

*Outline of the Evolution  
of the Falls of  
Niagara*

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FOR THE INTERNATIONAL GEOLOGICAL CONGRESS

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OUTLINE OF THE EVOLUTION OF THE  
FALLS OF NIAGARA

Contrast with the Falls of the Zambesi

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By J. W. SPENCER, A. M., Ph.D., LL.D.

(Author of "The Falls of Niagara; Their Evolution," Etc.)

Special Commissioner of the Geological Survey of Canada, under  
the Directorates of Doctors R. Bell and A. P. Low, for  
the Scientific Investigation of the Falls of Niagara

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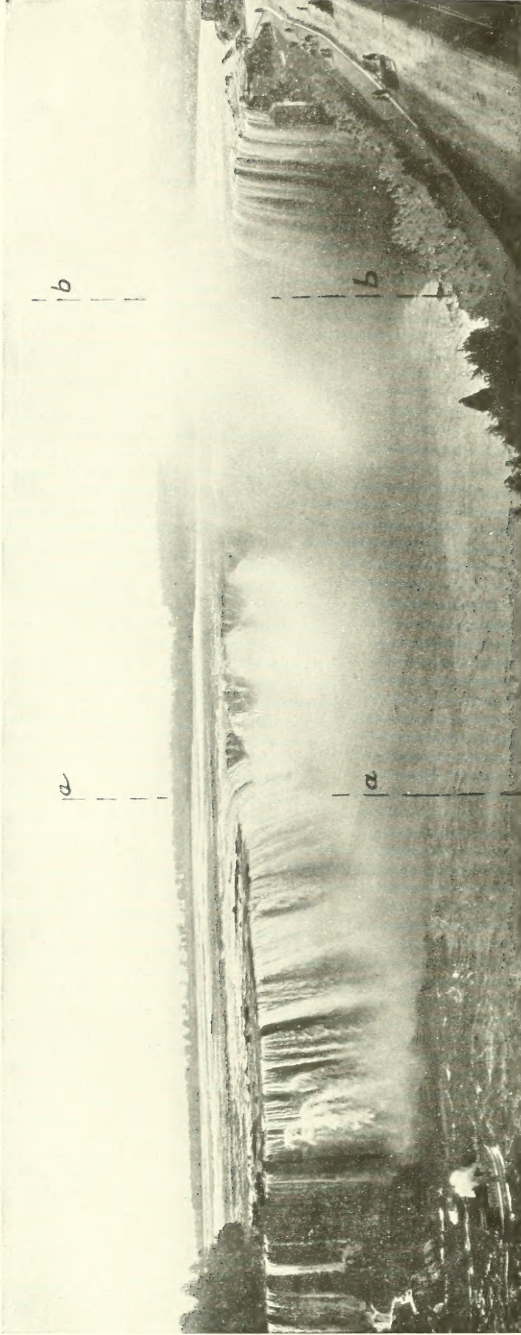


PLATE I. FALLS OF NIAGARA, CANADIAN BRANCH (LOW WATER, 1899)

Carrying 65 per cent of total discharge. (By permission of the Baker Art Gallery, Columbus, Ohio.) Sheet of water to the right of line *b b* (west side) has since been curtailed 415 feet. The falls to left of line *a a* are being drained by the diversion for power purposes, which will further reduce their perimeter by 800 feet upon the full use of the franchise amount.



## For the International Geological Congress

### OUTLINE OF THE EVOLUTION OF THE FALLS OF NIAGARA:

#### CONTRAST WITH THE FALLS OF ZAMBESI

BY J. W. SPENCER, A. M., Ph. D., LL. D.

(Author of "*The Falls of Niagara; Their Evolution,*" etc.\*)

THE MAGNITUDE OF NIAGARA FALLS has popularly made them "America's unique and greatest natural feature." Their evolution is more wonderful. In geological chronology they are most important. Their development doubtless may seem complex to and bewilder the superficial observer, but the student can see that the changing history is due to two or three primary causes.

The ordinary waterfall only requires a stream to descend somewhat abruptly from a higher to a lower country, having begun its descent at a not distant date in the past. The character of the rocks determines whether the form is a cataract or a series of rapids. Its age should be found by dividing the length of the gorge by the rate of recession of the fall, if such can be determined. These factors are known at Niagara, where, however, the results have been modified by great variations in the volume of water and in the height of the fall.

The variation of the volume of Niagara River has been due to earth-movements affecting the whole lake region, whereby the discharge of the river was increased. The Falls have also varied in height in both directions. The increasing height was caused by the lowering of the waters of the Ontario basin, due to the withdrawal of the ice-sheet, and the subsequent reduction in height was due to the raising of the lake level, owing to the recent tilting of the region. The complexity lies in the student being compelled to take into consideration many measured physical data which are not generally presented to the geologist.

The student of physical geography must refer to the author's full works, where the original discoveries of the great changes occurring in Niagara River have been described. Some of the features briefly men-

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\* "*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, pp. xxxi + 490, with many maps and illustrations, 1907, Geological Survey of Canada.

tioned will make the casual visitor better understand the exceptional character of the Falls of Niagara.

The crest-line of the double cataract (including Goat Island) was a mile long before it was shortened by 415 feet (1901-1903) at the Canadian end, due to the installation of power plants, leaving the "Canadian Falls," or greater cataract, 2,500 feet broad, and the smaller one—"American Falls"—1,000 feet wide. The height of the main Falls is 160 feet, but this begins at the foot of the upper rapids, which descend 55 feet. These rapids, however, have not been made by the river proper, but are primarily due to the water flowing down the side of a preglacial valley which trended to the southwest and joined the "Eriegan River," or ancient outlet of the Erie Valley, situated 12 to 14 miles west of the Falls. The grandeur of the Upper Rapids, as seen from the Canadian Park before the construction of the power-houses, was not inferior to that of the Falls themselves. The mean volume of the water descending the main falls was 194,000 cubic feet per second, with 10,000 cubic feet additional flowing over the American Falls. Thus 95 per cent of all the water passes over the Canadian Falls.

Only a few centuries have elapsed since the two cataracts were united below Goat Island, and only a few more will be required before the main falls will have receded above the island, thus causing the diversion of the water from the smaller cataract.

The water in the cauldron below the great falls has a depth of 72 feet to the loose blocks of limestone, which have fallen, owing to the removal of the soft underlying shales, etcetera. The depth of the water is here about 100 feet; but a quarter of a mile below the apex the deeper inner channel reaches to 192 feet, or to 94 feet below the level of Lake Ontario. For a distance of two miles below there is a navigable stretch of river having approximately the same depth. This is in the wide portion of the gorge, which in some places exceeds its mean breadth of 1,200 to 1,300 feet. Immediately beyond, the gorge becomes narrow, shrinking to 700 feet in width. Here the waters dash over the great blocks of limestone which give rise to the Whirlpool Rapids, with a descent of 52 feet, and reach the celebrated Whirlpool. Its measured depth is 126 feet; but as the points sounded were not quite in the middle of the outlet, this may be increased to 140 feet, or 94 feet below the level of Lake Ontario, which is the depth of the river above the rapids (see map).

The Whirlpool is situated at the head of a deep preglacial valley formed by an ancient small stream flowing northwestward (as discovered by Lyell, who, however, erroneously thought that it was the course of the ancient Niagara River. In 1881, Spencer first showed that the en-



ture river is modern). This channel was refilled by the drift of different Glacial epochs, which has been penetrated to a depth of 226 feet without reaching the bottom. This buried gorge has been reopened by the modern river with the formation of the Whirlpool itself. The narrows of the Whirlpool Rapids represent the shallow upper extension of the same buried valley, deepened by the modern falls (but also at a time when the volume of the river was temporarily reduced (Taylor)) to conform with the slope of its bed above and below this section. Here the river-made channel has been partly refilled by the masses of rocks which have since fallen into it (from the sides of the gorge), thus producing the Whirlpool Rapids.

A quarter of a mile below the Whirlpool the maximum depth of the river is reduced to 100 feet. In the direct line beyond, the whole natural breadth of the gorge is occupied by Foster's Flats, around which the narrow river channel curves at Foster's Rapids.

Foster's Flats preserve the most wonderful records in the history of Niagara River. Here are terraces, covered with hard rock strata, which once formed the floors of three separate cataracts, thus registering the heights of the extinct series of waterfalls. (The upper two were each about 120 feet high at this point; the lowest had a variable history of having once a great height reduced again.) Not only this, but the upper two cataracts were here united into one. The lowest floor (composed of hard sandstone resting on soft shale) was broken through at the head of the Flats when the volume of water was increased by the additional discharge from Lake Huron and the upper lakes; for until the falls had receded to this point, Niagara River drained only the waters of Lake Erie. Henceforth Niagara River was increased to nearly seven times its original volume. Heretofore the drainage of the three uppermost lakes had been to the eastward; but a differential tilting of the earth's crust had turned the drainage southward into Lake Erie and the Niagara (3,500 years ago). The lowest fall had been at the foot of the Flats; but later it channeled through the Flats. All the cataracts were then united.

While the head of Foster's Flats is situated about four miles below the Falls, the distance from this point to the foot of the gorge is scarcely three miles. In this distance the most important feature is a peculiar lateral chasm (Smeaton Ravine), where no existing stream could have formed it. However, it was due to a small stream flowing from the river itself around a little island, after the falls had receded above this point (see map).

The end of the cañon of Niagara is characterized by a series of terraces or other deserted shorelines which mark the lowering of the lake waters with the increasing height of the falls. At their birth the falls were only 35 feet high. As they were intermittently increased in height a series of cascades was formed, due to the harder layers of rock. After the waters had fallen below the level of the Iroquois Beach, the lowest of the great cataracts came into existence, descending from the Medina sandstone, now forming a splendid terrace at the mouth of the gorge. But the level of Lake Ontario continued to recede until it was twelve miles distant, subsiding nearly 180 feet below the present level (as found by soundings within and without the end of the cañon). This last cataract eventually reached a height of over 300 feet; but the volume of the water was only that from Lake Erie (15 per cent of the present). The strata beyond, all the way to the lake, were soft shales or drift materials and easily removable, not being protected by layers of hard rocks.

But the same tilting of the earth's crust which turned the waters of the upper lakes into the Niagara also raised the outlet of Lake Ontario and lowered the height of the lowest cataract by nearly 180 feet, which was further reduced when it had reached Foster's Flats, owing to a slight tilting of the rock strata.

The nearly horizontal strata are remarkably uniform in their character. The uppermost beds consist of hard Niagara limestone resting upon Niagara shales. Beneath these are the hard bands of Clinton limestone, underlaid by variable, easily yielding strata. Next comes the durable Medina sandstone, with hundreds of feet of shales beneath.

The buried valleys produced relatively little effect upon the whole recession of the falls, the greatest amount being at the Whirlpool, which was equivalent to the omission of only about 700 feet of solid rock in the direct course of the river.

Under the laws of erosion the recession in the same kind of strata varies according to the volume of the river and the height of the falls. The Falls of Niagara are receding at the mean rate of 4.2 feet a year. Taking the variations at each point of the excavation of the cañon, it is found that the recession of the falls for the upper four miles has required (approximately only) 3,500 years. The falls were located at the Whirlpool 3,000 years ago. Before soundings were made under the Canadian Falls, the required time was calculated to have been 5,000 years. But the soundings revealed the fact that the falls throughout the section above the Whirlpool were higher than now, which fact shortened the first calculation of the time. Indeed, the Whirlpool Rapids were completed less than 300 years ago.



The uppermost of the cataracts below Foster's Flats presented features so uniform that the mean height could be taken at 105 feet. The volume of water, as stated, was only 15 per cent of that of the whole modern discharge. The height of the Falls at their birth (35 feet) was also considered. The calculations based upon the changing physics give 35,500 years as the time required for the excavation of this lower and older section of the cañon. Accordingly, the whole life of the Falls of Niagara is calculated at approximately 39,000 years. There does not appear to be any feature of great importance affecting the age which has been overlooked. Recasting the use of the data (determined by measurements) and minor variations would not indicate a greater variation than ten per cent, or 4,000 years, unless the measurements be replaced by speculations based upon *a priori* deductions. If new discoveries should be made, the computations might have to be amended.

The question of the age of the Falls has always awakened the greatest interest. Ellicott (in 1789) gave then 55,440 years. Bakewell (in 1829) reduced the estimate to 12,000 years. Lyell (in 1841) raised the conjecture to 35,000 years, which figure became popular. All of these were based upon the length of the gorge divided by a conjectural rate of recession. Pohlman was the first to use a measured rate. Gilbert (1886) adopted the maximum measured rate of recession, reducing the time thereby to 7,000 years or less. Had any of these writers used the mean rate, the result would have been 9,000 years. Upham and Wright followed with 7,000 years, but did not take into consideration the changing physics. Spencer (in 1894) was the first to apply the variation in volume, height, and measurements of the different sections, and then provisionally computed the age to be 32,000 years. Gilbert afterwards withdrew his previous figures, but has never given others. Taylor (in 1898) gave the age at 50,000 years, but added that it might be as low as the figures of Lyell or Spencer. His figures were partly based upon the changing physics and partly conjectural. Taylor is the only student of Niagara, other than Spencer, who has used in any degree the changing conditions in estimating the age of Niagara Falls. Finally Spencer's revision (in 1907, in which soundings and borings have been most important) places their age at  $39,000 \pm 4,000$  years, more likely to be in excess of than below the principal figure.

The age of the Falls does not give us the date of the close of the Ice Age. From the region to the south of Niagara the glaciers had withdrawn some thousands of years before the birth of the Falls. The glaciers left the Saint Lawrence Valley a considerable time after the beginning of the history of the Falls, but no sufficient measurements

have been made for determining the exact date, which, based upon partial data, would seem to be more like 25,000 or more years ago than only a few thousand.

The Falls of Niagara reached their greatest perimeter or breadth about 1890. Then commenced a period of low water; but when high water stages returned after 1903, the breadth of Falls had been curtailed by man, and since then much water has also been diverted for power purposes; so that the present high water has not brought back the former conditions.

The mean gross horsepower of the Falls is almost 5,000,000, but much must be lost in its application, which would reduce it for mean water to 3,200,000, or for low water to 2,600,000. About 93 per cent of all the water passes down the Canadian side of the International Boundary. When the total amount of water now allowed to be diverted shall have been used, the volume of the discharge over the Falls will be reduced to 68 per cent of the natural amount for mean stages, or to 60 per cent for very low water. The effects of diversion may now be repeatedly seen during low water and prevailing ice conditions in winter, when the American Falls are broken into fragments, and the eastern side of the Canadian Falls runs dry. When the total amount of water now permitted to be used shall be diverted, the crest-line of both falls will have been reduced from 3,950 feet (in 1900) to 2,100 feet; but in the future the Falls are destined to be destroyed by man.

The investigations of the evolution of the Falls of Niagara have been closely connected with those of the Great Lake history, which should also be consulted.

THE VICTORIA FALLS OF THE ZAMBESI (discovered by Livingstone) had been popularly so lauded as to make the great African falls almost outrival those of Niagara. The writer turned to the lengthy papers of Mr. Lamplugh for reliable data, by which to compare the two cataracts. In these were found the description of local features, which are inconsequential at a distance. The features which are consequential relate to the character of the rocks, their age, the peculiar configuration of the falls and chasm and causes therefor, the size and volume of the falls, etcetera; but concerning them Lamplugh's papers were so deficient and speculative that they throw no new light which had not been shown in the short but clear and comprehensive paper of Molyneux.\* Indeed,

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\* "Physical History of Victoria Falls," by A. J. C. Molyneux. Geog. Jour. London, vol. xxv, pp. 40-54, 1905.



Lamplugh leaves himself open to the suspicion of mistaking hurried revision for research.† But from Molyneux may be gathered the data for comparing the Falls of the Zambesi and Niagara.

The Grand Cañon of the Zambesi is more than 40 miles long, excavated out of jointed basaltic rocks covered with a superficial formation of sands. The basalts are supposed to be of Tertiary age (Mennell and Molyneux). The breadth of the river above and at the falls is 5,580 feet, or 300 feet wider than the combined falls at Niagara. In both cases the islands are included. Deducting the breadth of these, the water-line of the Victoria is 3,200 feet long, and that of Niagara was about 4,000 feet. As one looks at the African cataract, its height toward the left side is 256 feet, while it increases to 343 feet toward the right side. Niagara Falls, including the rapids immediately above, are 215 feet high. The Victoria Falls cascade over the left wall of the gorge into a chasm only from 80 to 240 feet wide. At Niagara the gorge is 1,200 to 1,500 feet wide. Below the outlet of the Zambesi chasm, which is 400 feet deep, the river turns sharply into a similar chasm a mile long, stretching diagonally across the old course of the river. This zigzag course is repeated with the amplitude of the breadth of the river before it sank into the gorge.

This peculiar feature is plainly shown on Molyneux's map as being due to the opening of joints in the rock in two sets oppositely diagonal to the main course of the river. These are opened in the bed of the

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† Although the gorge of the Zambesi below the Victoria Falls had been discovered by Livingstone so long ago, and had been specifically and appropriately designated the Grand Cañon of the Zambesi by Molyneux (there being a smaller one far up the river), yet Mr. Lamplugh offers us a new name—"The Batoka Gorge"—as if renaming constitutes the discovery, the more so as he thus entitles his paper. With such a beginning, one needs not be surprised at hypotheses in place of research. He discredits the Tertiary age of the basalts (Mennell and Molyneux). He says that the evidence of their being Mesozoic, as supposed by Passarge, is on a "highly speculative basis," but himself gives no evidence of their age. Yet in his summary Lamplugh says that they are "probably Mesozoic." Again, in describing the superficial sands, Lamplugh adds: "The hypothesis that they are wind-blown under conditions different from those which now prevail agrees best with the general characteristics," without telling us how the wind acted differently. Such other speculations resulted from his very brief visit to the Zambesi. While his map indicates a jointed structure of the rocks, it gives no idea whatever of the manner of development of the Victoria Falls alternately from one side of the chasm to the other in place of at the end of the gorge, which is its most wonderful feature. (Brit. Assoc. Ad. Sc. Rept. for 1905, pp. 292-304; Quar. Jour. Geol. Soc. London, vol. lxiii, pp. 162-216; Geog. Jour. London, vol. xxxi, pp. 133-152, 287-303, 1908.)

river before it descends into the chasm. In course of time these submerged channels become so deep as to take the whole volume of water and thus withdraw it from the recent long crest-line. Now the stream runs around the newly formed spur, with the water cascading in the new chasm, but down the opposite side from that of the previous one. This alternating process is repeated, thus giving the Falls of the Zambesi their unique character. It would be difficult to conjecture the rate of recession, although obviously faster than if the erosion were at the head of the gorge, as in the case of other cataracts.

The rainfall in this African country occurs mostly in February and almost entirely within five months, so that the volume of the Zambesi is sometimes very large and at others very small. While the measured mean discharge of the river could not be obtained from the Chartered Company which has obtained control of the power, it is apparently much less than at Niagara. Under all of these conditions, the Victoria Falls may be considered a grand rival of Niagara and also unique, but not as eclipsing our famous American cataract or giving any measurements of geological time.

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NOTE.—In the investigation of the physical problems of Niagara Falls, the fundamental researches of Messrs. Thomas Russel and E. S. Wheeler (U. S. Corps of Engineers) are indispensable.



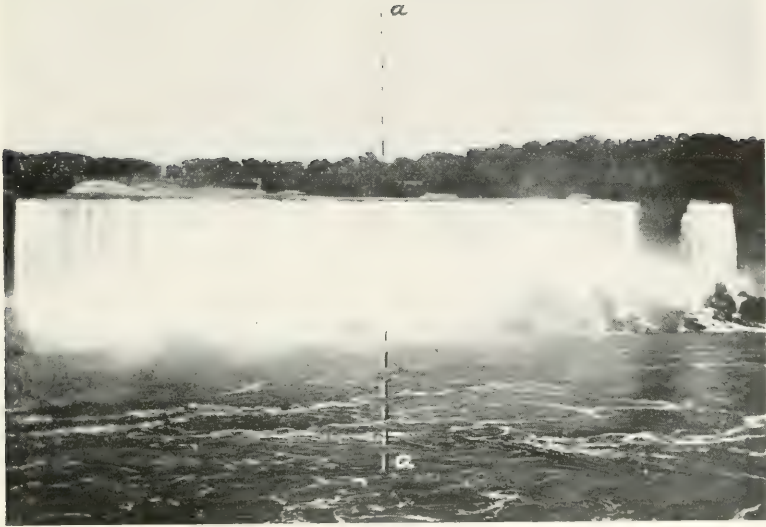


PLATE IIA. FALLS OF NIAGARA, AMERICAN BRANCH

The half of the falls on the right side of the line *aa* will be drained, and the other half broken by the full use of the franchise amount

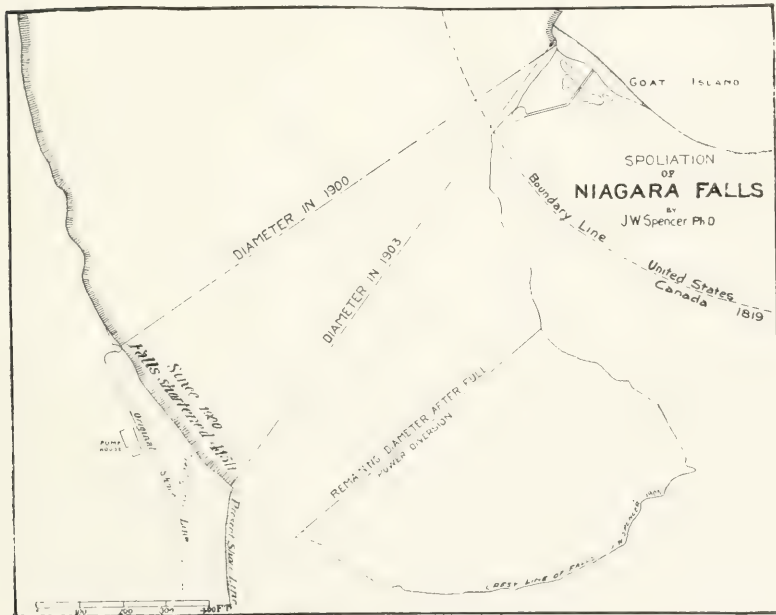


PLATE IIB. MAP OF CREST LINE OF THE FALLS IN 1905 (SPENCER)

Being shortened from 2,950 feet (in 1900) to 1,600 under full franchise diversions, and diameter curtailed from 1,200 to 800 feet









MAP  
of course of  
**NIAGARA RIVER**  
by the route from Niagara Falls  
to NEW YORK CITY  
**PHYSICS OF THE FALLS**  
by  
J. W. SPENCER, M. A., Ph.D., F.R.S.  
1895

REPR. DUCTILE FROM THE ORIGINAL DRAWING  
SCALE REDUCED ONE HALF





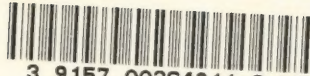








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