and is the most important in the history of the early Niagara river. The upper and intermediate Clinton falls continued separate, with the conditions still favouring the more rapid recession of the main cataract. As the falls receded, eventually the upper cataract had a height of 120 feet at Foster flats; the lower one also gained in height to 120 feet on their reaching the same locality, but this did not obtain until long after the Iroquois level was abandoned by the lake, and the third cataract had come into existence. The breadth of the river in the upper channel was much greater than in the lower, where, consequently, the water was deeper.

A characteristic of the Bell and Iroquois episodes, united, is to-day seen in the wider talus slopes along the sides of the gorge, indicating their slower formation at a higher base level, and in the narrower channel which has since been more rapidly trenched through the older by the subsequent scouring during the later rapid stages of the river. This is the condition seen from the end of the gorge to the foot of Foster flats.

UNION OF THE TWO UPPER CATARACTS AT FOSTER FLATS.

The floor of Foster flats was unquestionably a river bottom. I must conclude that the level of the lake was receding below the Iroquois plane, before the time that the secondary falls were at the lower end of Foster flats, thus lowering the Niagara river. Such was necessary for the gaining of the secondary falls upon the upper while passing this section of the cañon. The computed depth of the river was about ten feet. The increased rate of recession of the secondary cascade continued until it reached Wilson point, where the two cataracts finally united. The floor of the river above here is such as to show that the descent of the united falls from floor to floor was 240 feet—or the same as that of the two separated cataracts just below Wilson point, showing that the flats had not yet been broken through. From this height, however, must be deducted an increased depth of the water upon the upper end of the flats then retarded behind the higher spur of Wilson point.

MEDINA OR THIRD FALLS AND THEIR GREAT HEIGHT.

With the subsidence of the water below the Iroquois plane the Medina falls came into existence at the mouth of the gorge. They descended from a capping band of sandstone, twenty feet or more in thickness superimposed upon soft shales. The rate at which these falls could recede depended largely upon their height acting upon the shales. The subsidence of the Ontario waters was more or less rapid and eventually reached 320 feet below the sandstone band. This height resulted from a withdrawal of the lake for a distance of more than eleven miles. Although a great mass of the shale had now to be removed, its thickness, which was penetrated below the end of the gorge, did not exceed 225 feet, while farther down it was very much diminished, as the upper surface of the new country was composed of drift materials. The work of the third cataract and rapids was largely expended in cutting through the plains below the escarpment. The excavation of this trench in such material was, therefore, relatively very much more rapid than those of the Niagara and Clinton channels. Both of these were underlaid by hard beds of limestone beneath which were shales aggregating a much less thickness, and among them were some more resisting bands. While the lower reaches of Niagara river channel were being excavated, the Medina falls were also rapidly cutting their way back, removing the floor below the Clinton cataract, so that all now left of it are the plains of Foster flats.

The narrowness of the deeply drowned inner channel at the end of the cañon is an indication that the Huron drainage had not yet turned into the Niagara, as indeed this was the case until after the Medina falls had passed above the 120 foot sounding half a mile within the gorge. The general earth movement which has since tilted the land had not then begun to affect the river, as the drowned cataract (or rapid) situated above this point is shown by even the few soundings taken. The head of the third or Medina falls at greatest development is not definitely known for want of intermediate soundings. While it seems to have been situated just above the point of 120 feet sounding, it may possibly be found farther up the river, below the place where the sixty-three foot sounding was taken, which is a mile and a quarter above the end of the cañon. The lowest falls continued to be reduced in height, owing to the warping which began to show its effects upon the river by causing the waters to back into the channel and prevent its further deepening. Finally even these rapids, discovered in the deep soundings, were drowned.

The increased height during the episode of the Medina falls was favourable to the shallowness of the river above, in rapidly drawing off the water from the floor of the Clinton falls, on Foster flats. The drowned rapid just mentioned shows that the Medina falls had not receded so far, with a lower descent, as to penetrate Foster floor, which occurred long after the time when the upper united cataracts had receded past this section of the cañon. As the history of the upper cataract can be determined, it is immaterial whether the exact time and place when the upper falls were joined by the lowest or Medina falls be determined or not, for while the upper were retreating, the lower were accomplishing their work in extending the river channel nearly twelve miles beyond the end of the gorge, and in deepening the end of the cañon for only a distance between half a mile and one and a quarter.

In the earlier part of the investigations it seemed as if these different stages would increase the difficulty of solving the Niagara problem, but after finding the point of union of the Niagara and Clinton cataracts this disappeared, as also that of explaining the depth of the river channel which is somewhat shallower below Foster flats than above them, and in both sections much shallower than in the channel above Whirlpool outlet. The depth of the channel at Foster rapids does not require to be so great as the river above for the trench through the flats is of later date, and need not have reached to the full depth of the channel above.

INCREASED VOLUME OF NIAGARA AT FOSTER FLATS.

From the penetration of the floor of the gorge to a great depth, immediately above Foster flats, it is found that when the falls reached here, there was a great addition of volume, especially as there was no increase in height. (*See* Chapters XIV. and XXVII.) The amount has been calculated, showing that the addition was from fifteen to one hundred per cent. This augmentation arose from the Huron discharge being now added to that of the Erie. From the characteristics of the gorge it has been found that there has been no material change in the volume of the river since the falls receded from a point at the head of Foster flats, except a temporary partial diversion, when Niagara falls were receding past the Whirlpool rapids section.

EFFECTIVE END OF MEDINA FALLS—SHALLOWER CHANNEL BELOW WHIRLPOOL.

Upon the increased discharge of the river, cascading upon the floor where there was relatively little backwater, it became possible to excavate a channel to the depth of about 140 feet beneath the river surface above the upper end of Foster flats. Indeed this would be the excavating power for the height of the falls in this locality. That this was the case is shown by the soundings below the Whirlpool and at the Whirlpool, the former reaching ninety-nine feet below the surface of the river or about 135 feet below the floor of the flats; while at the Whirlpool, whose surface is seven or eight feet higher, the depth is about forty feet greater. The depth of the channel below the outlet of the Whirlpool is fifty-nine feet beneath the level of Lake Ontario; that in the river adjacent to the Whirlpool has been measured to seventy-nine feet without reaching the deepest part, while at the Cantilever bridge, and above, it is found to be eighty-seven feet, and at another point ninety-two feet below lake level, without allowing for the gradient of the bottom of the channel. The floor above the flats was broken into by the force of the augmented falls, at 600 feet above Wilson point, long before the Medina falls had trenched through the lower part of the flats. With the rapidly receding Medina falls cutting through the flats, by the time they had reached the outlet of the Whirlpool a lowering of the river by thirty or forty feet occurred, thus allowing the corresponding deeper excavation of the channel at the Whirlpool and above.

At first one is inclined to attribute the greater depth of the river above Whirlpool point to the occurrence of a pre-glacial channel, but, as shown by the borings at Cantilever bridge, this did not obtain, and yet nearly the maximum depth of the trench is found by the still incomplete soundings. Accordingly such a pre-glacial channel would not satisfy the whole case. However, this explanation regarding the time of the Medina falls cutting through Foster flats and lowering the river above fulfils all conditions. Indeed the newness of Foster channel is manifest, and this explains the greater depth of the river above them than below. It is not necessary that the channel at Foster rapid was ever as deep as the river above, though deeper than now, before the refilling by the blocks which have fallen into it, making the swift rapids around the flats which barricade the middle of the cañon. Indeed the Medina falls may be considered as not entirely ended, but represented by the descent of some seven feet at the mouth of the Whirlpool.

INCREASED EFFECTIVE HEIGHT OF FALLS ABOVE FOSTER FLATS.

As to the height of the united falls above Foster flats, it continued much the same as at the time of their union until reaching the Whirlpool, 240 feet. With the subsequent lowering of the barrier at Foster flats the descent of the river increased to from 260 to 280 feet, when they reached Hubbard point. Then the conditions of recent date began, with an effective descent of 180 feet together with sixty feet for most of this distance to the present site, due to the absence of rapids below.

CONCLUSIONS AS TO THE STAGES OF RECESSION.

Niagara falls at birth were thirty-five feet high. They formed a broad shallow sheet of water having fifteen per cent of the present volume of the river, cascading directly into the lake, producing a valley rather than a cañon, with ultimately a length of 450 to 500 feet. But part of this indentation was of older date, later modified by the accumulation of a terrace deposit, so that the actual cañon due directly to the falls had a length somewhat less. Upon the lowering of the Ontario waters the falls increased to a height of 120 feet. This established a secondary falls from the Clinton limestone. Then the lake level dropped so that the two cataracts had a descent of 150 feet during the Bell stage, which was of considerable duration. Later, during the Iroquois level, the river descended 190 feet. This epoch was still longer. The upper cataract in its later days fell 120 feet, though during an intermediate stage it was somewhat less on account of the dip of the strata, but the mean height was 105 feet. These falls receded one before the other to Foster flats, and before the time that they reached the lower end, the sum of their height was increased to 240 feet, reduced, however, by the depth of the river. This was after the lake level had begun to recede from the Iroquois plane.

Then a third or Medina fall appeared which at one time had a descent of 320 feet. All the cataracts continued to recede, and when the two upper ones reached a point 600 feet from the head of Foster flats they were united, but still there was the small volume of water, and a descent of 240 feet. Now was added to it the additional discharge of Lake Huron, since which time, except temporarily, it has continued to receive the full volume of 100 in place of fifteen per cent. The third Medina falls did not penetrate to Foster until the upper united cataract had reached the outlet of the Whirlpool. While passing the Whirlpool the only work for the river was that of clear-ing out the glacial débris. At the Whirlpool rapids the river was partly concentrated into a narrower pre-glacial channel, with a somewhat greater effective head of water but with greater resistance from the narrowness of the channel. At the same time minor portions were drawn off by way of the Chicago outlet. Above the Narrows of Whirlpool rapids, the river being no longer directed by the pre-glacial channel and again receiving the full volume, the falls were increased in breadth and continued to recede to Hubbard point under a head of 260-280 feet. Later this was reduced in retreating through the Falls-Chippawa trough to 240 feet. At Goat island shelf subsequently this superior head of water was reduced by the partial filling of the rapids, raising the upper reach of the river fifty or sixty feet. This completed the reduction of the great falls, less than 300 years ago, to their present height.

View of Outlet of Whirlpool, looking downward, before construction of Gorge Railway.

CHAPTER XXXIII.

AGE OF NIAGARA FALLS.

Episode of the modern stage.
Duration of Erie stage.
Total age of the falls.
Former conjectures as to the age of Niagara falls.
Date of Accession of Huron waters to Niagara falls.

EPISODE OF THE MODERN STAGE.

It is necessary to read backward. The falls have lately been receding at 4·2 feet per annum, that is since passing the angle of Goat island, a distance of 1,100 feet; this with an effective descent of 180 feet, would require 260 years.

Thence northward to a position after the falls had passed Hubbard point, a distance of 6,200 feet, with a mean effective descent of 240 feet (that is with a water level sixty feet lower than at present, which is only 180 feet beneath the bank since the raising of barrier at the Whirlpool rapids), and at the proportional rate of 5·6 feet per annum, the required time would be 1,100 years.

Beyond this section, to near Sinclair point at the head of the Whirlpool, a distance of 10,200 feet (where the old river floor is 316 feet above Lake Ontario, as seen in the old banks, and the river surface reduced to that below the outlet of the Whirlpool level) there was an effective descent of 260 to 280 feet, which represents a mean rate of recession of 6·5 feet a year. No appreciable time has been allowed for the falls passing a few hundred feet of the buried Whirlpool valley, which being filled with drift was quickly re-excavated when the falls were at this point. The time required for the recession in this section is found to have been 1,570 years.

From the Whirlpool to the head of Foster flats is 3,200 feet of distance. The effective head of water was 240 feet (from the floor of the river at Wintergreen terrace to the floor at the head of Foster flats before the Medina falls had penetrated them). With the proportional rate of 5·6 feet per year, the time for the recession of the falls. This section is computed to have been 570 years.

All these components indicate that the time required for the recession of the falls from Foster flats to the present site has been 3,500 years. This is also the length of time which has elapsed since the overflow of Lake Huron into the Niagara drainage.

Some modifications of this general result might be claimed, as the volume of the American falls (seven per cent) was not included. If seven per cent be added, this correction would shorten the time by 200 years. On the other side, if allowance be made for a diversion of a quarter or third of the water to the Chicago overflow, it would increase the time by 150 to 200 years, yet this appears to be too large an allowance. Again, the volume contracted within the pre-glacial shallow valley at the Narrows of the Whirlpool rapids, would cause a reduction of height by 30 to 40 feet, which would also increase the age by nearly 100 years. These are the principal variations, and may be included in the general estimates, as they are found to compensate each other. If others be found they can be only relatively small.

DURATION OF THE ERIE STAGE.

The Erie stage of Niagara was one of long duration. From the head of Foster flats to Wilson point is about 600 feet. The united falls with a height of 240 feet, but with volume only 15 per cent of that of the present time, required for receding this short distance, about 700 years.

Now working upward from the head of Roy terrace, near the mouth of the gorge to Wilson point is 13,300 feet. The recession of the upper cataract eventually reaching a descent of 120 feet, compared with a recent effective descent of 180 feet would be equivalent to 2·8 feet a year for the present volume of water. But with the discharge of 15 per cent the recession would amount to only 0·42 feet per annum. This rate would require 31,600 years. These are the proportional values based upon secularly uniform conditions, but here is an inaccuracy. The total height of the Upper falls at the end of the long epoch is used, (120 feet) in place of the mean of 105 feet; the reason for this being, to make allowance for one or two small factors tending to shorten the time. One of these is the omission of the equivalent volume of water diverted to the American falls. With the mean descent of 105 feet this would increase the time to 36,000 years, but allowing for the proportional part of the volume now going over the American falls it would be reduced to 32,600 years, thus leaving a thousand years for the acceleration of recession due to the thinner capping limestones at the mouth of the gorge, while the volume of the river was small. The thickness of the underlying shales is constant. As I have found the character of the falls during the middle portion of this long stage, these corrections will approximately cover the case, although their precise amounts are not determined more closely. I do not believe that the apparent error will ever be found to reach ten per cent, with the rainfall during the recession being approximately the same as at present.

The Roy terrace shows a not inconsiderable duration of the little falls. With the descent of only 35 feet, and the volume of 15 per cent, the proportional recession would be equivalent to about one-eighth of a foot per annum. The terrace here is strongly marked, as is also seen farther west (page 201), yet on account of a slight indentation in the face of the escarpment it is somewhat difficult to determine what proportion of the 450 or 500 feet of the valley was entirely due to the falls. There was a joint river and wave action for a time, as the falls cascaded directly into the lake with a delta deposit of 300 to 450 feet built up in front. The capping limestone was also thinner. The rate of recession should be increased above the proportional amount. Under these conditions, the new channel, if reduced to 400 feet in length, would seem to give a fair allowance for the work of the falls during the first episode; thus requiring about 3,200 years.

TOTAL AGE OF THE FALLS OF NIAGARA.

All these computations together, which bring Niagara out of the realm of speculation into one of inductive science, gave a total of 39,000 years as the age of the falls. During the first 35,500 years occurred all the great changes of the lowering of the Ontario waters from 320 feet above, to 180 feet below, the present height, and the return to the modern level. The lake level was nearly stationary for long episodes, when the Iroquois and Bell terraces were formed, and for shorter ones, during the making of other shores. If Mr. Russell's discharge value for the Erie basin be applied the result would be about 3,500 years less. This cannot be regarded as a serious discrepancy, that would discredit the general results, and it comes within the limit of ten per cent error. The Huron discharge was added to the Niagara 3,500 years ago. The falls passed the Whirlpool about 3,000 years ago; and the temporary diversion of some water into the Mississippi occurred between 2,000 and 2,500 years ago.

The age of the Falls of Niagara, which are post-glacial, is one of the great questions of geology having a world wide interest. The complexity of their history, which meets one on investigation, disappears in applying precise methods and carrying them sufficiently far. It was principally due to a failure in understanding the nature of the differential uplift of the land, and tilting of the water-basins, so as to change the height of the falls and their volume; and to previous failure in making the determination of the work of the falls at the different stages in their history.

There need be no suspicion that underlying hypotheses have been developed, as I had none to uphold, except what might come from the facts inductively. The problem has been a long one to solve, so that no one who has not at least examined the investigations is entitled to call in question the features of the falls, gorge, etc., as to their furnishing evidence in bringing us near the age of Niagara, even though he may be bewildered by the great mass of facts brought out by methods that had to be specially developed for this solitary problem. Had the question been as simple as Lyell supposed, this work would never have been undertaken. He divided the length of the gorge, guessing that the rate was a foot a year. At four feet, as measured, this long accepted conjecture would be reduced to 9,000 years from 35,000. Forty years after Lyell others thought this too much, also a conjecture, and so reduced the time to 7,000 years. A year or two later I found that only the Erie drainage supplied the early Niagara. It was this discovery by myself that caused opinion as to the age to be increased to a very long period; a tremendous step towards the determination of the true age, which however could not yet be established. Then I found the point where the falls were located when the old Erie stage ended, this was another step. The work of the Falls of Niagara along its whole course has now been made known.

FORMER CONJECTURES AS TO THE AGE OF NIAGARA FALLS.

Most of the estimates with regard to the age of Niagara have been simply conjecture. It was remarkable that one of these was made by Andrew Ellicott so far back as 1789, when he thought that the falls had required 55,440 years for the excavation of the cañon. Andrew Ellicott was a great observer. His description of the falls was but little inferior to that of Hall, fifty-three years later, which was one of the foundation works for subsequent studies.

Until a second survey was made in 1875 no one knew the rate of the modern recession. Bakewell had allowed 12,000 years. Later in 1841, Lyell assigned 35,000 years as mentioned, and on account of the reputation of this authority it came to be generally adopted. After the measurements of 1875, Dr. Julius Pohlman was probably the first to apply them to the question. However, he thought that the pre-glacial channel above the Whirlpool reached to almost the present site of the falls, and that the time required for re-excavation of more than half of the cañon was so inconsiderable as to be negligible, and that the gorge from its mouth to the Whirlpool was made in 3,500 years. This is the smallest estimate of the age of the falls ever made. In 1886, Dr. G. K. Gilbert presented the following formula:*

$$\text{Age of gorge} = \frac{\text{Length of gorge}}{\text{Rate of recession of falls.}}$$

= Effect of antecedent drainage.
— " thinner limestone.
— " thicker shales.
— " higher fall
— " floating ice.
± " variation of detrital load.
± " chemical changes.
± " changes of river volume.

showing that the age was 7,000 years or less, adopting the maximum in place of the mean rate of recession, which would have given 9,000 years. In his equation, all of the early determinable modifications tended to reduce this estimate with a further lessening when he says: 'The catchment basin was formerly extended by including a part of the area of the ice sheet.' But he entirely omitted the inferior height of the falls, which would

*Loc. cit.

have increased the age, although this feature had been observed long before in the high beaches at the mouth of the gorge. Indeed the suggested shortening of the age of the falls, due to the increased height, did not occur, as the acceleration of the cataract thereby was expended on only the lower reach of the river.

The supposed increased discharge of the Canadian glaciers was subsequently set aside upon the discovery that for a long time the Huron waters did not empty into the Niagara which diversion enormously increased the age of the falls. Although he had followed my changing physics to a remarkable degree, though scarcely mentioning me, yet after my computations, which were the first to be based upon these changes he endeavours to dispose of my results by now mentioning my name and stating that he agrees with Mr. Taylor that 'no estimate yet made has great value, and the best results, may perhaps be only a rough approximation.'† The summary disposal also covered the opinion of Dr. Warren Upham (whom he mentions) who without taking the physical changes into account had assigned 7,000 years as the age of the falls, wherein he followed Dr. Gilbert's previous showing, that even this time was excessive. Later Mr. Taylor says that 'revising our conclusions in the light of recent advances it may be said tentatively that 50,000 years may be regarded as an approximate estimate of the extreme limit for the making of the whole gorge of Niagara falls, but it may have been as short as the estimate of Lyell's (35,000 years),' which was only a foundationless guess, for by his own method, with accurate measurements, the result would have been 9,000 years only, or 'Spencer's (32,000 years).'*

The first computation of their age based upon the changing height of the river and former inferior volume was made by myself in 1894, with the result of giving the falls an age of 32,000 years. Even at that time it was not supposed to be a

† 'Nat. Geog. Monograph, No. 7, p. 236, 1895.
* Bull. Geol. Soc. Am., Vol. ix, p. 84, 1898.

final determination, as in the vicinity of the Whirlpool and rapids the physical changes were not well understood. Moreover the discharge data were inadequate: so much so in fact that the present determination of the drainage of the Erie basin alone has been reduced considerably below that formerly used. Thus the duration of the Erie stage has now been greatly increased. At that time, too, the details of the upper levels of the lake shown in the Ontario beaches were not regarded as of much importance, nor had the full significance of the records of Foster flats been appreciated. Nothing was known of the depth of the gorge except at one point. With the vast amount of light now thrown upon the subject, it is surprising that the former incomplete data should have so nearly balanced those of to-day. If the results had depended upon the history of the lower cataracts in place of the main upper falls, additional data would have been required, which might never have been obtained.

Mr. Taylor, appreciating the changing conditions in the history of Niagara, but thinking Huron turned a second time into Erie when the falls were above Cantilever bridge, says it would give 2,700 years as the age of the gorge above this point. He further states that:—'There is good reason to believe, however, that the rate was slower most of the time so that it would probably be nearer the truth to say that it has taken between 5,000 and 10,000 years.'*

Not merely because neither the former nor the present survey has shown me any grounds for reducing the rate of recession in this section, but because it is a substitution of conjectures for reasonable induction, I must at once dissent from Mr. Taylor. The data may be defective, but his method is one of assumption not based upon the evidence obtained. Mr. Taylor recognized that no time estimate of the age of the Whirlpool rapids had an approximate value. On this point I agreed with

* Bull. Geol. Soc. Am., vol. ix., 1898.

him, for at that time nothing better than a mere working hypothesis could be offered. With regard to the other sections of the river he says that he has previously endeavoured to draw examples of the past recession of the falls from that of the present American cataract; but he now has shortened the time to 50,000 years or less as above stated. But comparisons cannot be made with the American cataract, as the ancient volume was much greater and the height less.

While I was prepared in 1894 to modify the computation of the age of any section of the Niagara river upon fuller evidence I was presenting my results only as an *avant courier* of the inductions derived from the facts then at hand. Slowly I have arrived at the present conclusions, not knowing until the end of the investigations whether or not some insurmountables obstacle would present itself. Throughout the present work I have attempted to present the facts with the most complete information, so that they can be used by others.

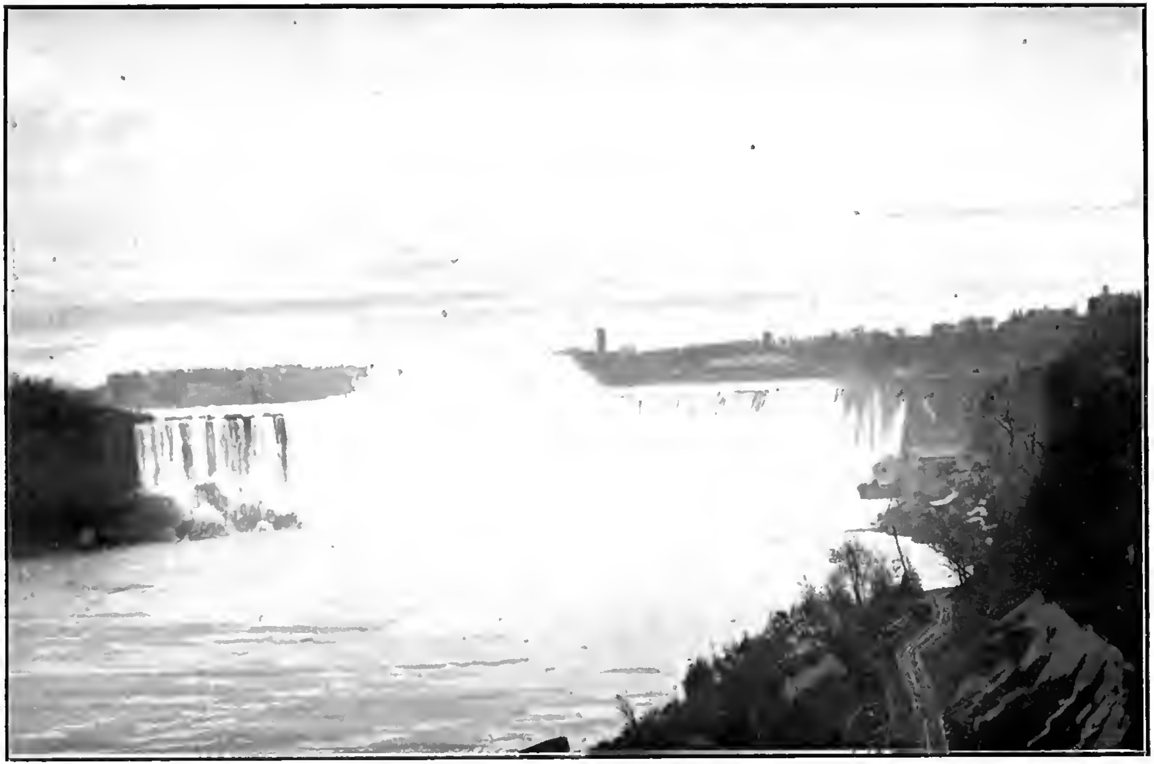
My fuller knowledge of the field and succession of new features found in working out the details enables me to offer conclusions as a consequence of the monographic studies; thus not only bringing the work down to the present time, but fully believing that a sufficiently close determination of the age of the falls has now been made. Indeed the importance of determining the age of Niagara falls does not lie in the variation of a few per cent; but it is a question whether the falls be 9,000 years old (as would have been the case had there been no changes in the height or volume), or a very great age of say 100,000 years, or one intermediate in length.

I congratulate Mr. Taylor on his conjectures, in finally stating them in terms so close to those found by much more precise research. Mr. Taylor has been one of the principal and best observers of the phenomena bearing upon the history of the lakes, and is therefore specially entitled to an opinion.

DATE OF ACCESSION OF HURON WATERS.

The Nipissing-Mattawa-Ottawa watershed is at present 112 feet above Lake Huron. The former barrier across Lake St. Clair, now scoured out, could not have raised the surface of the water less than ten or twenty feet, leaving ninety-two feet for differential elevation. To this must be added something for the depth of water in the Nipissing channel, so that the uplift may be taken at about 90 feet, as having occurred since the Huron waters emptied into the Erie drainage. The change occurring 3,500 years ago, would represent a mean elevation of the outlet at the rate of three feet per century if there had been a uniform rise. As observed everywhere, the beaches record a succession of shore-making pauses separated by abrupt subsidence of the waters. Accordingly, this mean rate of rise cannot be considered as having much value on the interpretation of future changes. With the computation of the age of the falls the work of the recession closes.

In the present investigations I have been led to the discoveries of some most remarkable early conditions in the region, even long before there was a Niagara river. One of the most important of these was a great drainage channel from the Erie basin in times pre-glacial, which then received, as a small tributary, the precipitation of the neighbourhood of the Niagara falls by way of the buried Falls-Chippawa valley. This has given rise to the local features about the present site of the great cataract. The pre-glacial outlet of Erie will be described in the following part of the work.



View of Canadian Falls—very high water, Oct. 25, 1906, when it is partly overflowing the wall lately drained for 415 feet. Canadian Niagara Company Power House behind the view of Falls.

CHAPTER XXXIV.

FUTURE RECESSION OF THE FALLS.

The survey of Niagara falls would be unfinished if the facts which bear upon the future recession as they finally appear were not brought together. There are two sides to this question: one the natural changes in progress, and the other those affected by the artificial modifications.

The falls have been undergoing changes tending to modify the recession. The rocky rim at the First cascade is lower on the Canadian side than on the Goat island, and the current naturally sweeps against the banks of stony clays above the Dufferin islands. These have been constantly washed away, tending to lower the river as the bedrock sinks in that direction.

The rate of recession of the falls during the last fifteen years has been greatly reduced, this being caused by changing features, with effects due to the diversion of the water for power purposes. The change is mostly due to the turn in the course of the river, with the apex of the falls now beginning to creep up the side of the Falls-Chippawa valley, where the thickness of the limestones forms a more resisting arch,—retarding the recession. About 2,500 feet above the apex, the rim of the First cascade, should be reached in about 600 years, if the mean rate of recession (during the last sixty-three years, or that of the 227 years since the falls were first seen by Father Hennepin) were to continue. In the meanwhile, as the falls retreat the hard capping stratum is not merely increased by the thickness of the rising floor of the rapids, but also by the dip of the limestone formation. On this account the rim at the First cascade might not be reached for much more than 600 years. At the rate of recession since 1890, the time required would be 1,500 years.

The falls, having reached this point and gaining a height of fifty-five feet with the extinction of the Upper rapids, would commence to trench the rim whereby the surface of the upper river would soon be lowered to the floor of the basin in the soft Salina beds south of the rim mentioned. The height of the falls would be then reduced to less than that of the present day. A new Upper rapids just below the outlet of Lake Erie would be established to a height of sixty feet or more, eventually becoming another cataract as the river passed over the Corniferous rock between Fort Erie and Black Rock, thus lowering the surface of Lake Erie.

Before the present investigations it was supposed that there were upward earth movements here which would counteract this lowering of the lake level, but these are found to have ceased, at least for the present. Such is the natural immediate future of the Upper rapids, while the falls themselves will be considerably reduced on account of the lower floor of the Chippawa valley. While the re-excavation of the superficial drift deposits in the basins, underlaid by the Salina formation, will be much more rapid than that of the rock, yet it might require a long time to complete these changes of the new Upper rapids. Accordingly there is still a long natural future for Niagara falls.

Turning to the artificial modifications of the falls. The protection of the banks of the Upper rapids is already completed by the railway company. The full diversion of the water under the present active franchise will reach 40 per cent of the low water discharge. This must greatly reduce the rate of recession of what is left of the falls, though to what extent only future measurements compared with those already made, can determine.

PLATE XXXVIII. A.

View of Goat Island shelf, adjacent to the Falls, which is being drained, with rocks appearing at surface. (Sept. 1906.) Electrical Development Company Power House in Victoria Park, shown in background.

PLATE XXXVIII. B

View of Carter Cove, Upper Arch Bridge, and factories on the N. Y. bank of the gorge beyond.

In Plate XXXVII. is a picture of the falls during high water (October 25, 1906), where thin streams are seen flowing under the retaining wall, made in curtailing the breadth of the falls on the Canadian side, thus in a degree restoring for a day nearly their former width. Plate XXXVIII. A shows the present draining of Goat island itself. Plates XXXIX. A and B are views of the Greens or First cascade over rocks which will be the first laid bare.

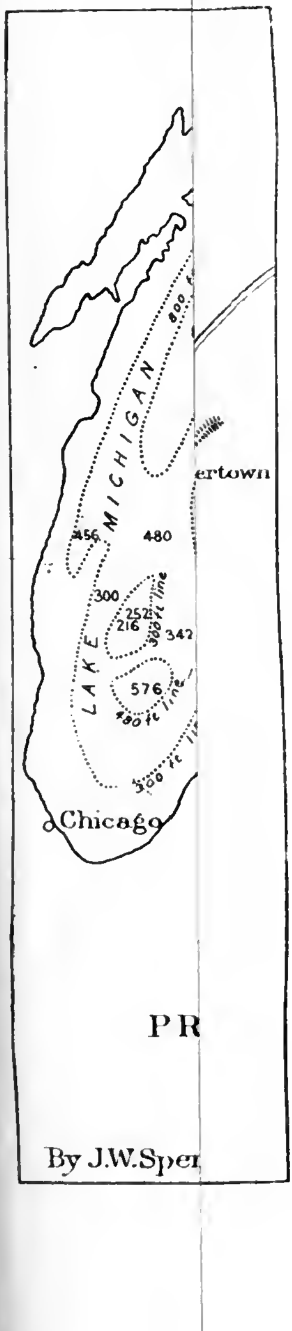
PLATE XXXIX. A.

Profile View of First Cascade from Goat Island.

PLATE XXXIX. B.

View of First Cascade above Middle Sister Island, and river bed from which water has lately been drawn off.

XL.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THE OUTLETS OF ERIE BASIN

AND

ORIGIN OF LAKE BASINS

CHAPTER XXXV.

ORIGIN OF THE LAKE BASINS—DROWNED AND BURIED VALLEYS.

PREFACE.

As has now been seen Niagara falls primarily owe their origin to the changing levels of the lakes. Their history has been modified by the buried channels which were tributaries of the ancient valleys now converted into the Great lakes of America. Again, these ancient valleys were more or less obstructed by drift deposits, and since the glacial period the region has been greatly modified by the tilting of the land surface, the evidence of which is seen in the now raised beaches, causing changes in the course of the lake drainage. In reality the history of Niagara began long posterior to the formation of these valleys, and if the history were told in chronological order the ancient valleys and their blockades should have been described before commencing the study of the falls. However, their origin has really been discovered by the observation of phenomena which of themselves were not obtained in their natural order, and it required many years to collect sufficient evidence to explain them. The exploration of the Whirlpool and Whirlpool rapids has brought to light an ancient gorge which of itself was unimportant; but owing to its effects upon the recession of the falls, giving rise to the Whirlpool, it assumes a prominence much greater than many other similar buried channels of larger size. The discovery of the Falls-Chippawa channel explains a still more remarkable feature, trending in a direction opposite to that of modern drainage and demanding the existence of a further buried valley sweeping round and entering the Ontario basin by some other route, while upon the surface of the country no such feature appears.

TOPOGRAPHY OF THE LAKE BASINS.

In front of the highlands of New York and Pennsylvania are the great plains of the Lake basins, broadly speaking, though really this term is not quite applicable. The Erie plains, north of the central part of the lake, rise slowly into hills and a high rolling country covered with drift, reaching to 1,700 feet above the sea. In front of the higher slopes of New York is the Niagara escarpment facing Lake Ontario, from the foot of which are plains extending to the lake. On the northern side of Lake Ontario the flat country passes into high drift ridges. While the Niagara escarpment has an elevation of 330 to 340 feet at Niagara river it rises somewhat higher at the head of the lake, and forms the northeastward face of the high country just mentioned beyond the plains of Lake Erie. This escarpment is the characteristic feature of the peninsula between Georgian bay and Lake Huron, of the islands of Lake Huron, across the upper peninsula of Michigan, and in the peninsula separating the lake of that name from Green bay. Between Lake Ontario and Georgian bay the face of the Niagara escarpment is so obscured by hills of drift that its true character is not always apparent in crossing the rugged, drift-covered country.

Beyond Lake Ontario, the St. Lawrence valley extends from the foot of the Adirondack mountains of New York northward for thirty miles or more to other ridges, characterized by drift hills. In the direction of the lower Ottawa river the undulating plains become more extended as the country is much lower than farther west. In fact the St. Lawrence valley may be considered as the extension of that of Lake Ontario, with the river now traversing it near the surface and not in a deep valley; although terraces occur to a height of 100 feet or more. These terraces are much below the level of the great deserted and much tilted beaches of the Ontario basin which have hitherto been surveyed.

Not only is Lake Ontario excavated out of almost level Palæozoic formations, but this is equally true of Erie, Huron, and Michigan basins, except on the northern side of Huron, where the formations are crystalline rocks.

FEATURES OF THE ONTARIO BASIN.

The special feature of the basin of Lake Ontario is the drowned escarpment on the southern side, showing the valley-like character of the lake as was first pointed out many years ago.* At that time there was an exaggerated idea of glacial erosion, which was a plausible way of explaining unknown features. The late Prof. J. S. Newberry was the leader of this school, and yet he thought that an ancient channel between Lake Erie and Lake Ontario might be found. Such a channel was described by the writer which is now known to be only one of two or three depressions across the Niagara peninsula.

Lake Ontario is simply a deep trough reaching to 738 feet in depth, while it has been only 246 feet above sea level. The deepest point is nearly north of Seneca lake which reaches 165 feet below sea level. Farther toward the outlet of Lake Ontario, the floor rises without any form of a channel such as

* 'Discovery of the Pre-glacial Outlet of the Basin of Lake Erie.' By J. W. Spencer. Proc. Am. Phil. Soc., Phila. Vol. XIX., pp 300-337. Also in Report of Geological Survey of Pennsylvania. Vol. QQQQ.

prevails to the eastward. This feature made the investigation of the origin of the basin very difficult, for undoubtedly there was a river-like valley throughout the lake without any manifestation of its continuing to the present outlet. It was to account for the rising floor, as well as the great depth of the lake below sea level, that recourse was had to glacial erosion, although the striations upon the rock surfaces were strongly marked in a direction always oblique to the face of the escarpment. This would disprove such an origin for the basins.

The more precise study of the details showed that at a point about twenty miles east of Toronto, and some half dozen miles from the northern shore, there was a channel reaching to 474 feet, while the soundings on either side of it have a depth of only about 200 feet.* At the head of the lake there is a broad valley which is really a refilled cañon. This is the Dundas valley with the rocky walls rising nearly 500 feet above the lake. On the side of this valley, extending to the city of Hamilton, a boring (at the Royal Hotel) showed that the buried channel reached 292 feet below Lake Ontario and cut into the Niagara plateau to a depth of more than 800 feet. The depth of the lake even as far west as south of Toronto is 400 feet. This buried Dundas valley completely penetrates the zone of Niagara limestone, and connects with a basin in the Salina formation beyond.

Returning to the soundings of Lake Ontario it is found that the northeastern extension of the lake is shallow and contains many islands. These are of limestone formation (Trenton and other allied series), lying in almost horizontal strata. There are undoubtedly deeper channels; for among the Thousand islands, a few miles below the outlet of the lake, the water reaches to a depth of 240 feet. Here the river crosses a narrow zone of crystalline rock of the Laurentian system. But the first rocky barrier across the river occurs at the Galops rapids

* On the B. A., but not on the U. S. chart.

sixty-six miles in a direct line from Kingston, at the outlet of the lake. Here the depth is reduced to twelve or thirteen feet at a point one-third of a mile below the old lock No. 27. This barrier is composed of limestones of the same character as those at the outlet of the lake.

It was several years after the observations of the fluviatile character of the lake basins before any rational explanation could be given of the barrier just mentioned. I was able subsequently to apply the warping recorded in the post-glacial features. From the deepest point at the outlet a line may be drawn somewhat parallel to that from Canastota to Cape Rutland (Prospect farm four miles east of Watertown), at the eastern end of the lake. Between these two points the Iroquois beach rises 282 feet. (*See* map Plate XXXIII.) As has been mentioned in Chapter XXII., page 284, the post-glacial rise between the outlet of Lake Ontario and the Galops rapids amounts to 500 feet or more. Here is found a differential warping sufficient to acount for the barriers across the outlet of Lake Ontario, for if straightened out it would not be sufficient to obstruct the flow of the river through the present lake basin. This result is obtained without having determined the last remnant of the differential change of level. Under such conditions the outlet of Ontario over the rocky rim would be 500 feet below sea level. At the same time it shows the continuity of the character of the Laurentian valley with that of the basin of Lake Ontario. These features have been somewhat fully explained in a general way in 'Origin of the Basins of the Great Lakes of America,'* and earlier papers.

A full investigation of the St. Lawrence valley has never been made, and possibly somewhat deeper channels adjacent to the rapids may be found, as recent observations suggest. Under any circumstances, however, such a deep valley below

* Quar. Jour. Geol. Soc. London, vol. xlvi., pp. 523-533, 1890.

sea level demands that it should have been formed during a period of high continental elevation.

FEATURES OF THE ERIE BASIN.

Lake Erie is situated in a broad plain. Much more than half of it has a depth not exceeding eighty-four feet; not over one-sixth of its basin has any considerable depth—the most profound soundings reached to only 204 feet, as shown in maps, Plates XXXIV. and XL. Numerous tributaries of the ancient basin have been discovered by borings. For instance, at Cleveland one such was found by Dr. Newberry† with a depth of 228 feet below lake surface, although adjacent portions of the lake are nowhere over eighty-four feet deep. Later, Dr. Warren Upham‡ mentions the occurrence of another at this locality with a depth of over 400 feet. Long ago Dr. T. Sterry Hunt* recorded channels at Port Stanley and Vienna, reaching below lake level to a depth of 152 to 200 feet, and at Detroit another to 212 feet. These are sufficient to show that channels everywhere traversed the now shallow basin of the lake, refilled during the glacial period.

At the eastern end of Lake Erie, Dr. Julius Pohlman called attention to the buried river channel at Buffalo creek, reaching to 120 feet,†† and Irving P. Bishop** reports that in this locality, at Blackwell canal, that bridge piles were driven to 120 feet without reaching rock, although the present floor of Lake Erie is found to be more than forty feet below the surface, so that the deep channel of Buffalo creek is buried beneath the much shallower lake. One of the piers of the International bridge across the Niagara river rests upon glaciated rock surfaces to a depth of forty-five feet, while at other piers the depth is greater. At a point, little more than a mile above Fort Erie,

† Geology of Ohio.
‡ Bull. Geol. Soc. Am., vol. vii., p. 328, 1896, Ib., vol. viii., p. 8, 1897.
* Geology of Canada, 1863.
†† Life History of Niagara, Trans. Am. Inst. Min. Eng., vol. xvii., 1889.
** Geology of Erie county, N.Y., Rept. State Geologist for 1897.

the head of the low terrace (five to eight feet) has a rock floor, with the river reduced in depth to seventeen feet. But the channels on either side of this col is thirty and twenty-four feet respectively, suggesting a buried valley between, but there was no passage for the ancient Buffalo creek. Other buried channels are also known, but these illustrate the features of buried ones to a considerable depth about the Erie basin.

FEATURES OF THE HURON BASIN.

The southern half of Lake Huron is a plain traversed by valleys submerged to form a shallow lake. Northward of this basin and extending obliquely across the lake for ninety miles is a submerged escarpment, facing the northeast with a height of from 300 to 450 feet (Map Plate XL.). The extreme depth of the lake reaches to 750 feet, while the deepest channel between Lake Huron and Georgian bay is unknown on account of drift filling, but soundings show 306 feet. On the western side of Georgian bay is a deep channel reaching to 510 feet in front of the Niagara escarpment. These channels in front of the submerged escarpment of Lake Huron and of the Niagara escarpment on the western side of Georgian bay are fragments recording the ancient drainage of the lake basin. On both sides of the Huron-Georgian lake our knowledge of the drainage system is further extended by deep borings.

FEATURES OF THE MICHIGAN BASIN.

The lake is divided into two basins, the more northerly with a maximum depth of 864 feet, in part bounded by vertical escarpments now submerged. One of these abrupt features shows a descent of 500 feet, with the deepest sounding in the outlet of the lake at only 252 feet. A fiord tributary is seen in Grand Traverse bay to a depth of over 600 feet. This and shallower fiords indicate the existence somewhere of a deep channel connecting Michigan with Huron, like the river valley buried beneath the drift material of the modern floor of Lake Erie. They establish the existence of channels though not shown by the soundings. Lake Michigan as a whole is carved out of Palæozoic formations, the newest of which are the Coal Measures.

There is a smaller basin in the southern part of Lake Michigan with a depth of 576 feet, and a ridge between the two basins submerged from 300 to 342 feet. Across the southern part of the peninsula of Michigan there is a valley dissecting the highlands of that State, the western portion of which is occupied by Grand river, and the eastern portion by a stream emptying into Saginaw bay. Well borings in the western section show the absence of rock to a depth of from 100 to 200 feet below lake level without reaching the greatest depth, while farther east there are several wells, one of which in the drift is 500 feet. This is equal to 350 feet below the surface of Lake Huron. The location is not, however, in the middle of the old valley. Other buried valleys and channels submerged demonstrate that the lake basins are simply the valleys of a great river and its tributaries of high antiquity before the glacial period.

BURIED VALLEY BETWEEN GEORGIAN BAY AND LAKE ONTARIO.

The distance between Georgian bay and Lake Ontario is about seventy miles, in a direct line. The country is characterized by rising plains, crossed by high transverse ridges of drift trending eastward and westward. Lake Simcoe, with a diameter of twenty miles, is situated between such ridges. These rise from 200 to 550 feet above Lake Huron.

From Georgian bay to Lake Simcoe in a direct line is a distance of twenty-five miles. It is a low, flat country. Rock is known to be absent far below the level of the bay. At Barrie, on the shore of Lake Simcoe, 140 feet above Georgian bay, a well was bored to a depth of 280 feet without penetrating drift. Twenty miles farther inland at Newmarket, and elsewhere, wells were also found reaching below the level of Georgian bay, without finding rock. Southward of Newmarket is a transverse drift ridge beyond which at Richmond hill (217 feet above Georgian bay) a well was sunk 400 feet without penetrating the drift. This proves that the channel is at least 700 feet under the drift ridge and here is a boring reaching to 183 feet below Georgian bay without meeting with rock. Southward of Richmond hill the country falls away to Lake Ontario, and this is channelled by deep ravines showing the absence of rock much below the level of Lake Huron.

Upon the eastern side of Lake Simcoe the country is covered with limestone rising 150 feet above the lake, while on the western side of the broad buried valley are the Niagara limestones. Thus a trough is found which is the continuation of Georgian bay extending southeastward in the direction of Lake Ontario, and parallel to the Niagara escarpment, although the deepest borings, to nearly 200 feet below Georgian bay, have not revealed the floor as they have not been sunk to the underlying rock. This trends toward the most interesting deep channel mentioned page 394, as occurring about twenty miles east of Toronto, to a depth of 474 feet below the surface of Lake Ontario.

The evidence now shows that with the drift removed the Huron-Michigan lakes would be very much lowered below the present level, even if the outlets mentioned had no greater depth than has been ascertained by direct observations. Indeed this is the only line along which channels so deep as this have been found. South of Lake Michigan deep borings also occur, which at one time were thought to be indicative of a Michigan outlet toward the south. More recently Mr. Frank Leverett collected evidence on this subject, and finds the lowest rock floor near the border of Lake Michigan is only about 230 feet below the lake, with the floor having an altitude of 350 feet above sea level. This is not the slightest indication that higher rock does not obtain between it and the Mississippi drainage. Even this level is hundreds of feet above the floor of Lake Michigan. The fiord-like valleys of Green and Grand Traverse bays show by their direction that the ancient drainage of Michigan basin was towards the northeast and not southwest. While borings to the full depth of the buried channel have not been made everywhere, yet they have reached far below that of the present lake surface, and where this method of investigation has been carried sufficiently far the chain of evidence is complete. As in the case of the Erie outlet, newly discovered and described in Chapter XXXVII., such a chain is not suggested in the surface features.

FORMER HIGH ELEVATION OF THE CONTINENT.

In glancing at the features of the Ontario basin the post-glacial deformation has been pointed out. So also deformation of Lake Huron is strongly marked by the raised shore lines, which are nearly horizontal at the southern end of the lake; but they increase in height so that they rise at the rate of nearly four feet per mile to the northeast (Chapter XXV.).

With the post-glacial deformation or warping of the earth's crust removed, by a depression of the raised parts of the plane of the earlier water levels, a considerable difference will be found in the topographic relief on proceeding to the northeast. Such a depression would admit the St. Lawrence estuary with a depth of 500 feet below sea level, where now is found the rocky rim over which the river passes by rapids on its way to the sea. As all the features of the lake basins are those of atmospheric action, such a trough becomes evidence of late high continental elevation of the land. This hypothesis is sustained by the deep channel of the Gulf of St. Lawrence.* Here was a plain now forming the floor beneath sea level. This, being a continuation of the Laurentian valley of fluviatile origin, necessitated

* 'High Continental Elevation preceding the Pleistocene period,' by J. W. Spencer. Bull. Geol. Soc. Am., vol. I., pp. 65-70, 1890.

a high elevation for the lake region, which lasted for long ages. That the continent was raised still higher at a later date is shown by partly explored cañons at the mouth of the Gulf of St. Lawrence, at the mouth of the Gulf of Maine, and many others; but especially that of the Hudson, which I have recently been able to explore in detail. Here the cañon of the Hudson, with a length of fifty miles, has a depth reaching to 4,000 feet below the floor of the continental shelf, and is traceable to a depth of over 7,500 feet below sea level.

According to my working hypothesis, requiring an elevation of the land to a height of 2,000 feet or more, the period of great elevation was very long, during the making of the Laurentian channel through the Gulf and the forming of the valleys of the Great lakes.

Such was the condition of the continent when the lake valleys were completed, before the glacial period. Whatever abrasion and rounding of the abrupt surfaces occurred during that time, the valleys were not ploughed out by glaciers, as shown by the direction of the glaciation on the rock surfaces, which is everywhere oblique to the face of the escarpment. As before mentioned the lake basins were formerly supposed to have been excavated by glaciers, but since the appearance of my earlier papers upon the origin of the basins this subject has been one that has received very little attention, controversy having ceased, interest in the subject has declined. While several geologists have added to our knowledge of the features south of the lake, the revival of the subjects of the basins themselves is seen in a later contribution by Prof, A. W. Grabau.*

In attempting to give a full history of the lake basins from the Palæozoic days he has continued the ancient drainage of the Archæan highlands of Canada, as he supposed it to be, to the

* Bull. N. Y. State Museum, No. 15, 1904. Also 18th Rept. Com. Reserv., Niag., for 1901, pp, 42-54.

latest times preceding the Ice age. In doing this he has drawn some remarkable conclusions. Assuming the country to have been 2,000 feet higher than now, by a process of tilting, he sees a valley running down from Georgian bay to Lake Ontario and joining the main valley of the lake. The course from Georgian bay to Lake Ontario is along that which I have described; then through Lake Ontario, producing a channel valley rising from a depth of about 500 feet below sea level, to more than 700 feet above it. His channel passes up the Dundas valley and beyond.

From the Dundas valley he assumes that there must have been a continuation of the river southwestward to the Erie basin, between exposures of the Devonian and Niagara limestone systems, now 700 or 800 feet above the sea; but it is not certain whether it continued up the Cuyahoga valley at Cleveland or the Maumee and across to the Wabash.

The post-glacial tilting is everywhere to the northeast, consequently this must be disposed of, and in so doing it increases the necessary rise from the deepest part of Lake Ontario to the Erie basin by a considerable amount. Beyond Dundas valley, in the direction which he indicates, there is no channel, but the buried valleys found are those transverse to it. It is now known that the deepest channel between Lake Erie and Lake Ontario is some distance eastward of that observed at Dundas. The topography of the country is entirely against this drainage. The post-glacial warping is a constantly increasing movement, but his channels would require deformation amounting to ten feet per mile if uniform (in excess of that obtaining since the glacial period) of which there is not the slightest evidence; nor would any uniformly progressive deformation give rise to the features which he supposes. In short, Prof. Grabau was not familiar with the geology or topography of the country he attempted to describe. Even if he had supposed the lake basins to have been excavated by glaciers, or if by some internal earth movement the lake basins alone had sunk, the topographic features of this region would not have supported his conclusions. Against all of this is the fact that the channel in the Ontario basin would have to convey waters upward to a height of more than 1,000 feet to the top of the Niagara escarpment, and proportionally would indicate thousands of feet of pre-glacial uplift to the northeast, while we know that the relative elevation there was much lower than now. At the same time this Niagara escarpment everywhere faces a broader and more open country to the northeast, without any suggestion that at the time of the formation of the lakes the country was so high as even the escarpment, but quite the contrary.

The work of Prof. Grabau, to which reference has been made, was intended as a guide to Niagara, and he has assembled into it much valuable information. Whatever were the earlier conditions in the Palæozoic days it is unfortunate that he should have attempted to carry his uniform hypothesis over such vast geological periods down to the time of the completion of the lake plateaus, such as obtained just before the glacial period.

SOUTHERN TRIBUTARIES OF THE ANCIENT LAURENTIAN VALLEYS NOW REVERSED—THE OHIO AND OTHERS.

As found many years ago by Mr. J. F. Carll, the upper branches of the Allegheny formerly emptied into Lake Erie. Later, from the evidence of borings, I suggested that the Upper Ohio, with its tributary the Monongahela, was formerly reversed, draining by way of the Beaver, Mahoning, and Grand River valleys into the Erie basin. This subject was further investigated by Dr. P. Max Foshay,* who named the reversed drainage after the present writer. This named river was again called into question by Prof. I. C. White, but upon further observation by Mr. Leverett the plane of the river was found at a higher level than that which had been questioned, so

* Pre-glacial Drainage, Western Penn., Am. Jour. Sc. iii, vol. xl., pp 397-403, 1890.

that Prof. White reversed his opinion, stating that—'It is now pretty surely established through the work of Carll, Spencer, Foshay, Hice, Chamberlin, Leverett and others that the Monongahela, Lower Allegheny and Upper Ohio waters drained northward into the Lake Erie basin in pre-glacial times.'†

Accordingly, the pre-glacial drainage area of the Erie basin had an extended watershed reaching for a hundred miles into West Virginia, thus the drainage and the whole upper basin of what is now the Ohio river then flowed into the Erie basin.

The Genesee of New York and Pennsylvania was a pre-glacial tributary of Lake Ontario, but its course was blocked at one point which it left, making a new channel for itself before reaching the lake. The modern river passes along a course forming three waterfalls at Rochester. Seneca (605 feet deep or 359 feet below the level of Lake Ontario) and Cayuga lakes were tributary valleys. To these I gave considerable attention when studying the origin of the basin of Lake Ontario, but more recently Prof. R. S. Tarr‡ has called attention to a buried channel at the head of Cayuga lake (435 feet deep) reaching to a depth of 430 feet below its surface, or 274 feet below the level of Lake Ontario. This lake is nearly due south of the deepest point in Lake Ontario (738 feet).

The conclusions as to the origin of the lake basins are that they were the valleys of the ancient Laurentian river and its tributaries, obstructed by deposits of drift and by subsequent warping. These valleys were formed when the continent stood much higher than at present, and the broad valley of the St. Lawrence river extended continuously from the lake region to the plains between New England and the Laurentian mountains; and thence on to the plains now forming the floor of the Gulf of St. Lawrence, traversed by a channel 2,000 feet below

† Am. Geol. vol. xviii., p. 368, 1896.

‡Jour. Geol. vol. xii., pp. 70-73, 1904.

sea level. This deep channel receives tributaries from several directions as has been described.*

The character of the lake basins being now described it will be easier to understand the relationship of the ancient drainage of the Niagara district. The outlets from the Erie valley to the Ontario basin have been deferred in this work, on account of their forming an additional subject beyond their immediate bearing upon Niagara.

* 'High Cootinental Elevation preceding the Pleistocene period,' by J. W. Spencer. Bull. Geol. Soc. Am., vol. i., pp. 65-70, 1890. Also, 'Evidences as to Changes of Sea Level,' Bull. Geol. Soc. Am., vol. vi., pp. 141-166, 1895.

CHAPTER XXXVI.

NIAGARA PENINSULA.

PREFACE.

The discovery of the Falls-Chippawa valley was the result of investigating the nature of the basin at Niagara falls. On account of its depth it demanded a search for its continuation with an outlet into the lower Ontario basin, if such could be found, for no other suggested itself except by the Dundas valley far away. Without finding such outlet, the basin at Niagara falls would have been unintelligible, but would probably have been attributed to glacial erosion. On the other hand the discovery which has been made by following theoretical lines completes a chapter in the Lake History.

FEATURES OF THE NIAGARA PENINSULA.

The Niagara peninsula which separates Lake Erie from Lake Ontario shows a serrated shore line along the northern side of Lake Erie, but if the points be connected by a line this is found to be comparatively straight. On the other hand, while none of the sharp points project into Lake Ontario, yet there is a sweeping indentation in the shore line of the latter, which is deepest between Port Dalhousie and Jordan harbour. Here the embayment indents the shore line by several miles inward of the mouth of the Niagara river. Inside of this shore line is a gently rising plain to the foot of the Niagara escarpment, which at the river is about seven miles from the lake, while at Grimsby, twenty-seven miles to the west, the escarpment is only a mile or less from the shores of Ontario. The foot of the escarpment limited by the plain in front of the Iroquois beach has a height of less than 130 feet at Niagara river. This slightly diminishes on proceeding westward. Near its brow the escarpment has a general elevation of 320 to 340 feet above Lake Ontario, with the watershed generally distant not more than from two to four miles.

Southwest of St. Catharines—that is behind the deepest part of the indentation in the shore of Lake Ontario—there is a large embayment in the Niagara escarpment. (*See* Chapter XXXVII.)

GEOLOGY OF THE PENINSULA.

The Niagara escarpment is formed by the same series of limestones and shales as are described along the gorge of the Niagara river. The limestones give rise to the bold feature. Wherever the small streams cross it picturesque waterfalls occur, with small cañons sometimes a half a mile in length, as along the Beaver Dam creek at De Cou falls, and Twenty-mile creek, south of Jordan. After passing the brow of the escarpment the superficial limestones are usually covered by a considerable depth of drift, with the widest exposure of the rock along the Niagara river.

On the Erie side of the peninsula there is another ridge of limestone buried beneath the plains. This occurs along the Niagara river to a distance of two miles from the lake. At the surface it is generally covered by a thin layer of drift, but at a depth of a few feet it is found. Still the surface of the country south of Lake Erie seldom rises higher than from twelve to twenty feet above the lake, though near Fort Erie it is higher as also near the watershed back of the Niagara escarpment

Upon reaching the surface of the country above the Niagara escarpment the general appearance is that of a remarkably level plain, and to the eye the features are the same all the way from it to the northern side of the low ridge of Corniferous limestone near Lake Erie, although there is a broad basin between these limestone zones underlaid by the soft Salina formation. This is composed of light, or dark or black shales, with or without gypsum nodules, or layers of gypsum and impure limestones, all easily destructible materials. This has given rise to a depression in the rock surface below the country, recognized for more than sixty years. Still it is covered by drift so as to make a continuous plain only a few feet above Lake Erie without showing any depression upon the surface due to the buried features.

ELEVATION OF THE ERIE PLAINS.

These plains are traversed in a western and eastern direction by a creek, which at Chippawa village is ten feet below the level of Lake Erie; at Welland, where it passes under the Welland canal, it is nine feet below the surface of the lake; and at Welland Port, as shown on the map, the creek is still below lake level. The southern part of the peninsula from Dunnville to Welland is traversed by the Feeder canal with the surface of the water eight feet above the lake. Extensive marshes have also continued until recent times, and, although now drained, the surface at many places can not be more than five feet above the lake. This gives a general idea of the flatness of the Niagara peninsula. Some exceptions must be made to this statement.

'SHORT HILLS' AND THE SAND RIDGES.

Sand and gravel ridges occur to a height of 443 feet above Lake Ontario south of St. David (page 215); a similar hill at Lundy Lane, Drummondville (page 212) rises to 465 feet; extending as a ridge to the vicinity of Niagara falls. Another eminence southeast of Chippawa village occurs. The most remakable ridge rises west of Font hill, to 320 feet above Lake Erie. It tapers southwestward for three miles, to near Fenwick, with a breadth of nearly a mile and a quarter, though the higher part does not exceed half a mile. This is entirely composed of drift, which in the deep gullies upon its northern side is shown to be largely composed of stratified clayey sand and gravel, although the higher part of the summit is a sandy clay containing a few boulders and small stones of drift origin. Round the hill occurs a fragment of the Forest beach, formed by wave action upon the material of the hill. Its height is 221 feet above the lake.

The gullies on the northern side of this hill (called the 'mountain') descend and unite with deeper ones which have partly excavated the buried valley. The country is broken up into sharp hills and deep ravines, which are designated the 'Short hills' and so known in history.

The main stream traversing the Niagara plateau has an old name which it received from the Indians, and throughout the country it is everywhere known as Chippawa creek, or 'the creek,' while 'the river' refers to Niagara. By an Order in Council in 1820 the name was officially declared changed to Welland river, yet this has never been adopted locally, though it appears upon late official maps.

Away from the sand ridges mentioned the surface soil is that of clay or sandy clay, with only a few places where bands of surface sand occur. At a few feet below the clay, sands or gravels are found. Where the sands surmount the clays, they are of the nature of beaches. Nowhere on the surface of this country south of Font hill is there any suggestion of buried valleys. This hill, rising higher above the plains, would seem to be opposed to the occurrence of such. (For characteristics of the upper Niagara river district, see Chapter IX.)

GRAND RIVER-DUNDAS VALLEY, ANCIENT DRAINAGE.

Westward of the meridian of Dunnville the land rises to a greater height with more varied features, though underlaid by the Salina formations, over which the Grand river generally flows. About Brantford, there is a deep, broad re-excavated valley forming a strong surface feature.

The northern watershed of the Grand river approaches the margin of high country faced by the Niagara escarpment, as south of Hamilton, where it is 492 feet above Lake Ontario. Near the southern margin of the valley, at Onondaga, is a buried valley to 110 feet, or to a level twenty feet below Lake Erie. To the northward the rocks are absent for a greater depth, as at Jerseyville (about twelve miles from Lake Ontario) where wells are 150 feet deep to rock, or to the level of Lake Erie. Thence to the buried Dundas valley the depth is known to be very great. Near Ancaster the rocky wall of the southern side of the Dundas valley occurs under the drift, which also forms hills in the upper part of the valley. Its breadth, cutting through the limestone escarpment, is two and a half miles, but it partly expands so as to include the plains of Hamilton in an enlargement at the head of Lake Ontario. At Hamilton, the buried Dundas valley reaches 292 feet below the lake level. Here is found to be a deep buried depression through the Niagara formation extending to the buried Salina valley and Lake Erie, with a tributary from the upper part of the Grand river district, also joining it.

The datum plane of this partly explored depression, below that of the present surface of Lake Erie, was further lowered in olden days, before the post-glacial warping which raised the district south of Dundas to a considerable height above the Erie plane.

Before the recent explorations the buried Grand River-Dundas valley was the only known depression between Lake Erie and Lake Ontario capable of lowering the upper lakes provided the drift deposits were removed. But the studies here were among the first investigations made, and they have never since been extended.

Later it became apparent that there was also a shallow depression near the Welland canal sufficient to lower Lake Erie if drift were removed.

When the Falls-Chippawa valley was found to reach far below the surface of Lake Erie, the question of the pre-glacial outlet of the Erie basin required further investigation. (See next chapter).

CHAPTER XXXVII.

DISCOVERY OF THE ERIE OUTLET.

Deep channels about Lake Erie.
Salina basin.
Well-borings.
Southern boundary of Corniferous limestone.
Northern boundary of Niagara limestone, and Thorold depression.
Features of the 'Short Hills' district.
Erigan cañon.
De Cou and Swaze falls.
Erigan channel and buried Erie outlet.
Slope of the Erigan outlet of the Erie basin.
Erigan tributaries.
Crossing of the lake depressions.

DEEP CHANNELS ABOUT LAKE ERIE.

Profound channels buried to depths below the floor of Lake Erie have been mentioned on page 396. They occur to depths of 120 feet or more near Buffalo, and 228 to 400 feet in the vicinity of Cleveland, as illustrating the pre-glacial drainage that formerly obtained beneath the present floor of the lake, which has since been covered with drift deposits. These demanded the discovery of an outlet for what is now the Erie basin.

SALINA BASIN.

It was ascertained that on Grand island (at Sour Grove) wells in drift reached sixty feet, though surface rock occurs on both the northern and southern ends of the island. At Tonawanda the buried rocks are fifty feet below the surface, while at Gatzville, five and a half miles east, a rock floor was shown as ranging from twelve to ninety-six feet deep (near the creek).

The Falls-Chippawa valley was found to reach ninety feet and more below the Erie level. This was deeper than any channel at the Welland canal. The Dundas valley was a long way off, so that further borings were sought for in order to ascertain what was the outlet of the Falls-Chippawa valley.

WELL BORINGS.

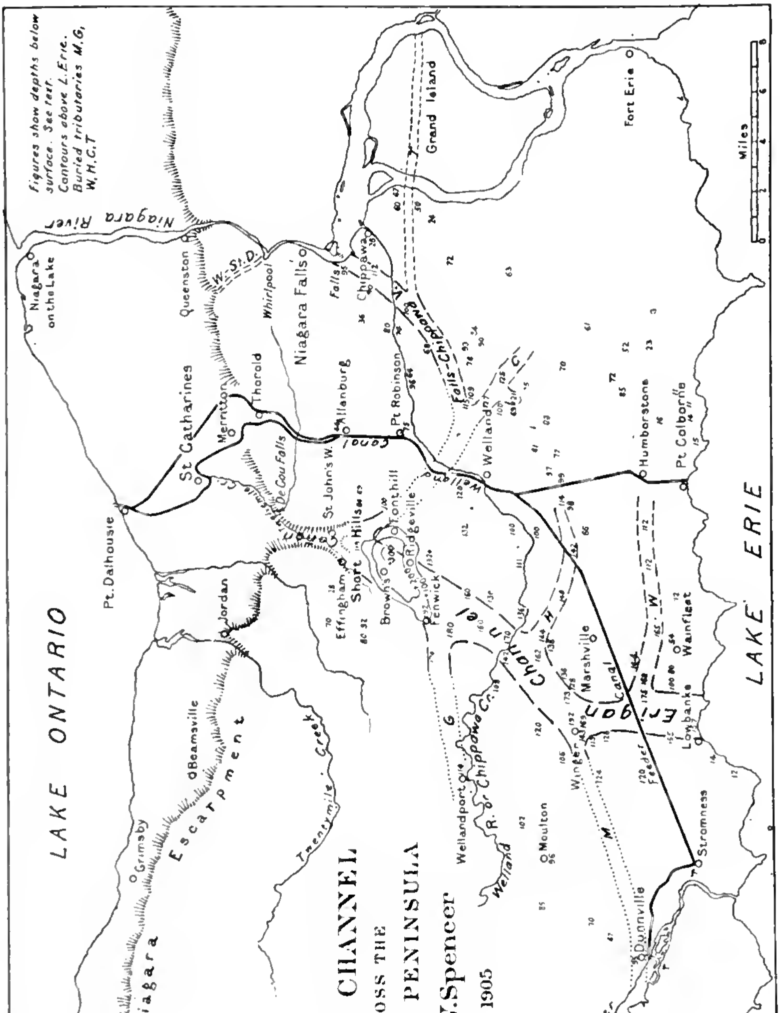
Scattered well-records showed the great depth of the buried valley or basin. Others were found indicating that the deeper parts of the basin did not extend nearly so far as the Dundas valley, although deep wells occurred over the whole distance.

Fortunately, at this time, a great deal of information was obtainable from the recently sunk gas wells, and water wells. The officers of the gas well companies and the water well borers and others were most courteous in placing information at my disposal. Many of the locations of these wells were visited by me in order to ascertain the surface topography.

The positions and depths of the Wells are shown in the map Plate XLI. Their heights above lake level are not given on the map, although many have been determined. Approximately, however, their elevation is known. Thus, the Feeder canal, which is eight feet above the lake, is at many places higher than the level of the country. The main creeks to beyond Welland Port are below lake level, with the banks rising twelve, or in some cases to twenty feet. The country is generally a plain, except at Font hill ridge, on the flank of which is Fenwick well (forty-eight feet above the lake). At the Quaker church the well is at fifty-one feet above the lake. This is just south of Ridgeville. Where not specified the general level south of Ridgeville and Fenwick does not exceed ten to twenty feet. The same may be said to be characteristic everywhere away from the mentioned ridge which rises to over 300 feet above Lake Erie. This hill is shown on the map by contour lines.

Upon the depths of the wells being plotted it became manifest that buried channels could be traced across the floor of the Salina basin. These ranged themselves into a system—a feature that was hardly to be expected without many more borings than were obtained.

PLATE XLI.


ERIGAN CHANNEL
ACROSS THE
NIAGARA PENINSULA
By J.W.Spencer
1905
Figures show depths below surface. See text. Contours above L.Erie. Buried tributaries M,G, W,H,C,T
LAKE ONTARIO
LAKE ERIE
Niagara River
Grand Island
Fort Erie
Miles
Niagara on the Lake
Queenston
Whirlpool
Niagara Falls
Chippawa
Falls-Chippawa
Pt Robinson
Allanburg
Thorold
Merritton
St Catharines
Pt. Dalhousie
De Cew Falls
St. John's W.
Fonthill
Ridgeville
Short Hills
Browns
Effingham
Fenwick
Welland
Humberstone
Pt Colborne
Marshville
Wainfleet
Lowbanke
Wingen
Welland Canal
Feeder
Wellandport
R. or Chippawa Cr.
Moulton
Stromness
Dunnville
Grand River
Jordan
Beamsville
Grimsby
Escarpment
Niagara
Twentymile Creek
Erigan Channel
W.St.D.

SOUTHERN BOUNDARY OF CORNIFEROUS LIMESTONE.

This has a general breadth of about two miles, though somewhat wider on approaching the Niagara river and narrower towards the west. It is two miles in width where crossed by the Welland canal. Its surface is thinly covered with earthy deposits. The northern side of this belt is sharply defined on account of its forming a now buried escarpment of eighty feet or more in height. This feature, all of which is buried, has been brought out by the well borings which reveal the abrupt disappearance of the limestone. The same rocks are occasionally seen upon the lake shore and pass under the shallow waters. Near Lowbank post office there is an embayment in the lake shore about two miles across. Here the shore is faced by sand dunes ten to twenty feet high, with a flat country behind not more than five or six feet above the water. Near the lake shore, east of Lowbank village (on the farm of Cyrenus Barrick) the limestone is entirely wanting, while the well is in drift to a depth of 157 feet or 150 feet below lake level. Another well a little farther inland shows the same absence of rock to a depth of 155 feet. Other wells to the east also indicate that there is no rock to a depth of 100 feet, with the Corniferous limestone ridge just beyond coming to near the surface. In short, the embayment of the shore of Lake Erie owes its form to the present buried valley crossing the belt of limestone. This valley has now been traced across Moulton and Wainfleet townships, but it is situated east of Lowbank village, which is on its western margin. Everywhere beyond Lowbank the limestone approaches the surface and gives character to the lake shore.

NORTHERN BOUNDARY OF NIAGARA, LIMESTONE, AND THE THOROLD DEPRESSION.

At the Niagara river the Niagara limestone belt is nearly seven miles across, and its southern boundary, as determined by well borings, is found to continue nearly due west from Chippawa village and south of Allenburg village, so that in the vicinity of the 'Short hills' it is reduced to an approximate breadth of four miles. This restriction in width, however, is due to an indentation in the brow of the escarpment on the surface of which the rocks appear. But, in going southward, they soon become buried to a moderate depth by drift.

The surface of the mountain facing Lake Ontario is no higher than the level of Lake Erie, or it may be twenty-five feet or more lower. The country behind seldom rises more than twenty-five feet higher. The Font hill 'mountain' already mentioned is only a ridge of drift forming the highest portion of the 'Short hills,' shown on map by contours.

Approaching the southern side of the Niagara limestone zone, two miles south of Allenburg, the wells become deeper and deeper as they pass into the Salina basin. The deep cut of the Welland canal (located south of Allenburg) is thirty-six feet above Lake Erie. At Thorold the rocks are seen adjacent to the canal. However, here is an ancient pre-glacial valley, indenting somewhat the face of the escarpment as if there might once have been a channel drawing waters from the Erie basin. It was formed by a little stream, which made a slight topographic feature in the face of the escarpment, possibly somewhat greater than the Whirlpool-St. David channel already described.

FEATURES OF THE 'SHORT HILLS' DISTRICT.

Westward of Thorold the Niagara escarpment sets still farther southward. For a distance of some twelve miles the trend of the 'mountain' forms an embayment, receding to a depth of three miles in the face of the escarpment. It reaches its farthest point in front of the 'Short hills.' So, also, in front of the indentation just mentioned is a corresponding but much deeper embayment of the shores of Lake Ontario, carved out of soft Medina shales, while the escarpment itself is capped by hard limestone. This indentation is a topographic feature of pre-glacial date due to erosion and it is not a bend in the zone of limestone, but it is cut out of them. Moreover, this embayment begins at a conspicuous promontory east of Merritton, and extends to another one on the western side, nine miles distant, at Jordan. Nor is this incision shown alone upon the face of the escarpment and shore of the lake, but it is seen in the depression on the surface of the country, in that the altitude is reduced twenty-five feet or possibly fifty feet, thus bringing the surface of the country below the level of Lake Erie, in conformity with the slopes of ancient times. At the head of this embayment, beginning at De Cou falls, is a great buried cañon, trending westward of south, but now re-occupied by drift deposits rising from the Bell terrace which crosses the outlet of the gorge. These plains have been extensively eroded and carved into great valleys 100 feet or more in depth, thus forming the 'Short hills,' which on their southern margin rise into the great drift ridge of Font hill already mentioned, which blocks the heads of the valleys.

ERIGAN CANON.

Erigan was the name I gave the buried valley* which traversed the Erie basin in pre-glacial times. It is formed from the Indian word Eriga (Erie). As its continuation across the Niagara peninsula has been discovered the name must be applied here as elsewhere.

The eastern end of the cañon begins near De Cou falls, and lies beneath the broken country just described, along Twelve-mile creek. Even at De Cou falls, known in the early settlement of the country as Beaver Dam falls, the higher rocks are removed to sixty-three feet below the level of Lake Erie, so that the outer margin of the cañon is somewhat farther east beneath the drift covering, as may be found in the shallower wells.

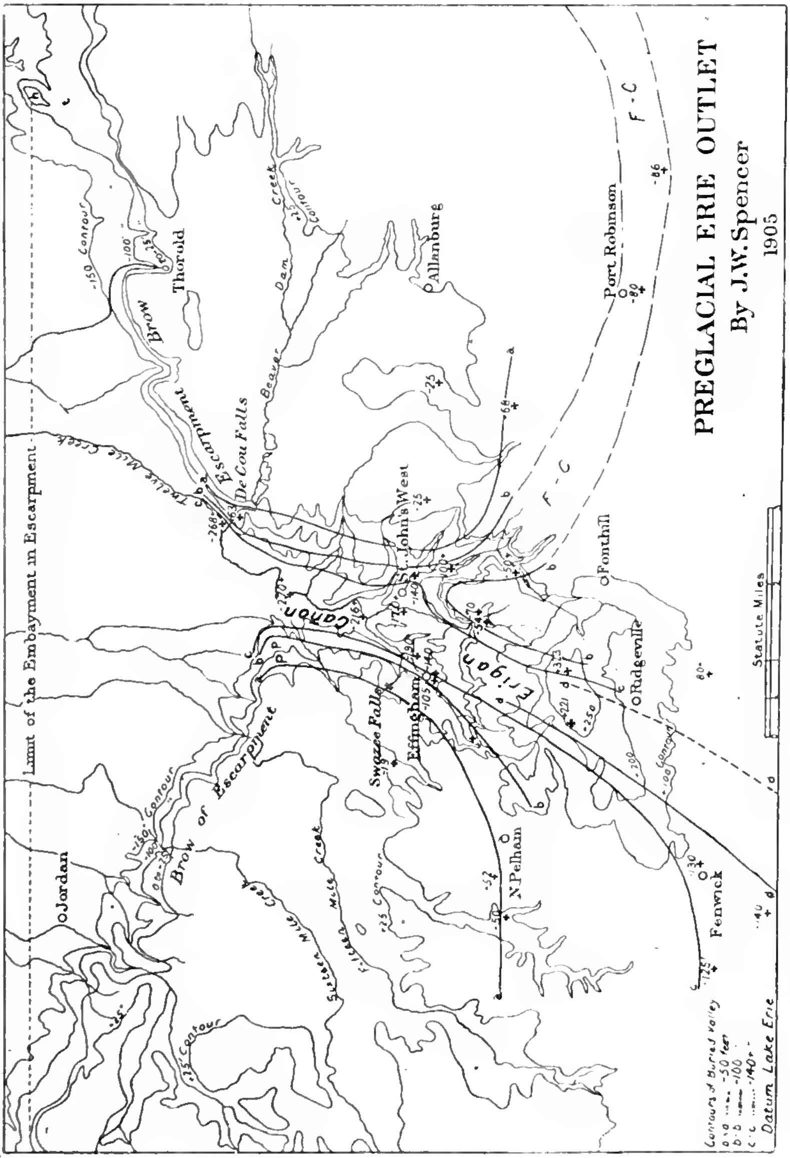
* Proc. A.A.A.S. for 1888, cited before.

At St. Johns West, two and a half miles within the ancient gorge, but upon its rising eastern side, the rocks occur at 140 feet below the Erie level. Beyond this point the valley trends more to the east, and depths of 100 and 68 feet, below Lake Erie, to rock were found at wells, showing that the zone of the Niagara limestone as a surface feature had been penetrated One mile east of St. Johns West the rocks on the right side of the valley have risen 115 feet (or twenty-five feet below the Erie level). (*See* Plate XLII.) Nearer the middle of the buried gorge, at a point two miles inward from De Cou falls, the channel is open to a depth of even 216 feet below the Erie level, with the depth of drift not determined.

On the western side the rock walls are better shown. At the outer point is a conspicuous headland cape. Here also is a step in the old topography, so that there is also an inner wall, as the cañon appears to have been double. The top of the inner gorge is here shown by the rock surface, being 232 feet above Lake Ontario, while the outer at half a mile farther has a height of 280 feet. The country rises higher beyond. In ascending these valleys the lower bench becomes covered with drift, except where lateral streams cross it; while the higher one can easily be traced as an escarpment two and a half miles to the southwest, at Effingham, or three miles and a half from the mouth at De Cou falls. At the Effingham mills the lower bench of rock is seen at 105 feet below the Erie level, while the gully leads down to the deeper valley extending from 140 to 190 feet below the Erie level. Here Medina sandstone of the western slope of the cañon is exposed. Above the mill the limestone rocks of the outer wall of the gorge are slightly exposed, but generally lie buried in drift. This is on the western side of the ancient valley, which has been reopened by streams for a further distance of about a mile towards the southwest, where the surface rises to the level of Lake Erie. From Effingham onward to the southwest, the wells show that the southern edge of the Niagara limestone zone to a depth of fifty feet or more, below the Erie level, has been passed. As a like turning has been found on the eastern side it is evident that the buried outer cañon dissects the hard beds of limestone for a breadth of between two and three miles, while the inner gorge is narrower. (*See* Plates XLI. and XLII.) The hill of deep drift makes exploration difficult, but towards the eastern side a ridge of rock rises to fifty feet below the Erie level, with a deeper channel beyond, where the Electric railroad crosses the great ravine. The borings in ravine to thirty feet do not reach rock. There seems to have been here an ancient tributary. The trend of the principal valley is to the southwest under the western part of the mass of Font hill. With the establishment of the fact that the buried valley crossed the Niagara zone, it was desirable to ascertain if rock formations occurred near the surface upon the southern side of the hill. Accordingly, borings were made at the Quaker church south of Ridgeville, through surface clay of eight feet, and then through quicksand to a depth of 132 feet without reaching rock. Operations were then stopped. It is a great pity that the full depth of the drift was not here definitely ascertained, but the operations were carried to a point eighty feet below the Erie level.

As has been shown, there is an indentation of three miles in the face of Niagara escarpment—a feature which suggests that here was the broad outlet of a great river, in ancient times. At the head of the embayment is now found a cañon more or less buried, with the creek bed within the gorge now reopened to a depth of 270 feet below the Erie level without reaching the rocky floor. For three miles farther in the cañon is the valley opened to 140 feet below Lake Erie, and lesser depths are exposed beyond, until blocked by the great drift ridge, Font hill, beyond which the valley has again been found by borings. This is the cañon section, through the Niagara formation. (*See* Plate XLII.)

PALTE XLII.



Map of Niagara peninsula, showing borings which reveal the ancient outlet of the Erie basin.

The trend of the cañon is slightly oblique to the line across its mouth westward from De Cou falls. As shown in Figure 29, the outer cañon is two miles wide, and the inner a mile and a quarter.

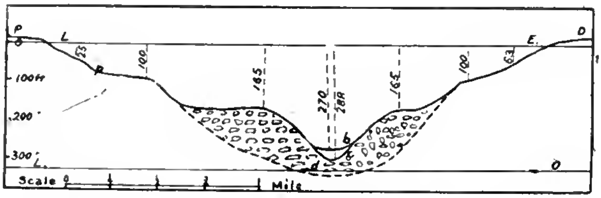


Fig. 29. Section across mouth of Erigan cañon. D., De Cou falls; Pp., points of outlets of outer and inner gorge on western side; L. O., level of Lake Ontario; b., bed of Twelve-mile creek; refilling of gorge to above Bell terrace or 165 feet above Lake Ontario.

There is no similar incision in the Niagara escarpment beyond this point until reaching the Dundas valley. The one at Thorold is comparatively small. No apparent stream could have made the great cañon, or accompanying features.

The country is away from any railway, and being broken with difficult roads it is avoided, although beautiful and fertile. The available maps do not show any topographic features. Accordingly this district has escaped the attention of explorers, or the railway geologists. But the indentation, which might have been suggestive, is further obstructed by Font hill, beyond which upon the surface of the low plains there is not the slightest topographic relief, or geological feature even until reaching Lake Erie, which suggested any buried valley.

DE COU AND SWAZE FALLS.

De Cou falls.—De Cou falls is at the angle which the valley of Twelve-mile creek makes at its exit through the escarpment. The falls are on the Beaver Dam creek, at the outlet of Erigan cañon. After descending from the Power Company's dam, about forty-two feet to the edge of the rock, they fall in three cascades with intervening rapids, the full height of 224 feet.

The cañon which they have made is nearly half a mile long. The upper cataract over the lower Niagara limestones and shales, now cascades about seventy feet; the second from the Clinton beds has a height of forty-five feet; and the third descends over the Medina gray sandstones. The whole is a post-glacial feature of the same age as Niagara falls.

Swaze falls is in a pretty little ravine on a western branch of Twelve-mile creek, three-quarters of a mile north of Effingham. It is partly excavated out of drift material and partly out of the Niagara limestone, with the underlying shales exposed. A little farther down the ravine the thick Clinton band of limestone, overlying a thin layer of Clinton shales, forms a second small fall or rapid. Farther on, some of the upper beds of Medina shale and red sandstone are also seen. The ravine is a tributary to the reopened Erigan cañon.

ERIGAN CHANNEL, OR BURIED ERIE OUTLET.

Turning now to map, Plate XLI., and studying the borings, I was surprised that the evidence, so far obtained, showed not merely a general basin, in the Salina formation, but also channels crossing it, now buried under even as much as 192 feet of drift, where the top of the well is no more than ten or twelve feet above Lake Erie. Accordingly, these borings bring to light a channel 180 feet below the lake level, which has been excavated out of the soft shale rock, while the general depth of the drift filling of the Salina basin is perhaps 100 feet or a little less.

The deep trough seems to have a breadth of about two miles. Lowbank is on the western side of the channel, but here the rock approaches the surface. At no considerable distance to the east a boring in the channel shows a depth to 150 feet below the lake. This also is west of the middle of buried trench. Near Winger many borings have been made, and these are often so close together that they can not be given on the map.

Here the channel reaches to 180 feet below the lake. Farther on, evidently without quite reaching the deepest part, the borings show an absence of rock to a depth of 160 feet. At Fenwick, on the western side, the buried valley was found by two wells (192 feet deep) to reach 134 feet below lake level. From Lake Erie to this point the valley has been located by borings at almost every mile, or at shorter distances. (*See* map, Plate XLI.) The greatest depth should be found between Fenwick and Ridgeville. Following the trend of the buried valley, from Lake Erie to Fenwick, and extending it along the same course, across a gap of only four miles, without direct observation, beneath the great drift mass of Font hill to Effingham, it is now found to be an open cañon whose course is in the same direction. This cañon has already been described. Accordingly the buried channel from the Erie basin across the Niagara peninsula and through the escarpment has now been found.

SLOPE OF THE ERIGAN OUTLET OF THE ERIE BASIN.

The deepest part of Lake Erie is twenty-seven miles south of Lowbank (as shown in the longitudinal section, fig. 30). The post-glacial rise of the region is about a foot and a half per mile in a northeastward direction (determined from the elevation of Forest beach at Brown's nursery, Font hill, and at Sheridan and Crittenden, N.Y.). The post-glacial rise at the western end of Lake Ontario is two feet per mile N. 25° E. Making corrections for post-glacial deformation it reduced the bed of the known channel at Lowbank, on its western side, to 190 feet; at Winger to 228 feet; at Fenwick on the western side, to 194 feet; and even at the Quaker church on the eastern side, where the well was not carried to rock, the depth is now known to more than 140 feet below the level of Lake Erie. As has been

* Proc. Am. Assoc. Ad. Sc., Vol. xxxii., p. 199, for 1888.

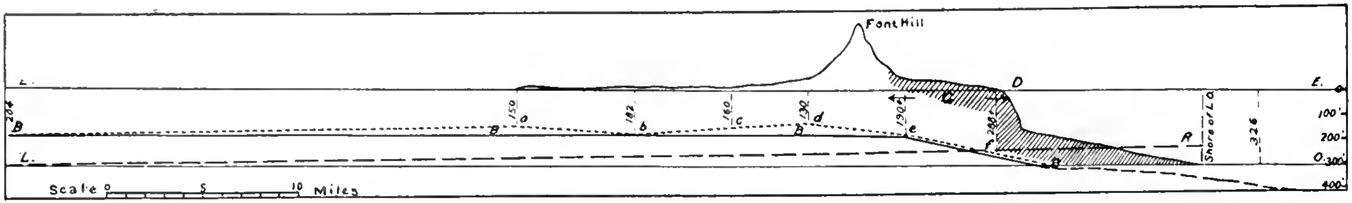


Fig. 30. Longitudinal section of Erigan channel across the Niagara plateau (a to D) via Lowbank and Effingham. L. E., level of Lake Erie; L. O., level of Lake Ontario. Deepest part of Lake Erie at 204. Shore of Lake Erie at (a). Here borings in drift reached 150 feet below lake level; (b) 180 feet at Winger; (c) 160 feet deep, towards eastern side of valley; (d) 130 feet on western side at Fenwick; (e) 190 feet in open gully at Effingham on west side; (f) 288 feet in bed of stream within end of cañon (C); all depths below the level of Lake Erie; L. R. represents post-glacial tilting; with which line again depressed to the water plane, the pre-glacial channel bed B B B B must be compared.

shown the depth of Lake Erie is only 204 feet. This channel is thus found to reach below the floor of the lake. Again in the creek bottom at Effingham (three miles within the gorge from De Cou falls) the open valley is now 255 feet below the Erie level, without reaching its rocky floor.

Accordingly I have been able to obtain data which conclusively establishes the existence of a buried channel from one to two miles wide crossing the Niagara plateau and dissecting the escarpment to a great depth.

As there has been a post-glacial uplift in Forest beach, of 121 feet between Cleveland and Font hill, of which only sixty feet pertains to the region between Cleveland and the deepest part of the lake, the other sixty feet belonged to the stretch between the 204 foot sounding and Font hill. By this amount the original outlet of the Erie basin was lowered in pre-glacial days below that of the present level. Accordingly, the floor of the open valley, without reaching bed rock, now within the limits of the buried gorge, represents a level of 305 feet below deepest sounding in Lake Erie. At the same time, there was a somewhat greater post-glacial change in the levels than that which has been measured. From these measurements the buried Erigan channel is found to reach to a depth more than sufficient to have drained the Erie basin in pre-glacial days.

ERIGAN TRIBUTARIES.

The Erigan channel is found to be not the only one upon the surface of the Salina formations. A considerable number of channels have now been located. There is one from the region to the west of the Erigan, approximately along the present drainage creek, which at Welland port is 100 feet below the Erie level. Another tributary valley is adjacent to Grand river, with an equal depth, which extends eastward and joins the Erigan, while the modern Grand river leaves its ancient course and passes over a rocky zone below Dunnville. (*See* map, Plate XLI.)

Again, from the eastward, a buried tributary has been found along the northern foot of the buried Corniferous escarpment and another still farther north and parallel to it; also one in New York adjacent to the Tonawanda creek. This crosses Grand island and extends westward to the Erigan channel already described; but on its way the Falls-Chippawa valley joins it. This was the feature which led to the discovery of the buried valleys, which gave the true explanation of the Upper rapids of Niagara river. Another tributary from the southeast is traced through Welland (town) joining the one just mentioned, which as a broad valley enters the southeastern side of Erigan cañon, south of St. Johns West; and at the same time rounding off the corner of the Niagara limestone belt. (*See* map, Plate XLII.)

The buried Buffalo creek joined the Erigan, or some tributary to it now buried under the floor of Lake Erie. The ancient Carll or Allegheny crossed the present lake basin directly to the débouchure at Lowbank, while the Spencer or reversed Ohio entered the Erie farther west. These rivers are shown on Map, Plate XL. The depth of the Buffalo buried valley is much greater than that near Welland. The trench through the Corniferous limestone, now occupied by the Niagara river just below the present outlet of Lake Erie, was a low col between a small valley tributary to Buffalo creek channel, and another joining the valley passing by Welland.

CROSSING OF THE LAKE DEPRESSIONS.

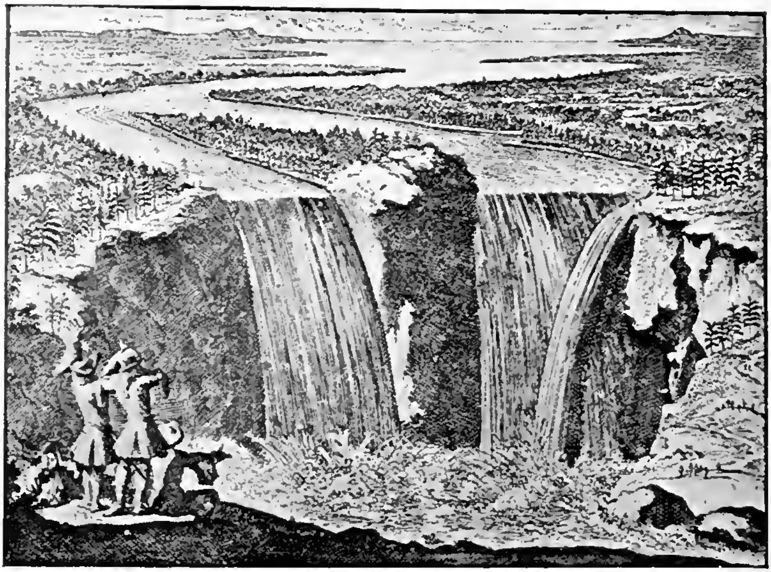
In pre-glacial times, the Erie formed a long trough, as today, with another one parallel to it in the Salina formation, but separated by the ridge of Corniferous limestone on the southern side of the present lake shore. The central Salina basin was separated by a prominent ridge protected by the Niagara limestone from the parallel Ontario basin, which last is excavated out of softer shaly rocks. The Corniferous range was dissected at Lowbank and at Niagara river. The Niagara highlands were incised by the trough or valley at Dundas, another little one near Welland canal at Thorold, and the great transverse Erigan channel and cañon, here for the first time described.

The Erigan channel crossing and connecting three parallel basins is a repetition of the feature of the Delaware river dissecting mountain ridges and also crossing the intervening valleys, of the Appalachian mountain system.

All of these features of the pre-glacial topography of the region described have been so concealed with drift and terrestrial warping as to have only slowly come to light.

The Wainfleet Marsh.—The great marshes of Wainfleet, and other lowlands in Niagara peninsula south of the escarpment, are of the latest origin—having been produced by the flooding of the lake region owing to the tilting of the land which raised the barrier at the outlet of Lake Erie, so that the waters rose more than 100 feet in the Erie basin. These at a recent date flooded the marshes mentioned, though now again the plains have emerged owing to the cutting down of the barrier at the outlet of Lake Erie, where may be seen the terrace of the town of Fort Erie, the height of which, with steep bluff behind it, is from five to eight feet above the river. This terrace is even cut out of limestone which occur at the southern end of the town, as well as out of drift deposits.

APPENDICES



Niagara Falls as represented by Father Hennepin who saw them in 1678.
Date of print 1697.

APPENDIX I.

EARLY DESCRIPTIONS OF NIAGARA FALLS.

(For early discoveries and name, *see* Appendix VIII.)

(A)

HENNEPIN'S DESCRIPTION OF NIAGARA FALLS.

(seen 1678)*

'A description of the Falls of the river Niagara, which is to be seen betwixt the Lake Ontario and that of Erie.'

'Betwixt the Lake Ontario and Erie there is a vast and prodigious column of water, which falls down after a surprising and astonishing manner, inasmuch that the Universe does not afford a parallel. 'Tis true Italy and Swedenland boast of some such things; but we may well say that they are sorry patterns when compared to this of which we now speak.

At the foot of the horrible precipice we meet with the Niagara river, which is not above a quarter of a league broad, but is wonderfully deep in some places. It is so rapid above the descent that it violently hurries down the wild beasts while endeavouring to pass it to feed on the other side, they not being able to withstand the force of its current, which invariably casts them headlong about six hundred foot high.

This wonderful downfall is composed of two great cross streams of water, and two falls, with an isle sloping along the middle of it. The waters which fall from this horrible precipice, do foam and boil after the most hideous manner imaginable, making an outrageous noise more terrible than that of thunder; for when the wind blows out of the south, their dismal roaring may be heard more than fifteen leagues off.

The river having thrown itself down the incredible precipice continues its impetuous course for two leagues together to the Great Rock above mentioned, with inexpressible rapidity: But having past that, its impetuosity relents, gliding along more

*London Edition of 1698. (Chapter VII.)

gently for other two leagues, till it arrives at Lake Ontario, or Frontenac.

Any boat or greater vessel may pass from the Fort to the foot of the high Rock above mentioned. This Rock lies to the westward, and is cut off from the land by the river Niagara, about two leagues farther down than the great Fall: for which two leagues the people are obliged to transport their goods overland by the way very good: and the trees are but few, chiefly firs and oaks.

From the Great Fall unto this Rock, which is to the west of the river, the two brinks of it are so prodigious high that it would make one tremble to look steadily upon the water, rolling along with a rapidity not to be imagined. Were it not for this great cataract which interrupts navigation they might sail with barks or greater vessels more than four hundred and fifty leagues, crossing the Lake of Huron, and reaching the farther end of Lake Illinois; which two lakes we may easily say are little seas of fresh water.'

(Reprinted from a photographic plate of the original in Report of New York State Survey, 1879.)

(B)

A LETTER FROM MR. KALM, A GENTLEMAN OF SWEDEN, NOW ON HIS TRAVELS IN AMERICA, TO HIS FRIEND IN PHILADELPHIA; CONTAINING A PARTICULAR ACCOUNT OF THE GREAT FALL OF NIAGARA.*

(This is the earliest account of Niagara falls written in English.)

ALBANY, September 2, 1750.

'SIR,—After a pretty long journey made in a short time, I am come back to this town. You may remember, that when I took my leave of you, I told you, I would this summer, if time permitted, take a view of *Niagara* Fall, esteemed one of the greatest curiosities in the World. When I came last year from *Quebec,* you enquir'd of me several particulars concerning this

*This is not published in the Travels of the author, but appears in Appendix to Travels of John Bartram, from Pensilvania to Onondaga, Oswego and Lake Ontario. (J. Whiston and B. White, Fleet St., London, 1851).

fall; and I told you what I heard of it in *Canada,* from several *French* gentlemen who had been there; but this was still all hearsay; I could not assure you of the truth of it, because I had not then seen it myself, and so it could not satisfy my own, much less your curiosity. Now, since I have been on the spot, it is in my power to give you a more perfect and satisfactory description of it.

After a fatiguing travel, first on horseback thro' the country of the *Six Indian Nations,* to *Oswego,* and from thence in a Canoe upon lake *Ontario,* I came on the 12th of *August* in the evening to *Niagara* Fort. The French there seemed much perplexed at my first coming, imagining I was an *English* officer, who under pretext of seeing *Niagara* Falls, came with some other view; but as soon as I shew'd them my passports, they changed their behaviour, and received me with the greatest civility. *Niagara* Fall is six *French* leagues from *Niagara* Fort. You first go three leagues by water up *Niagara* river, and then three leagues over the carrying place. As it was late when I arriv'd at the Fort, I could not the same day go to the Fall, but I prepar'd myself to do it the next morning. The commandant of the Fort, Monsr. *Beaujon,* invited all the officers and gentlemen there to supper with him. I had read formerly almost all the authors that have wrote any thing about this Fall; and the last year in *Canada,* had made so many enquiries about it, that I thought I had a pretty good idea of it, and now at supper requested the gentlemen to tell me all they knew and thought worth notice relating to it, which they accordingly did. I observed that in many things they all agreed, in some things they were of different opinions, of all which I took particular notice. When they had told me all they knew, I made several queries to them concerning what I had read and heard of it, whether such and such a thing was true or not and had their answers on every circumstance. But as I have found by experience in my other travels, that very few observe nature's works with accuracy, or report the truth precisely, I cannot now be entirely satisfied without seeing with my own eyes whenever 'tis in my power. Accordingly the next morning, being the 13th of August, at break of day, I set out for the Fall. The commandant had given orders to two of the Officers of the Fort to go with me and show me every thing, and also sent by them an order to Mons. *Jonqueire,* who had liv'd ten years by the carrying-place, and knew every thing worth notice of the Fall, better than any other person, to go with me, and show and tell me whatever he knew.

A little before we came to the carrying-place, the water of the *Niagara* river grew so rapid that four men in a light birch canoe had much difficulty to get up thither. Canoes can go half a league above the beginning of the carrying-place, tho' they must work against a water extremely rapid; but higher up it is quite impossible, the whole course of the water for two leagues and a half up to the great Fall, being a series of smaller Falls, one under another, in which the greatest Canoe or Battoe would in a moment be turn'd upside down. We went ashore, therefore, and walk'd over the carrying-place, having besides the high and steep side of the river, two great hills to ascend, one above the other. Here on the carrying-place I saw above 200 *Indians,* most of them belonging to the *Six Nations,* busy in carrying packs of furs, chiefly of deer and bear, over the carrying-place. You would be surpriz'd to see what abundance of these things are brought every day over this place. An *Indian* gets 20 pence for every pack he carries over, the distance being three leagues. Half an hour past 10 in the morning we came to the great Fall, which I found as follows: To the river (or rather strait), runs here from S.S.E. to N.N.W. and the rocks of the great Fall cross it, not in a right line; but forming almost the figure of a semicircle or horseshoe.

Above the Fall, in the middle of the river is an island, lying also S.S.E. and N.N.W. or parallel with the sides of the river; its length is about seven or eight french arpents (an arpent being 180 feet). The lower end of this Island is just at the perpendicular edge of the Fall. On both sides of this island runs all the water that comes from the lakes of *Canada,* viz.: Lake *Superior,* Lake *Michigan,* Lake *Huron,* and Lake *Erie,* which you know are rather small seas than lakes, and have besides a great many large rivers that empty their water in them, of which the greatest part come down this *Niagara* fall. Before the water comes to this island, it runs but slowly, compared with its motion when it approaches the island, where it grows the most rapid water in the World, running with a surprising swiftness before it comes to the Fall; it is quite white, and in many places is thrown high up into the air! The greatest and strongest battoes would here in a moment be turned over and over. The water that goes down on the west side of the island is more rapid, in greater abundance, whiter, and seems almost to outdo an arrow in swiftness. When you are at the Fall, and look up the river, you may see that the river above the Fall is every where exceeding steep, almost as the side of a hill. When all this water comes to the very Fall, there it throws itself down perpendicular! It is beyond all belief the surprise when you see this! I cannot with words express how amazing it is! You cannot see it without being quite terrified; to behold so vast a quantity of water falling from a surprising height! I doubt not but you have a desire to learn the exact height of this great Fall. Father *Hennepin,* supposes it 600 Feet perpendicular; but he has gained little credit in *Canada*; the name of honour they give him there, is *un grand Menteur,* or *The great Liar*; he writes of what he saw in places where he never was. 'Tis true he saw this Fall: but as it is the way of some travellers to magnify every thing, so has he done with regard to the fall of *Niagara.* This humour of travellers, has occasioned me many disappointments in my travels, having seldom been so happy as to find the wonderful things that had been related by others. For my part, who am not fond of the Marvellous, I like to see things just as they are, and so to relate them. Since Father Hennepin's time, this Fall, by all accounts that have been given of it, has grown less and less; and those who have measured it with mathematical instruments find the perpendicular fall of the water to be exactly 137 feet. Monsr. *Morandrier,* the king's engineer in Canada, assured me, and gave it me also under his hand, that 137 Feet was precisely the height of it; and all the *French* Gentlemen that were present with me at the Fall, did agree with him, without the least contradiction· it is true those who have tried to measure it with a line, find it sometimes 140, sometimes 150 feet, and sometimes more; but the reason is, it cannot that way be measured with any certainty, the water carrying away the Line. When the water is come down to the bottom of the rock of the Fall, it jumps back to a very great length in the air; in other places it is white as milk or snow; and all in motion like a boiling chaldron. You may remember to what a great distance *Hennepin* says the noise of this great Fall may be heard. All the gentlemen who were with me, agreed, that the farthest one can hear it, is 15 leagues, and that very seldom. When the air is quite calm, you can hear it to *Niagara* Fort; but seldom at other times, because when the wind blows, the waves of Lake *Ontario* make too much noise there against the Shore. They informed me, that when they hear at the Fort the noise of the Fall, louder than ordinary, they are sure a North East Wind will follow ,which never fails; this seems wonderful, as the Fall is South West from the Fort: and one would imagine it to be rather a sign of a contrary wind. Sometimes, 'tis said, the Fall makes a much greater noise than at other times; and this is looked upon as a certain mark of approaching bad weather, or rain; the *Indians* here hold it always for a sure sign. When I was there it did not make an extraordinary great noise· just by the Fall we could easily hear what each other said, without speaking much louder than common when conversing in other places. I do not know how others have found so great a noise here, perhaps it was at certain times, as above-mentioned. From the Place where the water falls, there rise abundance of vapours, like the greatest and thickest smoak, sometimes more, sometimes less: these vapours rise high in the air when it is calm, but are dispersed by the wind when it blows hard. If you go nigh to this vapour or fog, or if the wind blows it on you, it is so penetrating that in a few minutes you will be as wet as if you had been under water. I got two young *Frenchmen* to go down, to bring me from the side of the Fall at the bottom, some of each of the several kinds of herbs, stones and shells they should find there; they returned in a few minutes, and I really thought they had fallen into the water: they were obliged to strip themselves quite naked, and hang their clothes in the sun to dry. When you are on the other East side of the Lake *Ontario,* a great many leagues from the Fall, you may, every clear and calm morning, see the vapours of the Fall rising in the air; you would think all the woods thereabouts were set on fire by the *Indians,* so great is the apparent smoak. In the same manner you may see it on the West side of the Lake Erie, a great many leagues off.

Several of the French gentlemen told me that when birds come flying into this fog or smoak of the fall, they fall down and perish in the Water; either because their wings are become wet, or that the noise of the fall astonishes them, and they know not where to go in the Dark; but others were of opinion, that seldom or never any bird perishes there in that manner; because, as they all agreed, among the abundance of birds found dead below the fall, there are no other sorts than such as live and swim frequently in the water; as swans, geese, ducks, water-hens, teal, and the like. And very often great flocks of them are seen going to destruction in this manner: they swim in the river above the fall, and so are carried down lower and lower by the water, and as water-fowl commonly take great delight in being carried with the stream, so here they indulge themselves in enjoying this pleasure so long, till the swiftness of the water becomes so great, that 'tis no longer possible for them to rise, but they are driven down the precipice, and perish. They are observed when they draw nigh to the fall, to endeavour with all their might to take wing and leave the water, but they cannot. In the months of *September* and *October*, such abundant quantities of dead waterfowl are found every morning below the Fall, on the shore, that the garrison of the fort for a long time live chiefly upon them; besides the fowl they find also several sorts of dead fish, also deer, bears, and other animals which have tried to cross the water above the fall; the larger animals are generally found broken to pieces. Just below the fall of the water is not rapid, but goes all in circles, and whiter, like a boiling pot; which however doth not hinder the Indians going upon it in small canoes a fishing; but a little lower begins the smaller fall. When you are above the fall, and look down, your head begins to turn; the *French* who have been here 100 times, will seldom venture to look down, without at the same time keeping fast hold of some tree with one hand.

It was formerly thought impossible for any body living to come at the island that is in the middle of the fall: but an accident that happened twelve years ago, or thereabouts, made it appear otherwise; the history is this. Two *Indians* of the *Six Nations* went out from Niagara Fort, to hunt upon an island that is in the middle of the river, or strait, above the great fall, on which there used to be abundance of deer. They took some *French* brandy with them, from the fort, which they tasted several times as they were going over the carrying place; and when they were in the canoe, they took now and then a dram, and so went along up the strait towards the island where they proposed to hunt; but growing sleepy, they laid themselves down in the canoe, which getting loose drove back with the stream, farther and farther down till it came nigh that island that is in the middle of the fall. Here one of them, awakened by the noise of the fall, cries out to the other, that they were gone! yet they tried if possible to save life. This island was nighest, and with much working they got on shore there. At first they were glad; but when they had considered every thing, they thought themselves hardly in a better state than if they had gone down the fall, since they had now no other choice, than either to throw themselves down the same, or to perish with hunger. But hard necessity put them on invention. At the lower end of the island the rock is perpendicular, and no water is running there. This island has plenty of wood, they went to work directly and made a ladder or shrouds of the bark of lindentree, (which is very tough and strong,) so long 'till they could with it reach the water below; one end of this bark ladder they tied fast to a great tree that grew at the side of the rock above the fall, and let the other end down to the water. So they went down along their new-invented stairs, and when they came to the bottom in the middle of the fall, they rested a little; and as the water next below the fall is not rapid, as before mentioned, they threw themselves into it, thinking to swim on shore. I have said before, that one part of the fall is on one side of the island, the other on the other side. Hence it is, that the waters of the two cataracts running against each other, turn back against the rock that is just under the island. Therefore, hardly had the *Indians* began to swim, before the waves of the eddy threw them with violence against the rock from whence they came. They tried it several times, but at last grew weary; and being often thrown against the rock they were much bruis'd and the skin of their bodies torn in many places. So they were obliged to climb up their stairs again to the island, not knowing what to do. After some time they perceived Indians on the shore, to whom they cried out. These saw and pity'd them, but gave them little hopes of help; yet they made haste down to the fort, and told the commander where two of their brethern were. He persuaded them to try all possible means of relieving the two poor Indians; and it was done in this manner. The water that runs on the east side of this island is shallow, especially a little above the island towards the eastern shore. The commandant caused poles to be made and pointed with iron; two *Indians* determined to walk to this island by the help of these poles, to save the other poor creatures, or perish themselves. They took leave of all their friends as if they were going to death. Each had two such poles in his hands, to set against the bottom of the stream, to keep them steady. So they went and got to the island, and having given poles to the two poor *Indians* there, they all returned safely to the main. Those two *Indians* who in the above mentioned manner were first brought to this island, are yet alive. They were nine days on the island, and almost starved to death.*

Now since the way to this island has been found, the *Indians*

* These Indians had better fortune than ten or twelve Utowawas, who attempting to escape here the pursuit of their enemies of the Six Nations, were carried down the cataract by the violence of the stream and every one perished. . . . No part even of their canoe being ever seen again.

go there often to kill deer, which having tried to cross the river above the fall were driven upon the island by the stream; but if the King of *France* would give me all *Canada,* I would not venture to go to this island; and were you to see it, Sir, I am sure you would have the same sentiment. On the west side of this island are some small islands or rocks of no consequence. The east side of the river is nearly perpendicular, the west side more sloping. In former times a part of the rock at the Fall which is on the west side of the island, hung over in such a manner, that the water which fell perpendicularly from it, left a vacancy below, so that people could go under between the rock and the water; but the prominent part some years since broke off and fell down; so that there is now no possibility of going between the falling water and the rock, as the water now runs close to it all the way down. . . . The breadth of the Fall, as it runs into a semicircle, is reckon'd to be about 6 Arpents. The island is in the middle of the Fall, and from it to each side is almost the same breadth; the breadth of the island at its lower end is two-thirds of an Arpent, or thereabouts. . . Below the Fall in the holes of the rocks, are great plenty of Eels, which the *Indians* and the *French* catch with their hands without other means; I sent down two *Indian* boys, who directly came up with about twenty fine ones. . . Every day, when the Sun shines, you see here from 10 o'clock in the morning to 2 in the afternoon, below the Fall, and under you, when you stand at the side over the Fall, a glorious rainbow and sometimes two rainbows, one within the other.

I was so happy to be at the Fall on a fine clear day, and it was with great delight I view'd this rainbow, which had almost all the colours you see in the rainbow in the air. The more vapours, the brighter and clearer is the rainbow. I saw it on the East side of the Fall in the bottom under the place where I stood, but above the water. When the wind carries the vapours from that place, the rainbow is gone, but appears again as soon as new vapours come. From the Fall to the landing above the Fall, where the canoes from Lake *Erie* put on shore, (or from the Fall to the upper end of the carrying-place) is half a mile. Lower the canoes dare not come, lest they should be obliged to try the fate of the two *Indians,* and perhaps with less success. . They have often found below the Fall pieces of human bodies, perhaps of drunken Indians, that have unhappily come down the Fall. I was told at *Oswego,* that in *October,* or thereabouts, such plenty of feathers are to be found here below the Fall, that a man in a day's time can gather enough of them for several beds, which feathers they said came off the birds kill'd at the Fall. I asked the *French*, if this was true? They told me they had never seen any such thing, but that if the feathers were pick'd off the dead birds, there might be such a quantity. The *French* told me they had often thrown whole great trees into the water above, to see them tumble down the Fall. They went down with surprising swiftness, but could never be seen afterwards; whence it was thought there was a bottomless deep or abyss just under the Fall. I am also of Opinion that there must be a vast deep here; yet I think if they had watched very well, they might have found the trees at some distance below the Fall. The rock of the Fall consists of a grey limestone.

Here you have, Sir, a short but exact description of this famous *Niagara* cataract: you may depend on the truth of what I write. You must excuse me if you find in my account no extravagant wonders. I cannot make nature otherwise than I find it. I had rather it should be said of me in time to come, that I related things as they were, and that all is found to agree with my Description; than to be esteem'd a false Relater. I have seen some other things in this my journey, an account of which I know would gratify your curiosity; but time at present will not permit me to write more; and I hope shortly to see you. I am, &c.

PETER KALM.

(C)

DESCRIPTION OF THE FALLS OF NIAGARA

BY

ANDREW ELLICOTT IN 1789*.

Among the many natural curiosities which this country affords the cataract of Niagara is infinitely the greatest. In order to have a tolerable idea of this stupendous fall of water it will be necessary to conceive that part of the country in which

* In a letter from Andrew Ellicott, Esq., to Dr. Rush, of Philadelphia. Illustrated by a well engraved view of the Falls, delineated by Mr. Ellicott. Massachusetts Magazine, July, 1790, pp. 387-388. (Note.—The illustration can scarcely be considered as good.)

Lake Erie is situated to be elevated above that which contains Lake Ontario about three hundred feet. The slope which separates the upper and lower country is generally very steep and in many places almost perpendicular. It is formed by horizontal strata of stone, great part of which is what we commonly call limestone.

The slope may be traced from the north side of Lake Ontario, near the bay of Toronto, round the west end of the lake; thence its direction is generally east, between Lake Ontario and Lake Erie. It crosses the strait of Niagara, and the Cheneseco river, after which it becomes lost in the country towards the Seneca lake. It is to this slope that the country is indebted, both for the cataract of Niagara and the great falls of the Cheneseco.

The cataract of Niagara was formerly down at the northern side of the slope, near to that place which is now known by the name of the Landing; but from the great length of time, added to the great quantity of water and distance which it falls, the solid stone is worn away for about seven miles up towards Lake Erie, and a chasm is formed which no person can approach without horror. Down this chasm the water rushes with a most astonishing velocity, after it makes the great pitch. In going up the road near this chasm the fancy is constantly engaged in the contemplation of the most romantic and awful prospects imaginable ,until, at length the eye catches the falls—the imagination is instantly arrested, and you admire in silence! The river is about one hundred and thirty poles wide, at the falls, and the perpendicular pitch one hundred and fifty feet. The fall of this vast body of water produces a sound which is frequently heard at the distance of twenty miles, and a sensible tremulous motion in the earth for some poles round*.

A heavy fog, or cloud, is constantly ascending from the falls, in which rainbows may always be seen when the sun shines. This fog, or spray, in the winter season falls upon the neighbouring trees where it congeals, and produces a most beautiful crystalline appearance. This remark is equally applicable to the falls of the Cheneseco. The difficulty which would

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*It is said by those who have visited the stupendous cataract that the descent into the chasm is exceedingly difficult, because of the great height of the banks. A person, having descended, however, may go up to the bottom of the falls, and take shelter behind the torrent, between the falling water and the precipice, where there is a space sufficient to contain a number of people, in perfect safety; and where conversation may be carried on, without much interruption from the noise which is less here than at a considerable distance. This is not unworthy the attention of the philosophic reader.

attend leveling the rapids in the chasm prevented my attempting it; but I conjecture the water must descend at least sixty-five feet. The perpendicular pitch at the cataract is one hundred and fifty feet; to these add fifty-eight feet, which the water falls in the last half mile, immediately above the falls, and we have two hundred and seventy-three feet, which the water falls in a distance of about seven miles and a half. If either ducks or geese inadvertently alight in the rapids above the cataract, they are incapable of getting on the wing again, and are instantly hurried on to destruction.

There is one appearance at this cataract worthy of some attention and which I do not remember to have seen noted by any writer. Just below the great pitch the water and foam may be seen puffed up in spherical figures, nearly as large as common cocks of hay; they burst at the top and project a column of spray to a prodigious height; they then subside and are succeeded by others, which burst in like manner. This appearance is most conspicuous about half way between the island that divided the falls, and the west side of the strait, where the largest column of water descends.

I am, etc.,

Andrew Ellicott.

Niagara, December 10, 1789.

Mr. Ellicott's estimate of the age of Niagara is not given here, but it is found in the 'Journal of William Maclay,' (Appleton's, 1890.) This memorandum of Mr. Maclay, expressing astonishment, was made in 1789. (*See* page 20.)

APPENDIX II.

SURVEY NOTES OF THE RECESSION OF THE FALLS.

Prof. Hall's survey, which was the first made for determining the recession, must remain the starting point; and, accordingly, his map is reproduced in Plate v.

He and subsequent surveyors have left certain permanent monuments, to which I have added others. Only a few of these need be preserved, and the following is a list of them:—

Stations. T. P. No. 6, 1842 (Hall).—A square-topped stone monument about six inches across, rising seven inches above ground, in the path along the bluff on the southern side of Goat island, opposite the apex of the Canadian falls. A rude figure "6" appears on the northern side

M. 1890 (Kibbe).—A stone monument in edge of gravel walk at the head of the path leading to Terrapin rock on the southwestern side of Goat island; now covered with ten inches of gravel, but at present accessible through a small tile pipe. I used a station "S" 493.5 feet from T. P. 6, (which is an excellent point). "S" is almost identical with "M."

Loretto. 1886 (Woodward).—A brass screw one-half inch in diameter set into tin deck of cupola on Convent, directly under centre of cross. This station, which has an altitude of 192.5 feet above the bench mark at Table Rock House, is one of the best for observation. The top of the screw is marked by a cross.

G. 1890 (Kibbe).—Brass bolt one inch in diameter near edge of cliff 262.5 feet from the southeast corner of Table Rock House, and thirteen feet from crest line. The ground at this point has been covered by several feet, with a stone wall in front. However, a cast iron pipe about ten inches in diameter surrounds it and rises above the rocks near the pump house.

D. 1904-1905 (Spencer).—This monument of stone is six inches square with brass bolt. It is marked G. S. D. This is in the centre of the sidewalk about sixty-four feet south of the northeast corner of Loretto grounds. It was originally used by the Electrical Development Company, and is 123.0 feet above the bench mark at Table Rock House.

C. 1904-1905 (Spencer).—Brass bolt in stone monument six inches square marked G.S.C. on the brow of the hill above the Michigan Railway terrace (Falls View) 930 feet northward of Station D, between which points base line was taken. It was also an Electrical Development Company station. It is 138 feet above bench mark Table Rock House.

F. 1890 (Kibbe).—Brass screw with cross on top in platform round cupola of Table Rock House. It is 23.3 feet from northeastern edge of main body of the more eastern of the two southern chimneys, and 28.2 feet from northwestern edge of the more westerly one.

The distance	from	Loretto	to	D..	226.5	feet.
"	"	"	"	C..	1,143	"
"	"	"	"	G..	1,842	"
"	"	"	"	T P. 6..	2,916	"
"	"	"	G	C..	1,036	"
"	"	"	G	D..	1,620.5	"
"	"	"	G	T. P. 6..	1,547	"

The base of the flagstaff of the Natural Food Company, Niagara Falls, N.Y., is a very conspicuous feature, and may be found convenient in measuring angles from stations along the brow of the Canadian highland. From Loretto Convent bolt the angle between the flagstaff and T.P. 6 is 6° 12′ 30″, and between flagstaff and M it is 15° 43′ 30″. Other temporary positions were used which were easily connected with some of the points mentioned.

For the survey of the greater part of the crest, stations on the hill from 120 to nearly 200 feet (Loretto) above the datum of Table Rock House on the Canadian side, were found very much more valuable than the low ones on the Goat Island side. From these high positions the sharp line of the water was defined along the crest on the western side; while with good light the edge of the rock was distinctly shown beneath the thin sheet of water on the eastern side. Indeed from the Goat island side, it would be impossible to make a survey of the crest on account of the low sloping rock surfaces, and inability therefrom to determine the exact edges. However, a good tangent line at the head of the apex, and some of the rock features below the surface farther toward the Canadian side, could be well seen.

There were many points of rock that could be well distinguished from two or more stations. Again little channels in the river had more or less permanent features and could be used. Such was the foundation of the survey of 1904. In addition enlarged photographs were used in 1905, and it was found that many small rapids had points that could be recognized when using the photographs. I had hoped to correct and fill in additional data from the use of vertical angles after taking levels of the river; but in the irregular surface it was found to be impossible to get levels sufficiently accurate, as the horizontal error would amount to from five or twelve times that of the vertical.

As may be seen from a comparison of the successive surveys, some crest lines show more advanced positions than older ones, indicating an error of judgment. No two surveys would show exactly the same results in the minute detail owing to the personal equation. In my survey of 1904 all positions were agreed upon by Mr. Goodwin and myself. Our object was to find the position of the edge of the rock. In throwing the transit lines across the crescent, those striking the water at high angles were unquestionably good; but in the lines crossing the direction of the current, especially where the water was deep, the question of judgment was involved,—as to what point to take, whether to adopt that where the water first broke, or where it was actually falling, or an intermediate point. There is absolutely no means of eliminating this personal element.

In order to establish doubtful points it was said that Mr. Hall of the U. S. Geological Survey used searchlights, and worked at night, in order to eliminate the difficulties arising from want of proper pickets, as has been done by the Japanese. At first glance this method appeared to solve the difficulty; but after the experience with the question of personal element in fixing the points it remained precisely where I found it—judgment as to what part of the curve one should take. This could not be eliminated even by cross lights. But I lived with the falls and learned to recognize minute features. The appearance of the apex varies from different positions. Near station C one can look directly along the axis of the little central channel which is being formed, (*see* Plate 6) but nowhere is there a large V or a channel reaching down through the rocks. It is only a superficial incision. From T. P. 6 on Goat island, two or three small superficial crevices are apparent; from M on Goat island, owing to the low position and configuration of the floor of the river so that the actual edge of the rocks is not well seen, one might be led to suppose that a trough of some size existed. This idea is dissipated on examination from the Canadian side.

My survey of 1904 was the fifth made for the purpose of determining the recession, and the resurvey in October and November of 1905 makes it the last. Mr. Hall's survey came in between these two, but it was not published until after my second edition was printed. The first edition was made to accompany Summary Report of the Geological Survey of Canada, 1905. The accuracy of apex in my survey is shown in photograph Plate VI.

Besides determining the rate of recession during the last fifteen years, my survey establishes the fact that there has been no central recession. This confirms the earlier views of nearly twenty years ago—that the crest is alternately one of flattened form, succeeded by another with a sharp apex-retreat. The form of the crest line in 1819 has not been previously studied, but it establishes this view.

The fall of the rock during November (1905) mentioned on page 35 is sketched on map (Plate II.) from the appearance, such as is shown in a photograph. I had expected such a fall as this, and should look for a very considerable widening of the crescent, as the river beneath Goat island shelf is being undermined along the side of the deepest part of the channel.

If reference be made to Plate XIV. there will be observed a transverse zone of comparatively smooth water extending from the apex diagonally across the course of the rapids above the falls. This is a most important feature as here is a fragment of a transverse valley of pre-glacial date.

APPENDIX III.

WELLS IN NIAGARA TOWNSHIP BELOW ESCARPMENT.

		Feet.
Lot 90	N.W. to Medina ledge	30
" 89	S.W. on Bell terrace in sand and gravel to water	75
" 96	to water	90
" 97	S. of road (dug)	60
" 133	S. on terrace	65 (?)
" 99	W. below terrace rock	12
" 131	E. rock	20
" 25	E.	40
" 86	W. dug	35
" 84	W. "	31
" 129	S. E. (salty) rock	55
" 127	E. "	32
" 74	S. E. "	70
" 64	S. "	84
" 125	S. E. no rock	35
" 58	E. well no data	105
" 80	N. W. (Soules) no rock	100
" 81	S. W. dug	35
" 83	S. "	35
" 103	W. "	36
" 155	N. rock	14
" 120	N. "	30
" 112	N. W. rock	40
" 110	N. centre rock	42
" 109	N. dug	40
" 77	W. rock	40
" 61	dug	40
" 55	no rock	35
" 58	rock	50
" 64	S. middle rock	90
" 66	E. "	60
" 66	W. no rock	60
" 73	S. W. no rock	72
" 39	M. red shale	13
" 38	E. "	13
" 72	no rock	33
" 71	N. "	47
" 35	E. "	45
" 34	rock	44
" 31	no rock	53
Niag. on Lake	S. W. rock	25 to 30
" 19	E. no rock	80 (60 ft. above riv.)
" 20	E. "	75
" 80	S. W. dug	68

APPENDIX IV.

METEOROLOGICAL TABLES.

TABLE I.—SHOWING IN INCHES THE MEAN MONTHLY RAINFALL IN THE BASIN OF LAKE SUPERIOR.*

Years.	Jan.	Feb.	March.	April.	May.	June	July.	August.	Sept.	October.	Nov.	Dec.	Annual Mean.
1882	....	....	....	....	....	....	....	....	....	....	....	.. ..	......
1883	1·49	0·99	0·68	1·25	2·48	4·32	3·95	1·77	2·23	2·72	2·93	2 12	26·93
1884	0·83	1·75	1·14	2·57	3·22	1·21	2·74	5·22	5·25	4·52	1·42	3·62	33·49
1885	1·32	0·61	1·36	1·48	1·98	3·52	3·04	2·16	2·04	1·63	2·65	1·89	23·68
1886	1·71	1·75	1·27	1·76	1·43	2·71	1·50	2·08	3·66	2·84	2·04	1·05	23·80
1887	0·89	1·24	0·50	1·45	1·98	1·93	5·20	1·02	1·18	2·58	1·49	1·41	20·87
1888	1·88	1·12	1·85	2·01	2·67	3·79	1·85	2·84	2·72	2·03	2·00	0·86	25·62
1889	1·87	1·39	1·56	3·35	2·22	2·10	4·35	3 74	3·61	1·09	1·22	2·47	28·97
1890	2·30	2·34	1·02	1·67	2·36	3·09	4·19	3·02	2·45	2·03	0·69	0·84	26·00
1891	1 03	1·62	1·70	0·87	0·58	1·46	3·17	3·12	2·70	2·63	1·68	2·03	22·59
1892	1·33	1·03	1·11	1·64	2·49	1·82	2·75	3·53	1·79	2·18	2·01	1·39	23·07
1893	1 58	2·00	1·55	2·66	2·13	3·22	2·62	2·74	2·58	3·03	2·03	2·74	28·88
1894	1·70	0·64	2·28	2·08	3·78	1·88	2·02	2·05	2·75	4·51	2·39	1·63	27·71
1895	2·27	1·03	0·67	1·82	2·87	3·21	2·22	2·28	4·68	1·81	1·63	1·88	26·37
1896	1·76	0·96	1·23	3·38	4·60	1·78	1·62	2·62	1·59	3·08	4·23	0·66	27·51
1897	2·58	1·35	1·89	1·60	2·50	3·16	5·68	2·55	2 03	2·51	1·74	1·58	29 17
1898	1·13	1·77	1·55	0 77	3·37	4·28	2·42	2·48	2·43	2 76	1·73	1·40	26·09
1899	1·61	1·05	2·11	2·16	3·78	4·28	2·20	3·28	2·97	2·62	0·59	2·29	28·94
1900	1·29	1·55	1·30	1·67	1·36	2·04	4·32	4·99	6·22	2·46	1·80	1·29	30·29
1901	1·60	0·80	2·16	1·01	1·84	4·55	4·48	2·22	2·69	2·75	1·70	1·36	27·16
1902	1·74	1·09	0·79	1·76	2·62	2·88	3·10	2·18	2·23	2·49	2·84	2·14	25·86
1903	0·82	1·11	2·19	2·45	3·76	1·49	5·49	4·39	5·35	3·03	1·80	1·30	33·18
1904	0·90	1·00	1·90	1·30	3·40	3·40	3·40	3·66	4·50	3·60	0·60	2·00	29·60
1905	1·50	0·60	1·10	1·40	3·00	6·30	4·10	3·40	4·50	2·90	2·40	1·20	32·40

In table given by the Meteorological Bureau, years run from November to October. In present tables, calendar years are taken. Means will thus differ slightly.

* For years 1882–1898 as adapted from meteorological report in report of Chief of Engineers upon Survey of Northern and Northwestern Lakes, 1903, pp. 2878–2879; for subsequent years data obtained from Meteorological Bureau.

TABLE II.—SHOWING IN INCHES THE MEAN MONTHLY RAINFALL IN THE BASIN OF LAKES HURON AND MICHIGAN.

Years.	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	October.	Nov.	Dec.	Annual Mean.
1882	....	....	....	....	....	....	....	....	....	....	....	....	.....
1883	2·31	3·28	1·10	1·65	5·33	5·86	6·11	1·64	3·66	3·19	3·63	1·87	38·63
1884	2·67	3·13	2·28	2·02	2·57	2·73	3·10	2·47	3·50	4·44	2·16	4·54	35·61
1885	3·03	1·74	1·30	2·25	2·58	3·61	2·87	4·69	3·04	3·09	3·06	3·24	34·50
1886	4·00	2·20	3·21	2·23	1·86	2·67	1·43	3·94	4·62	2·67	2·66	2·07	33·56
1887	3·26	3·86	1·10	1·51	1·63	2·11	3·10	1·73	2·52	3·22	1·78	3·78	29·60
1888	2·20	1·81	2·84	2·20	3·11	1·63	1·77	2·59	3·11	2·43	2·64	2·00	29·33
1889	2·42	2·05	0·65	1·58	3·59	4·46	2·73	1·52	3·18	1·22	2·84	3·23	29·47
1890	3·71	2·30	2·00	2·73	3·62	3·94	3·07	3·17	1·97	3·68	2·01	1·58	33·78
1891	2·44	2·92	2·83	2·04	0·80	1·97	2·34	3·91	1·80	1·74	5·10	2·19	30·38
1892	2·77	1·95	1·15	1·89	4·17	5·01	3·05	3·16	2·81	2·13	2·64	2·39	33·12
1893	2·78	2·22	2·16	3·88	2·83	2·44	3·32	2·01	2·84	3·65	3·11	4·24	35·48
1894	2·57	1·52	2·60	1·82	4·82	2·70	1·45	1·16	3·72	3·26	2·56	2·52	30·70
1895	3·79	1·64	1·19	1·45	2·90	1·49	1·21	2·96	3·06	1·40	2·97	3·84	27·90
1896	1·90	1·53	1·57	2·84	3·06	2·34	2·26	3·49	4·45	1·71	3·72	1·33	30·20
1897	3·70	1·33	2·98	3·18	3·06	2·60	3·47	2·11	1·34	2·36	2·60	2·38	31·11
1898*	2·79	2·26	3·12	1·79	2·58	3·77	1·59	3·38	2·46	2·34	2·29	1·58	29·95
1899	1·59	1·34	2·68	1·53	3·70	3·20	3·79	1·37	2·87	2·58	1·14	2·35	28·05
1900	1·36	2·85	1·67	1·92	2·31	2·51	5·61	3·78	3·38	3·29	3·36	0·75	32·79
1901	1·78	1·54	3·16	0·95	2·25	2·83	4·10	2·07	2·56	3·29	1·34	2·21	28·08
1902	0·71	1·46	2·57	1·72	4·72	5·06	5·23	1·27	3·50	1·99	2·52	2·33	33·08
1903	1·46	1·89	2·21	3·25	2·86	2·28	4·25	4·79	3·65	1·94	1·50	1·90	31·98
1904	1·50	1·80	3·30	2·10	2·10	3·10	3·10	2·90	3·90	2·90	0·30	1·80	28·80
1905	Monthly record omitted in counting records of the two lakes.												35·30

TABLE III.—SHOWING IN INCHES THE MEAN MONTHLY RAINFALL IN THE BASIN OF LAKES ST. CLAIR AND ERIE.†

Years.	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Annual Mean.
1882	....	....	....	....	....	....	....	....	....	....	....	....	.....
1883	1·66	3·94	1·45	2·03	6·03	4·96	5·13	2·02	2·57	3·21	3·01	2·31	38·32
1884	2·15	3·93	2·61	1·51	2·72	2·59	3·61	1·79	2·37	2·46	1·96	2·81	30·51
1885	2·70	1·38	·96	2·64	3·91	4·78	2·89	5·34	2·56	3·79	3·21	2·50	36·66
1886	3·39	1·92	2·52	2·61	2·84	2·47	1·91	2·97	4·45	1·49	3·77	3·12	33·46
1887	1·97	6·11	1·94	1·73	2·49	3·03	1·43	2·33	2·71	2·25	3·12	2·85	31·96
1888	2·54	1·76	2·88	2·25	2·85	2·36	2·90	2·55	2·22	2·87	3·48	1·85	30·51
1889	2·99	1·66	1·60	2·15	4·51	3·43	2·71	1·15	2·77	1·44	3·41	3·42	31·24
1890	4·11	3·10	2·89	3·31	5·33	3·88	1·38	3·44	3·49	4·89	2·98	1·43	40·23
1891	2·14	4·20	3·13	2·02	1·61	2·92	2·76	3·21	1·96	2·07	5·55	2·20	33·77
1892	2·26	2·76	2·42	2·55	7·87	5·98	3·43	2·88	3·48	1·10	3·08	1·63	39·44
1893	2·79	4·58	2·13	4·75	4·11	2·89	2·42	2·07	1·50	3·80	3·16	3·23	37·43
1894	1·92	2·75	1·81	2·08	5·52	2·62	1·63	0·67	4·01	3·21	1·88	2·28	30·38
1895	3·15	0·71	1·43	1·66	2·29	1·50	2·09	2·74	2·32	1·27	4·62	4·63	28·41
1896	1·73	2·60	2·60	2·98	2·57	3·79	5·58	3·54	4·50	1·33	2·51	1·65	35·38
1897	2·51	1·66	3·62	2·59	3·83	2·77	4·04	2·82	0·78	1·21	5·28	2·09	33·20
1898	3·75	2·47	4·11	1·87	3·21	2·91	2·99	2·91	3·31	2·40	3·37	2·72	36·02

* Michigan only.

†For years 1882-1898 as adapted from Meteorological reports in Rept. of Chief of Engineers upon Survey of Northern and Northwestern Lakes, 1903, pp. 2878-79; for subsequent years data obtained from Meteorological Bureau direct.

TABLE III.—*Continued*—OF ERIE ONLY.

Years.	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	October.	Nov.	Dec.	Annual Mean.
1899	2·64	1·98	4·19	1·17	4·17	2·03	3·76	1·28	3.10	2.62	1·67	3·39	32·00
1900	2·10	2·04	2·39	2·11	2·31	3·06	5·31	3·18	1·89	2·23	3·91	1·00	31·53
1901	1·92	1·67	2·74	2·68	4·08	3·20	3·11	3·47	2·54	1·49	2·07	3·81	32·78
1902	1·29	0·96	2·79	2·00	3·79	7·31	5·98	1·47	5·47	2·55	2·03	3·11	38·75
1903	1·94	3·79	2·42	1·58	2·24	3·95	5·06	5·23	2·13	2·71	1·90	2·20	38·15
1904	4·50	3·00	4·90	3·00	2·10	4·20	1·29	3·30	2·60	1·80	0·40	2·20	36·20
1905	1·90	1·60	1·80	2·80	4·70	4·50	4·00	3·40	2·90	2·90	2·80	2·00	35·30

TABLE IV.—SHOWING IN INCHES THE MEAN MONTHLY RAINFALL IN THE BASIN OF LAKE ONTARIO.

Years.	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	October.	Nov.	Dec.	Annual Mean.
1882	....	....	....	....	....	....	....	....	....	....	....	....	....
1883	2·00	2·94	1·84	2·01	5·60	4·90	4·59	2·37	2·64	2·30	2·18	1·83	35·20
1884	3·67	3·06	3·11	1·13	3·64	3·46	3·45	2·59	2·22	2·43	2·28	3·08	34·12
1885	2·82	1·79	0·89	2·34	2·74	4·06	3·18	5·52	3·12	4·09	2·39	2·86	35·80
1886	3·79	2·02	3·05	3·20	2·31	2·33	3·35	2·77	3·77	1·93	4·74	1·97	35·23
1887	2·75	4·20	1·83	1·82	1·64	2·77	3·78	2·77	1·74	2·30	2·00	2·73	30·33
1888	2·47	1·84	2·75	2·85	2·35	3·39	1·88	4·13	3·40	4·29	3·59	2·70	35·64
1889	3·91	2·21	1·62	3·16	3·39	6·79	5·17	2·02	3·10	3·47	5·20	3·41	43·45
1890	3·98	3·29	3·09	2·80	6·26	4·24	2·76	4·81	6·68	4·90	2·93	2·98	48·72
1891	3·06	3·65	3·25	1·85	1·19	2·78	3·32	4·24	1·62	2·96	2·86	4·03	35·81
1892	3·72	2·28	2·93	1·09	5·61	5·52	4·28	5·70	2·16	1·89	3·65	1·46	40·29
1893	2·03	3·36	2·13	3·53	5·81	2·50	3·33	5·65	3·24	2·31	2·05	3·62	39·76
1894	2·94	2·61	1·65	3·55	6·77	3·23	2·62	1·43	4·97	4·22	2·07	2·45	38·51
1895	2·84	1·77	1·47	1·86	2·58	2·57	2·60	3·89	2·29	1·41	3·54	3·94	30·76
1896	2·16	4·47	3·96	1·07	2·59	2·89	4·86	2·50	4·36	2·66	2·68	1·41	35·61
1897	2·27	1·53	3·07	2·45	3·35	2·96	5·13	2·35	2·03	0·80	4·26	3·04	33·24
1898	3·71	2·02	2·19	2·51	3·58	3·00	2·30	5·57	3·20	4·92	2·90	2·84	38·74
1899	2·31	1·70	3·81	1·64	3·41	1·85	2·82	1·39	3·57	2·86	1·86	3·98	31·20
1900	3·13	3·97	3·84	1·41	1·71	2·27	4·40	2·10	2·38	3·08	5·54	2·21	36·04
1901	2·51	1·94	3·05	4·16	4·06	3·31	3·83	5·56	2·92	1·73	3·04	4·36	38·47
1902	2·49	2·50	2·93	2·59	2·69	4·78	6·52	2·63	2·71	3·28	1·71	3·47	38·30
1903	3·05	2·65	3·88	2·68	0·46	5·75	4·33	4·82	1·50	4·88	2·00	3·10	39·10
1904	3·40	2·90	3·50	3·20	3·30	4·40	4·40	3·40	3·90	2·40	0·70	2·60	38·10
1905	3·00	1·90	2·00	2·00	2·90	5·30	3·80	4·30	2·40	3·80	2·20	2·90	36·50

TABLE V.—SHOWING IN PER CENT THE MEAN MONTHLY RELATIVE HUMIDITY IN THE BASIN OF LAKES ST. CLAIR AND ERIE.*

Years.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Mean.
1882.	....	....	....	....	...	....	....	....	....	..	72·4	78·5	
1883.	78·2	77·3	70	65·6	68	70·6	70·5	67·3	71·9	72·8	68·5	73·5	
1884.	77·8	80·7	75·2	68·7	67·3	70·1	68 2	68·9	71	71·9	76	78·1	
1885.	76·1	76·5	75·2	72·8	73·2	72·5	74·6	79·8	73·3	78·5	80	79·3	
1886.	81·8	77·8	78·6	74·3	72·3	72·3	69·6	72·8	70·6	72·8	74	79·8	
1887.	78·1	82	76·5	68·8	68	72·6	68·1	66·3	72·3	69·8	71·5	77·7	
1888.	81	77·5	75·1	64·7	67·6	68·8	68·6	70·6	74·6	74·5	75·3	75·8	
1889.	80	80·5	74·3	70·3	65·5	76	71·8	67·1	74	70·8	80·5	77·1	
1890.	79·8	79·8	75·6	68·1	73·3	72·5	65·8	70·8	77·5	80·6	74·3	76·8	
1891.	82·5	77·1	77·6	72·6	65·6	71·6	67·6	70·1	71·6	69·5	73·6	72·5	
1892.	79·1	82·3	77	68·5	77·6	77.7	68·8	72·3	74·8	71·7	78·8	80·3	
1893.	82·7	82·3	76	74·8	71·8	71·5	66	66	69·6	73·3	72·6	79·8	
1894.	76·8	78	70·8	70	73·1	67·8	61·3	65	72·3	74·5	74·1	77·5	
1895.	83	80·3	74·7	69·3	66·1	65·8	62·7	67·1	68·3	65·1	76·3	81·1	
1896.	82·7	81	78·1	75·1	68·5	70·6	73·5	73·3	76·6	72·1	76	80·1	
1897.	82·5	80·6	77·5	73·6	71·8	67·8	71·1	71·1	65·5	69·1	77·8	79·8	
1898.	79·5	79·8	75·5	65 5	71·8	70·5	67·8	75·3	72·5	75·3	...	....	
Mean	80·1	79·6	75·4	70·1	70·1	71·1	68·5	70·2	72·3	72·6	75·1	77·9	73·60
Superior.	81 9	80·8	77·8	73·7	68·9	73·1	73·2	75·0	75·0	76·5	80·0	81·7	76·40
Huron and Michig'n	81·8	81·2	77·5	72·8	71·5	74	72·1	74·3	75·8	76·5	78·8	81·2	76.46
Ontario	80·9	80·2	76·5	70	71·2	72·8	72	72·4	73·7	75·6	75·7	78·9	74·99

TABLE VI.—SHOWING IN DEGREES F., THE MEAN MONTHLY TEMPERATURE IN THE BASIN OF LAKES ST. CLAIR AND ERIE.

Years.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Mean.
1882.	....	....	....	....	...	....	....	....	....	..	40·4	28·8	
1883.	21·8	26·4	28·5	43·9	53·1	66·6	70·3	67·2	59	50·7	43·2	32·6	
1884.	19·5	29	33·1	43·1	57	68·5	68·5	67·3	54·9	39	30·3	30.3	
1885.	21·5	16·4	24·6	43·5	55·5	64·5	72·3	65·6	61·5	49·6	40·7	30·8	
1886.	22·2	24·9	33·2	47·8	56·8	65	69 5	68·7	63·7	53·1	37·6	23·7	
1887.	22·8	28·4	29·8	43·6	61·6	67·8	75·8	68·5	60·2	48·1	38·6	30·1	
1888.	19·5	25·2	28·2	42·7	54·3	67	69·5	68·1	59·9	45·8	40·8	31·5	
1889.	30·8	20·3	35·8	45·4	57·4	63·9	71·6	67·5	62·5	46·5	40·6	39·9	
1890.	35	34	30·6	45·8	54·2	69·9	71·1	66·7	60·5	51·6	46·7	28·1	
1891.	29·4	32	31·3	47·2	53·9	67·4	66·8	69	67·1	51	38·3	37·1	
1892.	22·1	29·7	30	44·3	54·7	69·1	71	70·5	63·2	51·6	36·9	27·2	
1893.	16·2	23·6	33·1	44·3	54·3	68·8	72	69·1	62·1	52·9	38·9	29	
1894.	31·2	24·5	40·8	46·5	56·5	68·9	72·9	68·7	66·2	53·1	36·3	33·3	
1895.	21·3	18·2	29·1	46·9	58·7	69·9	69·1	70·5	66·5	45·6	39·6	31·6	
1896.	25·9	26·2	28·4	51·1	63·8	66·9	71·2	69·9	60·3	47·8	42·6	30·8	
1897.	23·5	28·2	35·8	45·3	54·4	63·8	73·9	67·2	65·1	55·8	40·2	30	
1898.	29·7	27·7	42	44·3	57·9	68·6	72·1	71·6	66·8	53·1	....	..	
Mean	24·5	25·9	32·1	45·3	56·5	67·3	71·1	68·6	63·2	50·7	40	30·9	48·0

* Authority same as preceding tables.

TABLE, SHOWING IN DEGREES F., THE MEAN MONTHLY TEMPERATURE IN THE BASIN OF LAKE SUPERIOR.

From the year 1882 to 1898 inclusive.

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Mean.
Mean	6·2	8·3	18·4	35·7	46·6	57·2	62·3	60·1	53·9	41·1	25·8	15·7	35·98

HURON AND MICHIGAN.

Mean	16·8	18·1	25·6	40·2	50·4	61·6	66	63·8	58·3	45·8	33·9	24·5	42·08

LAKE ONTARIO.

Mean	20·5	21·3	27·4	41·6	53·6	63·8	67·4	65·2	58·9	46·6	36·4	26·5	44·01

* Authority cited for preceding tables.

TABLE VII.—SHOWING IN MILES PER HOUR, THE MEAN MONTHLY VELOCITY OF WIND IN THE BASIN OF LAKES ST. CLAIR AND ERIE.*

Date.	Jan.	Feb.	Mar.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Annual Mean.
1882.	....	....	..	...	....	....	....	...	....	....	10	11·5	
1883.	11·6	11·7	11·5	10	10·3	7·6	7·5	8·1	8·7	9·7	13·2	11·3	
1884.	11·4	10·2	9·8	9·8	8·8	7·4	8·1	7·9	9	10·4	11·6	12·6	
1885.	13·2	10·2	11·2	10·9	9·1	8 9	8·3	8·5	9	9·4	11·4	12·9	
1886.	11·2	12·8	10·8	10·3	8·3	7·7	7	7·7	9	9·1	12·7	10·4	
1887.	14·2	13	10·9	11·2	7·3	7·1	8	7	8·2	10·7	12·1	10·6	
1888.	10 7	10·4	12	9·8	9·3	8 6	7·5	8 5	8·6	10·7	11	12·3	
1889.	12	12·1	9·6	9·6	9·7	8·9	7·3	7·7	9 3	9·8	10·2	12	
1890.	12·8	11·6	11·7	10·2	8·6	6 8	8·2	7·8	8	8·8	10·8	11·8	
1891.	9·1	12·4	11·6	9·9	8·5	7·5	8·7	7·7	7·9	10·4	12·6	13·1	
1892.	11·8	10·3	10·4	12·2	10·7	9·2	7·9	8·7	16	11	12·2	11·1	
1893.	11 7	13·4	12·7	14·2	10·6	9·3	9·2	8·4	11	11·3	13·1	14 1	
1894.	12·1	13·2	12	9·8	10·2	8·5	9	7·8	9·8	10·3	14·1	13·2	
1895.	13·2	13·1	12·5	10·2	9·7	8·1	8·5	8·1	10	12.8	11	12·6	
1896.	10·3	13·8	13·4	11·9	11·3	8·7	9·6	9·2	10·3	10·5	14·5	11·9	
1897.	13·9	12·1	13·8	12·6	10·2	9·1	8·9	9·2	8·8	10·8	14	12·7	
1898.	13·4	12·5	11·5	11·5	9·4	9·2	8·7	8·7	10·4	12	...	....	
	12	12	11·6	10·9	9 5	8 3	8·3	8·2	9·2	10·5	12·1	12·1	10·4
Superior.	9	9·4	9·8	10	9·3	8·2	7·5	7·8	9·3	9·5	9·5	9·4	9·05
Huron and Michig'n	11·2	11·5	11·4	11·5	10·4	8·5	8·3	8·3	9·4	10·4	11·4	11·3	10 3
Ontario	13·2	13·2	12·3	10·5	9·4	8·2	8·3	8·1	9·0	10 6	12·5	12·9	10·7

* Authority as cited in preceding tables.

APPENDIX V.

TABLE I.—FLUCTUATIONS OF LAKE ERIE AT PORT COLBORNE.*

Years.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean.
1850	....	1·91	2·11	2·21	2·27	2·05	2·16	1·98	1·82	1·77	1·45	1·26	1·90
1851	2·12	1·61	2·30	2·28	2·74	3·17	2·42	2·86	2·66	2·71	2·62	2·79	2·59
1852	2·07	1·75	1·86	2·78	3·62	2·82	2·57	3·25	3·15	2·82	2·98	3·21	2·90
1853	3·31	3·32	3·13	3·05	3·90	4·13	3·73	3·44	3·26	3·00	2·47	2·67	3·27
1854	2·94	2·01	2·37	2·52	3·30	3·14	3·27	2·64	2·31	2·16	2·47	1·89	2·59
1855	1·84	1·55	1·64	1·89	2·42	2·70	3·20	3·39	2·84	3·07	3·14	3·36	2·58
1856	2·74	2·31	1·98	2·40	2·57	2·78	2·81	2·70	2·48	1·79	1·70	1·98	2·35
1857	1·24	1·24	2·82	3·38	2·97	3·38	3·42	3·42	3·15	2·68	3·19	3·22	2·84
1858	3·35	2·92	2·98	3·04	3·32	4·63	4·63	4·53	3·98	3·87	3·46	3·56	3·69
1859	3·56	3·33	3·74	4·30	4·19	4·15	4·25	3·92	3·38	3·52	3·34	3·16	3·73
1860	3·04	2·70	3·20	3·39	3·59	4·10	3·74	3·55	3·26	2·93	3·29	2·87	3·30
1861	2·43	2·06	2·62	3·27	3·96	3 49	3·89	3·71	3·65	3·69	3·70	3·62	3·34
1862	3·29	3·06	2·85	3·47	4·11	4·05	4·19	3 87	3·60	3·45	2·92	3·03	3·49
1863	3·50	3·36	3·57	3·41	3·51	3·45	3·33	3·50	3·12	3·07	2·66	2·94	3·28
1864	2·74	2·28	2·22	2·75	3·44	3·45	3·17	3·05	2·86	2·74	2·83	2·70	2·85
1865	2·02	1·22	1·47	2·29	2·52	2·73	2·56	2·32	2·43	2·44	2·22	2·05	2·19
1866	2·13	1·34	1·62	2·30	2·61	2·85	3·01	2·82	2·39	3·07	2·71	3·17	2·50
1867	....	....	....	....	....	....	3·06	2·77	2·28	2·04	1·74	1·42	2·22
1868	1·39	1·11	1·09	2·28	2·39	2·96	2·88	2·62	2·27	1·63	1·68	1·87	2·01
1869	1 34	1·41	1·21	1·93	2·26	2·84	3·23	2·99	2·70	2·63	2·31	2·46	2·27
1870	2 98	2·67	2·27	...	3·19	3·27	3·46	3·27	2·73	2·82	2·68	2·69	2·91
1871	2·09	1·70	2·26	2·81	2·79	3·06	3·01	2·75	[illegible]	2·06	1·66	2·00	2·38
1872	1·26	0 77	0·73	1·01	1·55	1·85	1·96	1·78	1·80	1·29	1·84	1·22	1·42
1873	1·20	0·87	0·82	1·97	2·55	2·65	2·83	2·50	2·37	2·10	2·20	2·36	2·03
1874	2·81	2·59	2·87	2·68	2·61	2·04	2·84	2·59	2·27	2·15	1·94	1·59	2·49
1875	1·52	1·11	1·38	1·85	2·11	2.37	2·45	2·39	2·38	2·35	1·94	2·02	1·99
1876	2·46	2·89	3·28	3·79	2·96	4·00	4·02	3·66	3·26	3·15	2·95	3·04	3.37
1877	2·16	1·97	1·93	2·02	2·34	2·55	2·76	2·63	2·43	2·22	2·28	2·36	2·30
1878	2·06	2·25	2·52	2·90	3·18	3·08	3·02	2·90	2·83	2·47	2·30	3·19	2·72
1879	2·33	1·97	2·04	2·37	2·21	2·38	2·32	2·14	1·91	1·55	1·60	1·55	2·03
1880	1·75	2·24	1·90	2·31	2·50	2·70	2·74	2·30	2·34	2·13	2·00	1·90	2·23
1881	0·50	1·33	1·68	2·16	2·27	2·51	2·69	2·27	1·95	1·96	2·32	2·27	1·99
1882	2·64	2·50	2·92	3·03	3·14	3·63	3·50	3 29	2·83	2·53	2·26	2·33	2·88
1883	2·05	2·18	2·15	2·17	3·51	4·30	3·69	3·36	2·87	2 69	3·00	2·80	2·89
1884	2·49	2·42	2·74	3·16	3·58	2·24	3·41	3·33	2·83	2·66	2·42	2·33	2·90
1885	2·16	1·50	1·75	2·16	2·91	3·50	3·58	3·50	3·33	3·33	3·33	3·50	2·87
1886	3·16	2·41	2·08	2·75	3 33	3·50	3·41	3·08	3·25	2·66	2·83	2·50	2·91
1887	2·41	2·83	3·25	3·25	3·41	3·58	3.41	3·00	2·66	2·58	2·25	2·66	2·94
1888	1·75	1·50	1·58	2·33	2·33	2·50	2·83	2·75	2·33	2·08	1·91	2·08	2·16
1889	2·00	1·66	1·41	1·83	2·08	2·50	2 66	2·41	2·08	1·58	1·50	1·66	1·94
1890	2·08	2·00	2·41	2·75	3·16	3·50	3·25	2·75	2·25	2·25	2·41	2·08	2·58
1891	1·83	1·91	2·00	2·16	2·00	1·91	2·08	1·66	1·41	1·00	1·00	1·16	1·66
1892	1·08	0·41	0·66	1·08	1·83	2·58	2·83	2·50	2·08	1·83	1·50	1·33	1·66
1893	0·66	0·66	1·00	1·58	2 50	2·66	2·50	2·00	1·66	1·58	1·33	1·41	1·63
1894	1·41	1·25	1·33	1·50	1·91	2·41	2·25	1·66	1·50	1·25	1·50	1·08	1·58
1895	1 16	0·41	0·33	0·58	0·91	1·00	1·00	0·91	0·91	0·66	0·25	0·41	0·71
1896	0·50	0·41	0 16	0·75	1·08	1·16	1·33	1·50	1·08	0·83	0·75	0·66	0·86
1897	0·91	0·58	1·16	1·58	2·00	2·00	2·00	2·00	1·50	1·00	1·25	1·33	1·44
1898	1·16	1·33	1·50	2·08	2·08	2·16	2·00	1·91	1·66	1·41	1·25	1·41	1·66
1899	1·25	1·00	1·33	1·58	1·75	2·00	1·91	1·50	1·41	0·91	1·00	1·33	1·41
1900	1·08	1·16	1·25	1·41	1·75	1·58	1·91	1·83	1·50	1·08	1·16	1·16	1·41
1901	0·91	0·75	0·16	0·50	0·66	1·25	1·33	1·08	1·16	0·91	0·58	0·75	0·83
1902	0·58	0·08	0·33	1·25	1·25	1·58	2·33	2·33	2·00	2·00	1·41	1·33	1·48
1903	1·25	1·16	1·58	2·25	2·16	2·33	2·41	2·08	2·00	1·58	1·50	1·33	1·80
1904	0·58	0·66	1·33	2·66	2·75	2·91	2·91	2·66	2·33	....	1·75	1·50	1·99
1905	2 00	0·58	0·41	0·91	2·00	2·91	2·58	2·41	2·25	1·41	1·58	1·50	1·56
1906	1·66	1·33	1·08	1·50	1·75	1·92	2·00	1·92	1·66	1·92	1·88	1·97	1·69

Height of new lock at Port Colborne, 556·55; of old lock 2·92 feet higher); correction of 0·75 of a foot (by precise levelling to Greenbush) all of these equal 560·22 feet, and ten feet, omitted from monthly readings for condensation, equals 570·22 feet, to be added to the mean readings to give height above mean tide at New York.

* Compiled from the Canal records.

TABLE II.—FLUCTUATIONS OF LAKE ERIE AT CLEVELAND. MONTHLY MEAN HEIGHTS OF WATER SURFACE ABOVE MEAN TIDE AT NEW YORK.*

(Add 570 feet to the following heights.)

Years.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Mean.
1855	2·39	2·08	2·14	2·43	2·95	2·23	3·73	3·95	3·30	3·54	3·61	3·89	3·10
1856	3·25	2·85	2·52	3·01	2·97	3·35	3·38	3·23	2·98	2·32	2·20	2·49	2·88
1857	1·74	1·77	...	...	3·50	3·88	3·97	3·93	3·68	3·22	3·76	3·76	3·32
1858	3·85	3·45	3·48	3·59	3·85	5·21	5·16	5·07	4·51	4·41	3·99	4·09	4·22
1859	4·08	3·86	4·27	4·84	4·72	4·69	4·75	4·45	3·85	4·06	3·88	3·68	4·26
1860	3·26	2·90	3·30	4·00	4·21	4·18	3·92	3·76	3·42	3·12	3·03	2·87	3·49
1861	2·61	2·33	2·77	3·81	4·24	4·31	4·06	4·10	3·92	3·69	3·67	3·44	3·58
1862	3·43	3·14	3·28	4·18	4·42	4·42	4·39	4·01	3·70	3·32	2·98	3·01	3·69
1863	3·46	3·75	3·69	3·81	3·99	3·85	3·73	3·65	3·26	2·82	2·41	2·38	3·40
1864	2·09	2·24	2·45	2·95	3·65	3·60	3·34	3·07	2·85	2·54	2·37	2·44	2·79
1865	2·01	1·43	1·75	2·47	3·05	3·03	2·99	2·91	2·87	2·57	2·19	2·05	2·44
1866	1·78	1·62	2·01	2·59	2·81	3·07	3·18	2 93	2·87	2·86	2·62	2·63	2·58
1867	2·34	2·02	2·42	2·74	3·26	3·57	3·38	3·07	3·68	2·34	1·84	1·62	2·60
1868	1·42	1·04	1·63	2·46	2·91	3·30	3·27	2·75	2·48	2·03	1·87	1·66	2·23
1869	1·65	1·58	2 06	2·36	2·91	3·30	3·58	3·48	3·21	2·76	3·30	2·65	2·65
1870	2·89	3·12	2·89	3·54	3·75	3·72	3·76	3·71	3·46	3·08	2·78	2·66	3·28
1871	2·45	2·12	2·57	3·05	3·32	3·35	3·33	3·12	2·95	2·28	2·10	1·66	2·69
1872	1·58	1·34	1·25	1·45	1·89	2·26	2·25	2·22	1·99	1·82	1·49	1·26	1·73
1873	1·16	1·17	1·24	2·52	3·19	3·27	3·25	3·19	2·79	2·49	2·29	2·66	2·43
1874	3·05	3·10	3·13	3·30	3·39	3·46	3·49	3·33	2·87	2·43	2·01	1·80	2·94
1875	1·57	1·40	1·54	1·94	2·41	2·84	2·97	2·96	2·82	2·33	2·18	2·40	2·28
1876	2·36	2·92	3·57	4·09	4·41	4·52	4·41	4·11	3·94	3·41	3·49	3·15	3·69
1877	2·75	2·59	2·36	2·79	3·04	3·12	3·36	3·22	3·14	2·74	2·66	2·74	2·87
1878	2·82	2·96	3·09	3·51	3·75	3·75	3·75	3·53	3·40	3·05	2·85	2·93	3·28
1879	2·51	2·37	2·40	2·76	2·91	3·00	3·03	2·81	2·48	2·25	1·78	2·04	2·52
1880	2·54	2·58	2·72	2·88	3·15	3·26	3·35	3·11	2·88	2·44	2·36	2·02	2·77
1881	1·61	1·72	2·04	2·74	3·14	3·38	3·33	3·01	2·66	2·61	2·43	2·64	2·61
1882	3·11	3·11	3·56	3·78	3·98	4·13	4·06	3·92	3·65	3·20	2·88	2·37	3·48
1883	2·28	2·49	2·68	2·80	3·26	3·96	4·16	4·10	3·79	3·47	3·09	3·12	3·26
1884	2·79	3·05	3·24	3·79	4·06	4·14	3·92	3·76	3·33	3·00	2·52	2·45	3·33
1885	2·27	2·06	1·92	2·74	3·47	3·98	3·94	3·95	3·80	3·70	3·58	3·53	3·24
1886	3·55	2·82	2·63	3·51	3·81	3·91	3·89	3·69	3·44	3·21	2·92	2·83	3·35
1887	2·61	3·04	3·82	3·87	4·05	4·07	3·84	3·52	3·29	2·70	2·43	2·45	3·29
1888	2·27	2·00	2·10	2·73	2·98	3·11	3·26	3·16	2·72	2·35	2·41	2·29	2·60
1889	2·31	2·15	1·99	2·34	2·52	2·95	3·15	2·84	2·45	2·03	1·76	2·02	2·37
1890	2·38	2·67	2·79	3·28	3·62	3·99	3·61	3·15	2·98	2·79	2·76	2·53	3·05
1891	2·31	2·29	2·75	2·62	2·44	2·58	2·48	2·21	2·03	1·65	1·21	1·28	2·15
1892	1·31	1·10	1·14	1·70	2·50	3·26	3·38	3·03	2·71	2·15	1·82	1·55	2·13
1893	1·17	1·25	1·47	2·20	3·04	3·23	2·95	2·61	2·23	1·88	1·48	1·56	2·08
1894	1·84	1·72	1·75	2·15	2·54	2·75	2·73	2·36	2·19	1·87	1·63	1·56	2·09
1895	1·23	1·00	1·01	1·26	1·48	1·57	1·46	1·38	1·28	0·80	0·70	0·86	1·17
1896	0·96	0·88	0·83	1·28	1·66	1·93	1·81	2·02	1·70	1·46	1·09	1·12	1·39
1897	1·09	1·29	1·66	2·21	2·54	2·64	2·63	2·47	2·19	1·70	1·57	1·54	1·86
1898	1·59	1·79	2·05	2·63	2·78	2·81	2·59	2·39	2·01	1·81	1·69	1·52	2·13
1899	1·67	1·46	1·83	2·13	2·44	2·56	2·28	2·09	1·85	1·61	1·62	1·34	1·90
1900	1·36	1·57	1·92	2·23	2·39	2·47	2·34	2·31	1·00	1·75	1·49	1·45	1·94
1901	1·35	1·00	0·88	1·29	1·31	1·72	1·91	1·78	1·71	1·33	1 16	1·19	1·38
1902	1·08	0·63	0·94	1·49	1·86	2·12	2·74	2·72	2·38	2·29	2·02	1·82	1·84
1903	1·72	1·70	2·28	3·05	3·09	3·05	2·98	2·76	2·59	2·25	1·77	1·31	2·37
1904	1·19	1·28	1·86	2·91	3·17	3 32	3·41	3·10	2·84	2·49	2·12	1·77	2·45
1905	1·52	1·31	1·18	1·83	2·46	2·98	3·07	2·88	2·59	2·30	1·93	1·92	2·16

* Rept. Engineers Northern and Northwestern lakes.

TABLE III.—FLUCTUATIONS OF LAKE HURON* MONTHLY MEAN HEIGHT OF WATER SURFACE AT SAND BEACH † ABOVE MEAN TIDE AT NEW YORK.

Add 580 feet (except when whole number is 9 when add 570).‡

Date.	Jan.	Feb.	March.	April	May	June	July	August	Sept.	October	Nov.	Dec.	Mean
1854	....	..	....	1·15	1·80	2·07	2·39	2·35	2·24	1 67	1·40	1·22	....
1855	1·06	1·03	1·10	1·18	1·75	2·08	2 17	2·28	2·37	2 24	2·04	2·14	1·78
1856	2·20	1.71	1·73	1·86	2·29	2·22	2·29	2·10	1·98	1·79	1·73	1·50	1·95
1857	1·30	1·58	1·71	2·17	2·52	2·82	3·25	3·44	3·29	3·36	2·55	2·59	2·55
1858	2·52	2·23	2·15	2·67	3·15	3·57	3·96	3·92	2·52	3·37	3·04	3·06	3·09
1859	2·57	2·70	2·76	3·40	3·55	3·55	4·20	3·90	3·66	3·33	2·83	2·90	3·28
1860	2·83	2·78	2·92	2·89	2·94	3·18	3·27	3·19	3·00	2·62	2·50	2·20	2·86
1861	1·99	2·03	2·17	2·37	2 99	3·33	3·45	3·56	3·48	3·26	2·95	2·82	2·86
1862	2·44	2·43	2·34	2·55	2·92	3·04	3·09	3·07	2·85	3·13	2·81	2·52	2·76
1863	2·36	2·21	2·16	2·23	2·55	2·68	2·59	2·60	2·46	2·20	2·16	1·93	2·34
1864	1·79	1·75	1·75	1·95	2·38	2·39	2·34	2·23	1·91	1·38	1·21	1·08	1·84
1865	0·72	0·81	0·98	1·47	1·63	1·67	2·10	2·12	2·00	1·76	1 20	0·89	1·44
1866	0·63	0·39	0 44	0·88	1·07	1·36	1·62	1·68	1·53	1·42	1·33	1·07	1·12
1867	1·05	1 10	1·28	1·57	1·79	2·10	2·25	2·18	1·91	1·58	1·12	0·77	1·56
1868	0·61	0·57	1·25	1·15	1·43	1·64	1·67	1·33	1·09	0·86	0·79	0·51	1·07
1869	0·41	0·48	0·22	0·59	0·92	1·45	1·83	2·09	1·98	1·62	1·50	1·22	1·19
1870	1·28	1·37	1·67	2 09	2 43	2·57	2·68	2·59	2·73	2·33	1 93	1·58	2·10
1871	1·73	1·65	2·25	2·45	2·80	2·84	2·87	2·56	2 24	1·74	1·53	1·16	2·15
1872	0·99	0·79	0·29	0·71	1·11	1·51	1·61	1·58	1·48	1·36	1·06	0·77	1·10
1873	0·60	0·57	0·64	1·05	1·55	1·95	2·15	2·16	1·99	1·96	1·86	1·70	1·51
1874	1·72	1·86	2·00	1·75	1·90	2·24	2·46	2·29	2.11	1·84	1·30	1·45	1·91
1875	1 16	1·10	1·14	1·33	1·68	1·99	2·18	2·15	2·19	2·00	1·89	1·62	1·70
1876	1·74	1·72	1·85	2·13	2·73	3·22	3·66	3·60	3·49	3·09	2·94	2·75	2·74
1877	2·46	2·45	2·38	2·46	2 63	2·59	2·77	2·67	2·40	2·26	2·21	2·16	2·45
1878	2·06	1·89	2·06	1·99	2·39	2·56	2·60	2·50	2·21	2·22	2·03	1·83	2·20
1879	1·53	1·29	1·25	1·28	1·41	1·55	1·59	1·46	1·38	1·14	1·02	1·00	1·32
1880	1·05	0·99	0·98	0·99	1·39	1·88	2·19	2·09	1·97	1·61	1·49	1·29	1·49
1881	1·16	1·55	1·56	1·58	1·90	2·07	2·22	2·05	1·89	2·14	2·27	2·10	1·87
1882	1·95	1·72	1·86	2·08	2·25	2·48	2·62	2·68	2·56	2·33	2·08	1·93	2·21
1883	1·73	1·68	1·72	1·73	2 30	2·72	3·20	3·40	3·08	2·75	2·86	2·75	2·49
1884	2·56	2·41	2·45	2·76	2·98	3·04	3·12	3 00	2·65	2·81	2·46	2·20	2·70
1885	2·47	2·38	2·38	2·49	2 89	3·18	3·24	3·39	3·29	3·06	2·87	2·67	2·86
1886	2·67	2·74	3·93	3·22	3·55	3·64	3·48	3·57	3 15	3·02	2·75	2·43	3·08
1887	2·26	2·45	2·66	2·57	2·77	2·89	2·97	2·76	2 41	2·19	1·74	1·45	2·42
1888	1·34	1·25	1 42	1·56	2·00	2·30	2·33	2·37	2·07	1·78	1·60	1·39	1·78
1889	1·25	1·17	1·15	1·08	1·22	1·55	1·81	1·75	1·58	1·21	0·87	0·71	1·28
1890	0·78	0·66	0·64	0·78	1·09	1·52	1·71	1·71	1·44	1·23	1·03	0.73	1·11
1891	0·53	0·42	0·39	0·72	0·96	0·91	0 94	0·84	0 65	0·28	9·97	9·91	0·54
1892	9·93	9·87	9·93	0·01	0·14	0·67	0·96	1·04	0·87	1·66	1·33	0·09	0·37
1893	9·84	9·79	9 87	0 25	0·88	1·63	1·35	1·21	0·92	0·71	0·48	0·28	0·60
1894	0·23	0·24	0·39	0·62	1·02	1·32	1 47	1·20	1·01	0·77	0·58	0·28	0·76
1895	0·03	9.91	9·92	0·02	0·17	0·26	0·23	0·14	0·01	9·72	9·33	9·09	9·90
1896	9·16	9·28	9·18	9·21	9·61	9·98	0·04	0·08	9·90	9·70	9·56	9·44	9·59
1897	9·52	9·43	9·57	9·91	0·48	0·72	0·96	0·91	0·65	0·30	0·18	9·88	0·20
1898	9·73	9·79	0·02	0·51	0·63	0·79	0·89	0·78	0·59	0·28	0·20	0·01	0·35
1899	9·75	9·61	9·76	9·93	0·47	0·86	1·15	1·06	0·86	0·45	0·31	0·12	0·36
1900	9·89	9·90	9·93	0·05	0 20	0·37	0·62	0·71	0·79	0·71	0·73	0·53	0·37
1901	0·44	0·37	0·26	0·55	0·82	0·91	1·07	1·11	0·88	0·66	0·43	0·12	0·63
1902	0·00	9·81	9·73	9·91	0·16	0·48	0·76	0·84	0·52	0 27	0·14	9·93	0 21
1903	9·75	9·79	9·92	0·27	0·39	0·56	0·75	0·73	0·80	0·83	0 41	0·12	0·36
1904	9·90	9·92	0·09	0·61	0·99	1·41	1·55	1·53	1·36	1·26	0·95	0·50	0·84
1905	0·38	0·30	0·29	0·66	0·95	1·40	1·51	1·56	1·45	1·22	0.93	0·67	0·95

*From Rept. of Engineers, U. S. A. 1904.

†Fluctuations from 1860-64 at Port Aux Barque, Mich.; 1865-70 Milwaukee, Wis.; 1871-'4 Port Austin, Mich.; 1875-1900 Sand Beach, Mich.

‡The above are new corrected elevations. 0·507 ft. above old which were based on G.T.R. gauge ·80 miles below Lake Huron and 0·66 ft. below lake at Ft. Gratiot.

TABLE IV.—LAKE ONTARIO AT TORONTO.

Monthly mean of water levels above zero of Harbour Commissioners' gauge, elevation of which is 244·79 feet above mean tide at New York.*

Years.	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Mean.
1854	1·67	1·75	1·83	2·00	2·54	2·96	2·83	2·25	1·83	1·42	·87	·75	1·89
1855	0·67	·83	·42	·50	1·33	1·67	2·21	2·33	2·17	2·04	1·83	1·92	1·49
1856	1·67	1·50	1·42	1·67	2·42	2·58	2·50	2·96	1·75	1·37	·87	·58	1·77
1857	·33	·42	·96	1·46	2·46	3·00	3·50	3·42	3·25	2·75	2·75	3·08	2·28
1858	2·58	2·50	2·00	2·33	2·54	3·25	3·54	3·37	2·92	2·42	2·08	1·75	2·61
1859	1·75	1·79	1·92	2·83	3·46	3·46	3·25	2·96	2·33	1·83	1·29	1·42	2·35
1860	1·42	1·42	1·33	1·42	1·67	1·87	1·92	1·87	1·50	1·25	1·25	1·29	1·52
1861	1·17	1·08	1·51	2·08	2·79	3·12	3·00	2·83	2·33	2·46	2·42	2·25	2·26
1862	1·75	1·54	1·67	1·58	3·42	3·33	3·08	2·75	2·29	1·75	1·33	1·00	2·13
1863	1·00	1·17	1·46	2·25	2·75	2·75	2·50	2·08	1·58	1·08	·96	1·00	1·71
1864	·71	·71	·75	1·46	2·42	2·79	2·29	1·92	1·50	1·00	1·17	1·33	1·50
1865	1·12	·79	·92	1·96	2·25	2·25	1·87	1·50	1·08	·67	·33	·17	1·24
1866	— ·08	— ·33	— ·12	+ ·42	·92	1·42	1·50	1·33	1·17	1·17	1·04	1·42	·82
1867	1·42	1·37	1·50	1·87	2·75	3·12	2·83	2·33	1·50	·92	·25	— ·08	1·65
1868	— ·33	— ·62	— ·29	+ ·33	·75	1·25	1·25	·92	·67	·25	·21	·17	·38
1869	·08	·00	·21	·83	1·50	1·92	2·12	2·08	2·00	1·67	1·37	1·46	1·27
1870	1·96	2·08	2·08	3·12	3·83	3·50	3·12	2·75	2·17	1·79	1·33	1·21	2·41
1871	1·00	1·50	1·08	1·50	1·92	1·79	1·62	1·33	·83	·42	— ·08	— ·33	1·05
1872	— ·42	— ·75	— ·96	— ·50	— ·17	+ ·25	·17	·00	— ·25	— ·42	— ·58	— ·83	— ·38
1873	— ·87	— ·96	— ·75	+1·04	1·75	1·79	1·67	1·58	1·08	1·50	·50	·58	·74
1874	1·25	1·58	1·83	2·00	2·17	2·25	2·21	1·92	1·42	·87	·33	·00	1·49
1875	— ·37	— ·71	— ·50	+ ·08	·62	·83	·83	·75	·42	·17	·00	— ·08	·17
1876	·25	·83	1·62	2·33	2·92	3·17	3·17	2·75	2·21	1·75	1·50	1·08	1·97
1877	·79	·46	·58	1·25	1·42	1·33	1·33	1·08	·67	·33	·08	·21	·79
1878	·33	·50	1·08	1·46	1·79	1·83	1·75	1·67	1·58	1·17	1·00	1·58	1·31
1879	1·50	1·17	1·17	1·46	1·71	1·58	1·33	·92	·50	·17	— ·29	— ·29	·91
1880	·17	·42	·75	·92	1·25	1·50	1·37	1·12	·71	·25	·21	·00	·72
1881	— ·42	— ·29	+ ·17	·62	·92	1·17	1·08	— ·83	·42	·00	— ·17	— ·12	·35
1882	·33	·58	1·25	1·50	1·79	2·37	2·25	2·04	1·67	1·17	·71	·33	1·33
1883	·08	·08	·33	·92	1·83	2·42	2·75	2·62	2·25	2·00	1·50	1·42	1·52

1884	1·29	1·50	2·12	2·92	3·21	3·08	2·83	2·62	2·17	1·83	1·42	1·00	2 17
1885	·92	·83	·58	1·04	2·17	2·33	2·54	2·46	2·29	2·12	2·17	2 17	1·80
1886	2·50	2·50	2·54	3·25	3·67	3·42	3·08	2·54	2·17	1·79	1·42	1·42	2·52
1887	1·25	1·75	2·17	2·54	3·08	3·17	2·83	2·42	1·75	1·37	·79	·67	1·98
1888	·46	·25	·42	·92	1·25	1·29	1·25	1·17	·92	·58	·42	·33	·77
1889	·42	·67	·67	1·00	1·17	1·42	1·75	1·50	1·00	·42	·08	·50	·88
1890	1·00	1·46	1·75	2·00	2·33	2·92	2·87	2·37	2·00	1·71	1·50	1·33	1·94
1891	1·04	1·08	1·58	2·21	2·21	1·83	1·50	1·00	·67	·08	— ·62	— ·79	·98
1892	— ·58	— ·79	— ·75	— ·33	·00	·58	1·00	1·08	·87	·46	08	·00	·14
1893	— ·37	— ·46	— ·17	+ ·50	1·67	2·17	1·83	1·37	1·12	·58	·17	·04	·70
1894	·25	·46	·67	·79	1·00	1·46	1·33	·83	·37	— ·08	— ·25	— ·58	+ ·52
1895	— ·83	—1·08	—1·03	— ·53	— ·27	— ·38	— ·71	— ·97	—1·20	—1·67	—1·89	—1·75	—1·02
1896	—1·50	—1·25	—1·17	— ·17	·17	·08	— ·17	— ·37	— ·79	—1·04	—1·21	—1·33	— ·73
1897	—1·46	—1·42	— ·71	— ·25	+ ·29	·50	·50	·42	·00	— ·58	— ·83	— ·67	— ·35
1898	— ·46	— ·08	+ ·33	·67	·92	·96	·79	·37	·00	— ·12	— ·21	— ·33	+ ·24
1899	— ·12	— ·21	+ ·04	·62	·96	1·04	·92	·50	— ·04	— ·33	— ·54	— ·67	+ ·18
1900	— ·54	— ·37	·00	+ ·58	·96	·87	·67	50	·00	— ·29	— ·54	— ·35	+ ·12
1901	—0·46	—0·68	—0·73	+0·33	0·77	0·89	0·72	0·44	0·05	—0·41	—0·86	—0·75	—0·05
1902	—0·58	—0·72	—0·05	+0·39	0·44	0·46	0·94	1·00	0·66	0·30	0·04	0·20	+0·22
1903	—0·27	—0·16	+0·54	0·41	1·55	1·46	1·47	1·33	1·02	0·58	0·20	—0·12	+0·75
1904	—0·32	—0·14	+0·41	1·70	2·44	2·79	2·80	2·54	2·18	1·77	1·25	0·69	1·51
1905	0·66	0·19	0·12	0·94	1·28	1·66	2·00	2·03	1·83	1·48	1·09	....	1·10
1906	1·18	1·16	1·00	1·21	1·35	1·46	1·61	1·33	0·79	0·64	0·53	0·64	1·07

For mean annual fluctuation of St. Lawrence river, see Chapters xix. and xxxi.

* Altitudes of Can., James White, F.R.G.S., 1901, p. 254 for years 1854-1890; For years 1891-1895 from data kindly furnished by Mr. Colin W. Postlethwaite, Harbourmaster, Toronto.

TABLE V.—FLUCTUATIONS OF LAKE ONTARIO AT TORONTO, CHARLOTTE AND OSWEGO.

Years.	Toronto.	Charlotte.	Charlotte above Toronto.	Oswego.	Oswego above Toronto.
1850		245·74		245·49	
1851		245·47		245·72	
1852		246·34		246·48	
1853		246·91		246·96	
1854	246·68	246·21	−·47	246·46	−·22
1855	246·28	246·02	−·26	245·62	−·66
1856	246·56	246·33	−·23	245·78	−·78
1857	247·07	246·74	−·33	246·72	−·35
1858	247·40	248·33	+·93	248·22	+·82
1859	247·14	247·92	+·78	248·10	+·96
1860	246·31	246·83	+·52	247·05	+·74
1861	247·05	247·61	+·56	247·52	+·47
1862	246·92	247·60	+·68	247·72	+·80
1863	246·50	247·20	+·70	247·27	+·77
1864	246·29	247·02	+·73	247·03	+·74
1865	246·03	246·76	+·73	246·98	+·95
1866	245·62	246·42	+·80	246·22	+·60
1867	246·44	247·37	+·93	246 92	+·48
1868	245·17	245·95	+·78	245·64	+·47
1869	246·06	246·80	+·74	246·62	+·56
1870	247·20	247·88	+·68	247·67	+·47
1871	245·84	246·51	+·67	246·27	+·43
1872	244·41	244·98	+·57	244·91	+·50
1873	245·53	246·05	+·52	245·95	+·42
1874	246·28	246·80	+·52	246·66	+·38
1875	244·96	245·51	+·55	245·36	+·40
1876	246·76	247·37	+·61	247·19	+·43
1877	245·58	246·18	+·60	246·01	+·43
1878	246.10	246·78	+·68	246·59	+·49
1879	245.70	246·43	+·73	246·30	+·60
1880	245·51	246·03	+·52	245·90	+·39
1881	245·14	245·72	+·58	245·60	+·46
1882	246·13	246·79	+·66	246·65	+·52
1883	246·31	246·82	+·51	246·76	+·45
1884	246·96	247·34	+·38	247·37	+·41
1885	246·59	246·80	+·21	246·92	+·33
1886	247·31	247·52	+·21	247·70	+·39
1887	246·77	247·10	+·33	247·14	+·37
1888	245·56	245·88	+·32	245·99	+·43
1889	245·67	246·11	+·44	246·11	+·44
1890	246·73	247·08	+·35	247·24	+·51
1891	245·77	246·17	+·40	246·20	+·43
1892	244·93	245·45	+·52	245·47	+·54
1893	245·49	246·09	+·60	246·07	+·58
1894	245·31	245·89	+·58	245·87	+.56
1895	243·81	244·44	+·63	244·37	+·56
1896	244·06	244·70	+·64	244·71	+·65
1897	244·44	244·94	+·50	244·90	+·46
1898	245·03	245·40	+·37	245·45	+·42
1899	244·97	245·33	+·36	245·28	+·31
1900	244·91	245·35	+·44	245·32	+·41
1901	244·73	245·24	+·51	245·27	+·54
1902	245·01	245·46	+·45		
1903	245·54	245·99	+·45		
1904	246·29	246·63	+·34		
1905	245·91	246·31	+·40		

APPENDIX VI.

TABLE I.—MEAN MONTHLY DISCHARGE OF NIAGARA RIVER IN UNITS OF A THOUSAND CUBIC FEET.*

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean.
1860	234	225	235	250	255	254	249	245	237	231	229	225	239
1861	219	213	223	246	256	257	252	253	249	243	243	238	241
1862	238	231	234	254	260	250	259	251	244	235	227	228	243
1863	238	245	243	246	250	247	244	243	234	224	215	214	237
1864	207	211	216	227	243	241	236	229	225	218	214	215	223
1865	206	193	200	216	229	229	228	226	225	218	210	207	215
1866	201	197	206	219	224	229	232	226	225	225	219	220	218
1867	213	204	215	222	234	241	236	229	221	213	202	197	219
1868	192	184	197	216	226	235	234	222	216	206	202	198	211
1869	198	196	207	214	226	235	241	239	233	223	212	220	220
1870	225	231	225	240	245	244	245	244	238	230	223	220	234
1871	216	208	218	229	235	236	235	230	227	212	208	198	221
1872	196	191	189	193	203	211	211	210	205	201	194	189	199
1873	187	187	188	217	232	234	234	232	223	216	212	220	215
1874	229	230	231	235	237	238	239	235	225	215	206	201	227
1875	196	192	195	204	215	224	227	227	224	213	209	214	212
1876	214	226	241	252	260	262	260	253	249	237	239	231	244
1877	222	219	214	223	229	231	236	233	231	222	220	222	225
1878	224	227	230	239	245	245	245	240	237	229	225	226	234
1879	217	214	214	223	226	228	229	224	216	211	201	206	217
1880	218	218	222	225	231	234	236	230	225	215	214	206	223
1881	197	199	206	222	231	236	235	228	220	219	215	220	219
1882	230	230	240	245	250	253	252	249	243	232	225	214	239
1883	212	216	221	223	224	249	254	253	245	238	230	231	234
1884	233	229	233	246	252	254	249	245	235	228	218	216	236
1885	212	207	204	222	238	250	249	249	246	244	241	240	233
1886	240	224	220	239	246	248	248	243	238	233	226	224	236
1887	219	229	246	247	251	252	247	240	234	221	215	216	235
1888	212	205	207	222	227	230	234	232	222	213	215	212	219
1889	212	209	205	213	218	227	231	224	216	206	200	206	214
1890	214	220	223	234	242	250	242	232	227	223	223	217	229
1891	212	212	222	219	215	218	216	210	206	198	188	189	209
1892	190	185	186	199	217	234	236	229	221	209	201	195	209
1893	187	189	194	210	229	233	227	219	211	203	194	196	207
1894	202	199	200	209	218	222	222	214	210	203	197	196	207
1895	188	183	183	189	194	196	193	192	189	178	176	180	187
1896	182	180	179	189	198	204	201	206	199	193	185	186	192
1897	185	189	198	210	218	220	220	216	210	199	196	195	205
1898	196	201	207	220	223	224	219	214	206	201	198	195	209
1899	198	193	202	208	215	218	212	207	202	197	197	191	203
1900	191	196	204	211	214	216	213	212	205	200	194	193	204
1901	191	183	180	189	199	203	203	201	199	190	187	187	193
1902	185	175	182	194	202	208	222	222	214	212	206	201	202
1903	....	....	....	....	....	....	....	....	....	....	....	....	213
1904	....	....	....	....	....	....	....	....	....	....	....	....	215
1905	....	....	....	....	....	....	....	....	....	....	....	....	208

* From Rept. of Chief of Engineers, U.S.A., pp. 2875-76, 1903.

TABLE II.—MEAN MONTHLY DISCHARGE OF ST. CLAIR RIVER IN UNITS OF A THOUSAND FEET.*

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean.
1860	198	178	185	201	230	254	259	257	254	245	242	231	228
1861	182	163	171	191	231	257	263	266	265	260	251	225	227
1862	190	171	174	194	230	247	249	252	248	259	252	213	223
1863	189	167	171	188	223	241	239	241	239	235	237	197	214
1864	178	158	163	183	220	231	235	234	226	213	208	193	203
1865	157	140	148	174	205	217	231	232	229	224	210	196	197
1866	156	132	138	163	195	208	215	218	214	211	210	191	187
1867	163	145	154	176	208	226	212	212	227	220	210	186	198
1868	155	135	152	168	201	214	215	209	204	201	200	200	188
1869	151	133	134	157	192	209	218	226	225	218	218	207	191
1870	168	151	161	186	221	239	242	240	216	237	227	196	210
1871	182	161	178	198	233	250	251	243	235	225	221	191	214
1872	162	139	143	160	195	219	225	221	220	216	213	209	194
1873	155	135	142	166	204	225	230	231	228	232	231	203	198
1874	176	160	168	181	210	235	238	235	232	226	211	207	207
1875	165	145	151	171	206	230	233	233	238	233	233	229	206
1876	177	157	165	186	226	248	262	263	267	258	254	218	223
1877	190	171	175	193	224	246	249	247	241	237	233	212	218
1878	183	160	169	184	220	239	238	236	231	235	234	196	210
1879	173	149	153	170	201	196	215	213	213	208	208	201	192
1880	164	143	148	165	201	222	230	229	228	219	217	217	199
1881	166	154	159	176	210	225	230	225	224	237	240	213	205
1882	181	157	165	185	217	223	228	230	228	236	230	229	209
1883	176	156	162	179	218	238	243	252	219	243	255	219	216
1884	192	170	176	198	231	245	247	248	241	251	245	227	223
1885	190	170	175	193	229	254	258	262	261	258	251	223	227
1886	194	177	185	207	242	272	266	262	259	257	253	204	232
1887	187	171	180	195	227	248	251	246	238	236	226	203	217
1888	169	148	157	175	212	240	236	239	232	227	222	190	204
1889	167	147	152	166	198	214	222	222	219	213	205	191	193
1890	158	137	142	161	195	206	214	218	213	209	202	175	186
1891	154	132	137	159	193	202	201	200	195	187	180	178	176
1892	142	123	128	146	177	185	193	199	195	195	190	182	171
1893	140	120	127	150	191	219	208	205	200	196	193	182	178
1894	148	129	137	158	194	210	215	208	204	199	197	159	180
1895	144	123	128	146	178	189	187	184	182	178	168	166	164
1896	127	110	114	131	167	177	177	175	174	169	171	174	156
1897	134	113	121	144	183	195	199	200	195	188	186	196	171
1898	138	120	130	155	186	194	196	195	192	186	183	179	171
1899	140	117	125	144	183	199	207	204	202	192	190	186	174
1900	141	122	128	147	178	187	192	194	200	200	202	179	173
1901	149	127	132	157	190	207	210	212	202	200	196	179	180
1902	144	121	124	145	178	192	190	194	190	180	182	169	167
1903	....	....	....	....	....	....	....	....	....	....	....	....	....
1904	....	....	....	....	....	....	....	....	....	....	....	....	†170
1905	....	....	....	....	....	....	....	....	....	....	....	....	†179

*From Rept. of Chief of Engineers, U.S.A., pp. 2874-'75, 1903.
† Approximately.

TABLE III.—MEAN ANNUAL DISCHARGES OF ST. LAWRENCE AND ST. MARY RIVERS.*

Years.	Saint Lawrence.	Saint Mary's.
1860	271,510	91,429
1861	287,921	92,223
1862	288,625	86,540
1863	277,158	79,934
1864	271,063	73,733
1865	269,369	81,569
1866	250,559	81,294
1867	268,441	85,763
1868	236,011	81,974
1869	260,929	88,434
1870	287,209	82,460
1871	251,596	74,591
1872	217,423	77,959
1873	244,173	82,462
1874	261,439	82,397
1875	228,842	85,245
1876	275,449	91,235
1877	244,376	82,768
1878	260,138	73,475
1879	251,966	60,635
1880	242,402	69,637
1881	234,732	78,347
1882	261,593	77,508
1883	264,699	73,252
1884	279,607	69,912
1885	268,382	75,173
1886	287,753	71,539
1887	273,812	70,296
1888	242,381	66,956
1889	247,784	67,532
1890	274,235	65,174
1891	249,782	58,199
1892	231,594	57,427
1893	246,915	63,048
1894	241,539	74,143
1895	203,625	76,796
1896	212,293	77,978
1897	217,155	78,879
1898	231,123	72,231
1899	226,661	85,655
1900	227,714	87,211
1901	226,499	87,220
1902	232,100	......
1903	245,800	......
1904	262,300	......
1905	255,300	......

*Report of Chief Engineers, U.S.A., pp. 2872-73, and 2877, 1903.

APPENDIX VII.

The following is a reprint of the original abstracts which formed the caveat of the discovery of the diversion of the Huron waters from Lake Erie, which became shrunken to a pond, and the subsequent overflow of the Huron waters into the Erie drainage. The channel of the buried Laurentian valley between Georgian bay and Lake Ontario, as also other features connected with the lake history, were described for the first time in the abstract reprinted here.

Notes on the Origin of the Great lakes of North America.

BY J. W. SPENCER.

(Read before the Cleveland meeting of the American Association for the Advancement of Science, 1888.) Proceedings of American Association for the Advancement of Science, volume xxxii, pp. 197-199.

ABSTRACT.

Discovery of the ancient course of the Saint Lawrence river.—Previous investigations by the author showed that there was a former river draining the Erie basin and flowing into the extreme western end of Lake Ontario, and thence to the east of Oswego, but no further traceable, as the lake bottom rose to the northeast. Upon the southern side there was a series of escarpments (some now submerged) with vertical cliffs facing the old channel. By recent studies of the elevated beaches it is demonstrated that the disappearance of this valley of the Saint Lawrence was one with that of Lake Ontario. Recent discoveries of a deep channel, upon the northern side of Lake Ontario (a few miles east of Toronto), and of the absence of rocks to a great depth under the drift, far beneath the surface of Lake Huron, between Lake Ontario and the Georgian bay,—and in front of the Niagara escarpment, between these lakes,—

of a channel in Georgian bay at the foot of the escarpment, and of the channel across Lake Huron, also at the foot of a high submerged escarpment, show that the ancient Saint Lawrence during a period of high continental elevation rose in Lake Michigan basin, flowed across Lake Huron basin, and down Georgian bay and a channel, now filled with drift, to Lake Ontario; thence by the present St. Lawrence valley to the sea —receiving on its way the ancient drainage of the Erie basin and other valleys.

ORIGIN OF THE BASINS OF THE GREAT LAKES.

The two questions involved are the 'origin of the valleys' and the 'cause of their being closed into water basins.' The basins of Lakes Ontario and Huron are taken for consideration. The previous paper upon the course of the ancient St. Lawrence shows that the Huron and Ontario basins are sections of the former great St. Lawrence valley, which was bounded, especially upon the southern side, by high precipitous escarpments, some of which are submerged. Upon its northern side there were lesser vertical escarpments, now submerged, with walls facing the old valley. The valley was excavated when the continent was at a high altitude, for the eastern portion stood at least 1,200 feet higher than at present, as shown by the channels in the Lower St. Lawrence, in Hudson straits and off the New York and Chesapeake bays. The valley was obstructed in part by drift and in part by a north and northeastward differential elevation of the earth's surface, due to terrestrial movements. The measurable amount of warping defied investigation until recently, but it is now measured by the uplift of the beaches and sea cliffs. Only one other explanation of the origin of the basins need be considered—that of the 'Erosion by Glaciers,' (a) because the lake basins occur in glaciated region; (b) glaciers are considered (by some) to erode; (c) supposed necessity, as the terrestrial warping was not known.

In reply: living glaciers abrade but do not erode hard rocks, and both modern and extinct glaciers are known to have flowed over even loose moraines and gravels. Again, even though glaciers were capable of great plowing action, they did not affect the lake valleys, as the glaciation of the surface rocks shows the movement to have been at angles (from 15° to 90°) to the trend of the vertical escarpments against which the movement occurred. Also the vertical faces of the escarpments are not smoothed off as are the faces of the Alpine valleys, down which the glaciers have passed. Lastly, the warping of the earth's surface in the lake region, since the beach episode, after the deposit of the drift proper, is nearly enough to account for all rocky barriers which obstruct the old valley and form lake basins.

ESTABLISHMENT AND DISMEMBERMENT OF LAKE WARREN.

This is the first chapter in the history of the Great lakes and is subsequent to the deposit of the upper boulder clay, and therefore the lakes are all very new in point of geological time. By the warping movements of the earth's crust, as shown in the beaches—after the deposit of the later boulder clay—the lake region was reduced to sea level and there were no Canadian highlands northward of the Great lakes. During the subsequent elevations of the continent beaches were made around the rising islands. . . With the rising of the continent, Lake (or perhaps Gulf of) Warren—a name given to the sheet of water covering the basin of all the great lakes—was formed. A succession of beaches of this lake have been worked out in Canada, and from Lake Michigan to New York, extending over many hundreds—almost thousands—of miles. Everywhere the differential uplift has increased from almost zero about the western end of the Erie basin, to three, five, and, in the higher beaches, more feet per mile. With the successive elevations of the land this lake became dismembered, as described in succeeding papers—and the present lakes had their birth. . . . .

DISCOVERY OF THE OUTLET OF HURON-MICHIGAN-SUPERIOR LAKE INTO ONTARIO, BY THE TRENT VALLEY.

With the continental elevation described in the last paper—owing to the land rising more rapidly to the northeast—Lake Warren became dismembered and Huron, Michigan, and Superior formed one lake; the Erie basin was lifted out of the bed of Lake Warren and became drained, and Ontario remained a lake at a lower level. The outlet of the upper lake was southeast of Georgian bay by way of the Trent valley into Lake Ontario, at about sixty miles west of the present outlet of this lake. The outlet of this upper lake was twenty-six feet deep where it connected with the Trent valley, and the channel was from one to two miles wide. This, for a few miles, is cut across a drift ridge to a depth of 500 feet. With the continued continental uplift to the northeast (which has raised the old beach at the outlet, into the Trent valley, about 300 feet above the present surface of Lake Huron), the waters were backed southward and overflowed into Erie basin, thus making the Erie outlet of the upper lakes to be of recent date. This is proven by the fact that the beach, which marked the old surface plain of the upper great lake, descends to the present water level at the southern end of Lake Huron.

ERIE THE YOUNGEST OF ALL THE GREAT LAKES.

The Erie basin is very shallow, and upon the dismemberment of Lake Warren was drained by the newly constructed Niagara river (except perhaps a small lakelet southeast of Long point.) Subsequently the northeastward warping (very much less in amount than farther northward at the Trent outlet) eventually lifted up a rocky barrier and formed Erie into a lake in recent times, thus making Erie the youngest of all the lakes. The beaches about Cleveland are not those of separated Lake Erie, but belong to the older and original Lake Warren.

Note.—To distinguish from the modern, the ancient valley of the St. Lawrence, above described, is named the 'Laurentian'; the ancient river from the Erie basin, the Erigan; the Huron-Michigan-Superior lake, the Algonquin, as also the beach which marked its shores, and the river which discharged its waters by the Trent valley. The expanded, but separate, Lake Ontario is named the Iroquois, as also its principal beach, now at 116 feet above its modern surface, at the extreme western end of the lake, while at about 135 miles northeastward (near Trenton) its elevation is 386 feet.

APPENDIX VIII.

ON THE DISCOVERY OF NIAGARA FALLS AND THE NAME.

ON THE DISCOVERY.

CARTIER.—After the discovery of the northern continent by Cabot in 1497, it is said that French fishing vessels visited the Banks of Newfoundland, but concealed the knowledge of their hunting ground, so that not until the voyages of Jacques Cartier, in 1534 and 1535, were the Gulf and River St. Lawrence discovered. On October 3, 1535, Cartier ascended Mount Royal (at Montreal), and from there he saw the impetuous Lachine rapids, with a smoother stretch of the great river of Canada (St. Lawrence) extending far above. He was also shown another river (Ottawa) coming from the west. The guides indicated three rapids above the Lachine, beyond which one could navigate westward for three months without obstructions.* Accordingly Cartier was the first European to discover the beginning of the route to Niagara.

CHAMPLAIN.—The Lachine rapids were not again visited until Champlain reached them in 1603. These he tried to ascend, but failed. However, he inquired of the Indians about the head of the 'Great River of Canada,' Their accounts are given in 'Histoire de Nouvelle France' by Marc Lescarbot, published in 1609, and were taken from Champlain's 'Des Sauvages' (1604)†. These descriptions closely agree, and two of them, taken from an original copy of his Carbot (pp. 381-384), may together be briefly repeated. A third account, by other Indians, gives more details as to the St. Lawrence, differs somewhat in distances, and refers to the Thousand Islands.

After passing the Lachine rapids, at Montreal, which they could see, at a distance of two or three leagues, there is a river leading to the Algoumequin country (this reference is to the Ottawa river). Continuing up the river, they pass five rapids in a distance of eight or nine leagues, where each rapid is a

* 'Jacques Cartier and His Four Voyages to Canada.' By Hiram B. Stephens. Montreal, p. 66.

† See Quebec edition (1870), Vol. II., and "Champlain not Cartier" by Peter A. Porter, Niagara Falls, 1899.

quarter of a league. The rapids are most difficult to pass. Then they enter a river which is like a lake, fifteen leagues long according to one, and six or seven as given by the other account. (These are the rapids between the expanded portions of the St. Lawrence, forming Lakes St. Louis and St. Francis.) Beyond, they pass five other rapids in a distance of twenty or twenty-five leagues, above which they enter a 'very great lake,' 150 leagues in length according to one, and 300 leagues according to the other. At the end of this great lake (Ontario) are other falls, a league in breadth, descending with a very great current of water into the lake. Passing these falls, and having to carry their canoes, they enter another great lake, where they see no land on either side, as the lake is as large as the first. At the end of this second lake there is a sea, but beyond this second lake they have not been.

In this combined narrative is a very clear account of Lake Ontario, where they also mention what is now called the Trent river and Bay of Quinté, down which the Algounequins came to war with the Iriquois, who descended other rivers on the south side of Lake Ontario. Here is the first reference to Lake Erie, which is clearly set forth, and also to the Niagara river and the great Falls mentioned—with even an estimate of their breadth. But all these distances are largely divisible. The location of Niagara river some forty miles out of position is here only an error of detail. Such a clear account of necessity largely by diagram obtained from the Indians, who spoke a tongue that could not have been very well understood, is most remarkable; and had the book been published at a later date, one might have doubted the antiquity of the narrative. This first announcement, to the world of the existence of the celebrated Falls, must be credited to Champlain, although he never saw them, even in his later travels.

Traders and missionaries were in the region of Niagara as early as 1626 (perhaps Brulé in 1611); but they have left no account of the Falls. On Champlain's map of 1632 (of which I have seen an original copy) Lake Erie is represented rather as a strait or expanded river, with islands non-existent, or exaggerated, connecting the 'Fresh water sea of the Hurons' (Lake Huron) with the end of Lake Ontario, where Champlain locates the great falls. In the explanatory note (No. 90) in the volume he says: 'Sault d'eau au bout du Sault Saint-Louis fort haut, où plusieurs sortes du poissons descendans s'estourdissent.' Translated—"A very high fall of water, at the end of the rapids of St. Louis, where many kind, of fish in descending, are stunned.' (Lac St. Louis is the same as Lake Ontario). Champlain's map is inferior to Indians' account of Lake Erie, given a quarter of a century before, and shows no advance in the knowledge of Niagara falls.

LALEMENT AND RAGUENEAU.—In 1641, Father Lalement came from the Ste. Marie mission, in the Huron country, seemingly across the peninsula of southwestern Ontario, into the country of the 'Neutral Nation,' and thence 'four days going to the entrance of the so celebrated river of that nation, into the Ontario or Lake St. Louys.' 'The stream or river is that through which our Great Lake of the Hurons, a fresh-water sea, empties; it flows first into the Lake of Erie, or of the Nation of the Cat, and at the end of the lake, it enters into the territory of the Neutral Nation, and takes the name of Onguaahra, until it enters into Ontario.'*

In 1648, Father Ragueneau wrote: 'Almost due south from the country of the Neutral Nation we find a great lake 200 leagues in circumference called Erié. It is formed by the discharge of the fresh water sea (that is, Lake Huron) and throws itself over a waterfall of dreadful height into a third lake named Ontario.'†

While these accounts more fully describe Lake Erie and correctly locate the Niagara river, they add no information as to the character of the falls, beyond that narrated by the Indians to Champlain, although one gives the name of the river and the other mentions the falls. Who was the first European to see the falls will never be known, as he was probably among the *coureurs de bois,* or perhaps some missionary, who did not leave a written record. But he or they had made them known as 'so celebrated' when Lalement visited the river, and later, Ragueneau the falls, the names of whom thus become the pioneers them among the visitors to the region. The hostile Iroquois had turned the tide of early exploration from this region, and sent it to Lake Huron and beyond, by another route, before Lake Erie was known except by report.

LA SALLE, accompanied by Dollier de Casson and René de Gallinée, was in this region in 1669. Gallinée speaks of passing near the mouth of Niagara river and hearing the roar of the falls.‡ On his map of 1670, he says that the falls

* Jesuit Relations. 1641, Thwaite's edition, pp. 191, 193.

† Ib. 1648, (French and English edition, by Reuben Gold Thwaites, 1988), p. 63.

‡ O. H. Marshall's writings, p. 219, where he cites Galinée's Journal.

descend, according to the report of the Indians, more than the height of 200 feet.* Another map, unnamed, was made three or four years later, on which Niagara is described as 'Chute haute de 120 toises par où le lac Erié tombe dans le lac Frontenac' (Ontario).† Thus, the estimated breadth and height of Niagara falls were mentioned before the visit of La Salle and Hennepin in 1678.

Hennepin's celebrated visit was soon followed by a glimpse of the cataract by La Houtan in 1688 (who assigned a height of 800 feet to them).

CHARLEVOIX‡ was the first careful observer who visited the falls (in 1721). He estimates the crest line at 400 paces. He says that exactly in the middle, the cataract was divided in two, by a very narrow island half a mile long, which comes to a point, but that the two falls soon reunite. He tried to measure their height, and gives it at 140 feet (French). He said that the one falls had several points which jutted out, but that the other appeared very smooth. At that time the cross-fall of Hennepin had disappeared. The narrowness of the end of the island was confirmed by Kalm in 1750, and by Pierie's picture in 1768.

CAVAGNAC, the son of the Governor General of Canada, was here in 1722, and gives the height of the falls at 26 fathoms (166 English feet).

The fuller account of Kalm (1750) is reprinted in Appendix I.

This short account covers most of our information, regarding the great Falls of Niagara, which was handed down during more than a century after they were first mentioned by Champlain.

ORIGIN OF THE NAME NIAGARA.

Lalement tells us that the name given to the river, by the people through whose territory it flowed, was Onguaahra, but he gives no meaning. In the Mohawk language the name Oneagerah-Onyara as given by one, and Oh-nya-ga-ra by

* Parkman's La Salle. Notes at end of volume.

† Parkman also mentions the second man.

‡ 'Voyage to North America,' by Charlevoix. Dublin Edition, 1766, p. 206.

another,† meaning the 'neck,' in allusion to the river cutting off the Niagara peninsula between the two lakes. The Seneca Indians called them Nya-geah. The Iroquois called it O-ny-a-ka-ra, and also Oienkwara, which last meant tobacco smoke. On Sanson's map (1656) the name is given as Ongiara. They are also given as Unghiara. Hennepin gives the spelling Niagara in the map of 1683, accompanying his volume on Louisiana. In 1686, the form Oneigra was given in a document. On Ooronelli's map of 1688 the word Niagara is used. In 1701, the Senecas deeded to the English a tract of land, 'including likewise the Great Falls of Okinagaro,' and in the treaty of 1726, the word used is Oniagara. The Indians pronounced the word Nee-aug-ara. In the latter part of the Eighteenth Century it was given as Niagàra, and in the early Nineteenth Century it appeared as Niagara.

P.S.—This appendix should have been placed as the first article of Appendix I, but it was only prepared while the work was awaiting the press, and the page references in index could not be disarranged.

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† See O. H. Marshall, for many forms of the word ; also 'Brief History of Old Fort Niagara,' by Peter A. Porter. Niagara Falls, 1896.

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NOTE.—After primary references to features have been made, subsequent mention of them, when introduced in an explanatory manner, is not always indexed.