

POSTGLACIAL EROSION AND OXIDATION¹

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EROSION IN THE VALLEY OF THE GREAT LAKES

Northern Ohio furnishes unrivaled opportunities for estimating the amount and rate of erosion since the final withdrawal of Wisconsin ice from that region. The watershed between the basin of the Great Lakes and that of the Mississippi Valley is nowhere more than 100 miles south of Lake Erie, averaging not more than 50 miles. The elevation of the cols through which the drainage passed into the Mississippi Valley, as the ice retreated northward from the watershed, ranges from about 300 feet above Lake Erie, at Warren, Ohio, and Lodi, to 200 feet at Fort Wayne, Indiana. Of these, the col at Fort Wayne is most important in regulating the level of the temporary glacial lake which was formed north of the watershed. The occupation of this col by the drainage stream was so long that a well-defined shoreline, 200 feet above Lake Erie, can be traced across Ohio for hundreds of miles. This affords an excellent starting point for forming estimates of post-Glacial erosion; for, while south of the watershed the problems are complicated by the effect of the streams during all the period which elapsed while the ice was retreating from the southern boundary to the watershed, north of this watershed there is no such complication. The entire amount of work accomplished since the opening of the channel at Fort Wayne and the formation of the 200-foot shoreline south of Lake Erie, is everywhere open to inspection.

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tion. Even a cursory examination of these streams can not fail to impress the observer with the small amount of work which has been done by them; while in the case of Plum Creek, in Oberlin, an unusual opportunity has been offered for definite calculations.

Plum Creek is a branch of Black River, draining an area of 25 or 30 square miles. At Oberlin the elevation of its bed is 800 feet above sea-level, or approximately 235 feet above Lake Erie, which is distant 10 miles in a direct line. The descent from Oberlin to the falls in Black River at Elyria, 8 miles distant, is 100 feet, or 12 feet to the mile. But the bottom of its trough averages 17 feet below the general level of the country. This trough is entirely one of erosion, the original stream having begun its work 250 feet above the level of Lake Erie and 50 feet above the 200-foot shoreline, which is 5 miles to the north. The region is so deeply enveloped in till that the underlying rock is nowhere exposed in the bed of the creek. The entire trough has been eroded in till, so that there is no complication of rock barriers requiring an indefinite time for removal.

A section of this trough 5,000 feet long, where it had been least modified by artificial interferences, was found to average 400 feet in width and 17 feet in depth, showing that a total amount of 36,000,000 cubic feet of till had been removed by the stream from this section since the beginning of its flow.

Opportunity to obtain an approximate estimate of the rate of erosion effected by the stream was fortunately furnished by the town's taking possession of its trough for a reservoir and their turning the drainage around through an open ditch, 14 years ago. We have thus been able accurately to determine the rate at which this stream removes the material under the new conditions produced by this change in its course. On measuring a section of this new channel, 500 feet long, and noting from year to year its enlargement, it was ascertained that the original ditch, which was 21 feet wide at the top and 10 feet at the bottom, had in 12 years been enlarged by the erosion of the stream to a width of 51 feet at the top and 17 at the bottom, showing that, from this 500-foot section, 8,450 cubic feet of material had been removed every year.

But, to make the estimate applicable to the older section of 5,000 feet, where the erosion represented the entire work since the opening of the Fort Wayne outlet, it was necessary to go into this 5,000-foot section and measure the length of the sections where the present stream is impinging against the original till bank and eroding it under conditions similar to those existing in the 500-foot cut-off. As will be seen on slight reflection, in the 500-foot cut-off the stream is acting directly upon 1,000 feet

of freshly exposed banks of till, but upon the 5,000-foot section the present meandering of the stream permits it to touch the till bank only here and there. But it was found on measurement that, of the 10,000 feet of till banks originally exposed to the action of the stream in this 5,000-foot section, 1,600 feet are still exposed to it in its meandering. On the supposition that in these exposed places the erosion is proceeding at the same rate per foot as in the 500-foot cut-off, we arrive at the conclusion that the annual erosion in the 5,000-foot section is 13,568 cubic feet.

That the rate of erosion in these exposed places is approximately equal to that in the 500-foot cut-off is evident from the fact that the water in its curves impinges against the banks in substantially the same way and with substantially the same force in the one place as it does in the other; and, furthermore, while we have not definitely measured the amount of erosion in the 5,000-foot section, we do know that great changes have been produced by the erosion there during the last few years. Large trees standing on the top of the bank have in several cases been undermined and toppled over into the stream and the top of the bank pushed back beyond the area on which they were firmly rooted.

Dividing 34,000,000 feet of material, the total amount removed from the 5,000-foot section, by 13,568, the number of cubic feet estimated to be annually removed by the stream at the present time, we find that the whole work would be accomplished in 2,505 years—a result so startling that we are compelled to study carefully the modifying conditions under which the erosion has proceeded. Some of these we shall find to be retarding in their effect, while there are others that will be accelerating. The principal retarding conditions are connected with the existence of the forests which prevailed over the area for an indefinite period of time previous to the advent of civilized man a hundred years ago. While we have no definite calculation on which to base an estimate of this retarding influence, I have thought it safe to assume that it would not be more than tenfold, so that the erosion in the forest would accomplish as much in 1,000 years as would be accomplished under present conditions in 100 years. This would extend the time to 25,000 years.

But there are various considerations which would cut down this estimate, the chief of which is that the present exposures to erosion in the 5,000-foot section are at a minimum in their extent. Originally the conditions were identical with those produced in the cut-off around the reservoir; that is, the creek was a narrow stream eroding from both banks throughout the entire distance. As the stream enlarged its trough and began its meanderings, the exposures to erosion became less and less, but the average would be twice those of the present time, thus reducing the

period necessary to effect the observed results to 12,500 years, which probably is not far from correct.

There are, however, some other modifying causes on both sides which must be considered. In the cut-off around the reservoir the shortening of the course has slightly increased the gradient of the stream through that district. This would evidently increase its efficiency. But, on the other hand, the original gradient (about 12 feet to the mile) with which the stream began its work would have been the same as that in the cut-off at the present time. Again, the retarding influence of the forests would not begin until some time subsequent to the beginning of the erosion. Probably, also, the precipitation in that early period was much larger than now, thus increasing the early rate of erosion. These things may therefore be permitted to balance each other so nearly that the withdrawal of the ice from the northern part of Ohio is to be measured by *thousands* of years rather than by *tens of thousands*, fully sustaining the general impression which is made upon the observer almost everywhere in the entire section of country.

As this region is 300 miles south and west of the Mohawk and Saint Lawrence valleys, it is evident that the opening of the drainage lines, which would permit the Niagara River to begin its erosion of the gorge above Lewiston, must have been considerably later—probably two or three thousand years later. This we should infer from the size of the various shorelines or lake ridges which occur south of Lake Erie, and from our general impression of the rapidity with which the ice-front retreated. At any rate it is impossible to extend the age of Plum Creek sufficiently to be consistent with a date of thirty or forty thousand years for the beginning of the erosion of Niagara. There must be some error in the data from which those calculations have been made which give tens of thousands of years to the age of the Niagara gorge.

A similar conclusion follows from my observations upon the lateral erosion at the mouth of the Niagara gorge, detailed in the *Popular Science Monthly* for June, 1899, and the *American Geologist*, volume 29, pages 140-143, and summarized in the fifth edition of the *Ice Age in North America*, pages 548-552.

STREAM EROSION SOUTH OF THE SAINT LAWRENCE-MISSISSIPPI WATERSHED

In considering the effects of stream erosion in front of the continental ice-sheet in the channels which opened freely to the south, we have to bear in mind the enormous floods of water set free by the melting ice.

In the Missouri River² we have direct evidence, in the boulders which were carried to Tuscombina, 60 miles up its southern tributary (the Osage River), that there were annual floods, in the latter part of each summer during the closing stage of the Iowan epoch, rising to a height of 200 feet. Floods to this extent are also made to seem credible from the amount of ice which the sun would be capable of melting over the glaciated area tributary to the Missouri River. Floods of similar dimensions must also have poured through troughs of the Ohio and Alleghany rivers. So enormous were these floods that it is difficult to set limits to the work accomplished by them. Wherever they or their tributaries were eroding channels they would effect results which can not be measured at all by the work accomplished by present comparatively insignificant streams.

On the other hand, in the Alleghany Valley there are certain features of deposition, pointed out by Prof. E. H. Williams, which indicate an entirely different interpretation from that ordinarily given of the high-level gravels which border the Alleghany River throughout its entire middle and lower course. Mr. Williams has pointed out that these deposits uniformly occur where a tributary glacial stream came in with sufficient force to throw coarse gravel to a high elevation on the other side, as at Kenerdell, where tributary streams from the melting ice-front near by came into the Alleghany River at right angles, through Scrub Grass Creek, with power sufficient to push gravel up 300 feet upon the opposite side. Lower down the stream, beyond the direct influence of glacial tributaries, the high-level gravel terraces occur below bends in the trough of the river where the direct action of the swollen current would throw gravel on and over the rock shelves which furnished the most direct outlet for the rushing torrent at that elevation.

In detailing the phenomena at Kenerdell,³ I had shown the impossibility of considering this gravel deposit as a remnant which had existed during the entire period demanded for the rock erosion of the gorge, but had supposed that it did involve the filling of the gorge with glacial gravel and the subsequent erosion of the trough. But Mr. Williams' explanation is more credible. The plunging current from the glacial border, coming down through the trough of Scrub Grass Creek, kept the trough of the Alleghany scoured out and threw the material upon the opposite bank. Below this point the high-level gravels which I had noted, at Gates Ferry, Emlenton, Bradys Bend, Orrsville, Kittanning, Tarentum, Springfield post-office, and Verona, besides numerous intervening places, are accounted for by the shifting angles at which the glacial tor-

² See *American Geologist*, vol. 33, April, 1904, pp. 205-222.

³ See *American Journal of Science*, vol. 47, March, 1894, p. 175.

rents impinged on the sides of the deeply eroded rock channel. At Alleghany City and below Pittsburgh the same forces were at work, modified by the entrance of the Monongahela River from the south and Beaver Creek from the north. By attention to these considerations these high-level terraces can for the most part be eliminated from the evidence implying a great antiquity to the closing scenes of the Glacial period in the Ohio Valley.

It is difficult for the imagination fully to comprehend the conditions attending the closing stages of the Glacial epoch in the upper Alleghany Valley, for down this valley there escaped the drainage from north-western Pennsylvania, western New York, and a good part of Ohio drained by French Creek and the Beaver, producing a deep, torrential stream whose surface was covered with bergs and smaller masses of floating ice dropped from more than 100 miles of ice-front. Two different forces were at work tending to deposit high-level gravel and at the same time to keep the main channel well scoured and free from sediment. I quote from a private communication from Professor Williams, after the completion with ample assistants of his survey of the region during two seasons:

"1°. The abnormal amount of berg material from so long a front would not go sailing quietly down the stream, but would go grounding on the margins, heaving and tossing in midstream, choking up narrow passages to form temporary ice dams, which would raise the level of the flood till the pressure was sufficient to break the dam, when away the mass would go on a wave that would send a part of the ice on high shelves, where it would strand above the average level. I have seen in our little stream here in Woodstock [Vermont] such a wave to carry debris 30 feet above stream level. This spring [1910] the ice will leave a deposit of (average) 6 inches deep up to 10 feet above the average level and the greatest thickness of the ice pile was only 12 feet.

"The overwash from the glacier carried both free gravels and gravels frozen in masses of ice. The carrying power of ice has not been as fully considered as it should be. Ordinary freshets in Vermont streams, with break-up of ice in spring, show that ice 2 and 3 feet in diameter, frozen down to the stream bottom, will lift and carry when the break-up comes stones up to one ton weight. I have an instance of such a stone left, with gravel heaps, in a mowing 50 feet from the water's edge, and every year the Vermont farmers have to clear away gravels with cobbles weighing anywhere from a pound to 50 pounds. We can now see that the overwash of a glacier would carry everything of small enough mass to be influenced by the force of the current. This accumulation would be of sands and clean gravels of certain size and sands and boulders frozen in ice, the latter being of many times the size.

"A current of 1 foot per second will carry sands. The transporting force of a current varies as the sixth power of the velocity. A current 3 feet per second or 2 miles per hour will move stones 3 ounces in weight (hen's egg); a torrent⁴ of 20 miles per hour will carry fragments of 100 tons weight.

⁴ See Le Conte's *Geology*, pp. 19 and 20.

"Now, this is merely a torrent carrying clean stones. If we have these stones mingled with ice (not frozen to them) the carrying power of the ice aids the current, as the torrential power of the water drives ice and stones together wherever the current reaches to the bottom of the trough.

"If we in addition consider the ice actually frozen to the stones we shall see that there is nothing to prevent the statement that gravels of any size may be transported in a glacial overwash.

"2°. A second deposit due to ice, which would also be stratified, would occur when the current, which is always more sinuous than the channel, would strike against a gentle slope and force the large cakes with their high momentum sliding up the slope. This is the case of sporadic gravel patches along the Juniata, which are over 100 feet above present water level, while the average of the gravels is but 80 feet above that level.

"3°. Wherever a sudden widening of the valley formed a cove, across which the current did not flow, an eddy would form, and into the cove would drive the bergs, circling in a path influenced by the contours of the sides and dropping their burden from the grinding action of the mass rather than its ablation. This would not be usual iceberg clay formed in still water, but a more or less stratified mass. A very good example is Fountain Hill, a part of South Bethlehem, Pennsylvania, which is an eddy hill formed of gravels and huge masses of rock. One Medina mass was 11 feet long, 5 wide, and 3 thick. These huge stones were in the core of the hill, and around them were stratified gravel, rising over 100 feet above the present level of the Lehigh.

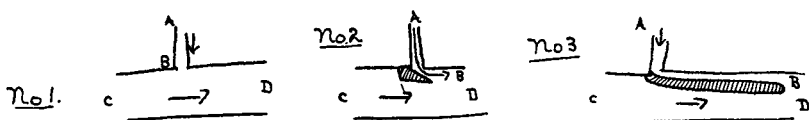


FIGURE 1.—Diagram illustrating the Effect of torrential Affluents on the main Stream

No. 1 is the state of affairs before the trouble begins. A-B is a torrential side affluent into C-D, a stream with lower velocity, and with the checking of the current of A-B there forms a sedimentary deposit which forms a ridge in the bed of the main stream.

"One thing noticeable in the Warren [Pennsylvania] gravels was the infrequent, but constant presence of large cobbles in strata of finer gravels and sands, and in a small lenticular stratum of fine quicksand was found a mass of native copper, or rather a nugget, about 5 inches long and a little thicker than the thumb. Considering the difference in size, and still greater difference in specific gravity, I felt that only floating ice could thus mix things.

"4°. The accumulations of debris dropped by the ice driven up the hillsides by momentum or sporadic dams would be, under the influence of a changeable current, diverted by lodgments of ice that did not readily dislodge, so that such a current deflected transversely to the general direction would sweep away these sporadic accumulations into still water and form a pile out of the general direction of sedimentation.

"5°. Then comes the usual case of a deposit in the form of a bar wherever the current swept round a hill; but such a deposit would run up the hill and not be isolated from it, as would be the case with the 'eddy' hills above noted.

"6°. Wherever a side affluent came in at a wide angle, there would be a tendency to form an eddy. The general case here is like a long eddy hill.

"There is one thing I have tried to keep in mind, and that is that the Alleghany deposits are the remainders of the sediments deposited before the ice reached that river, as modified by the actual presence of the ice, which probably did no work in the valley bottoms, owing to the great depth and buoyancy of the water and as further changed by the action of the retreating glacier.

"In every case of an abnormal form or situation of a deposit I have tried to imagine how the forces must have acted, and the first thing was to get the

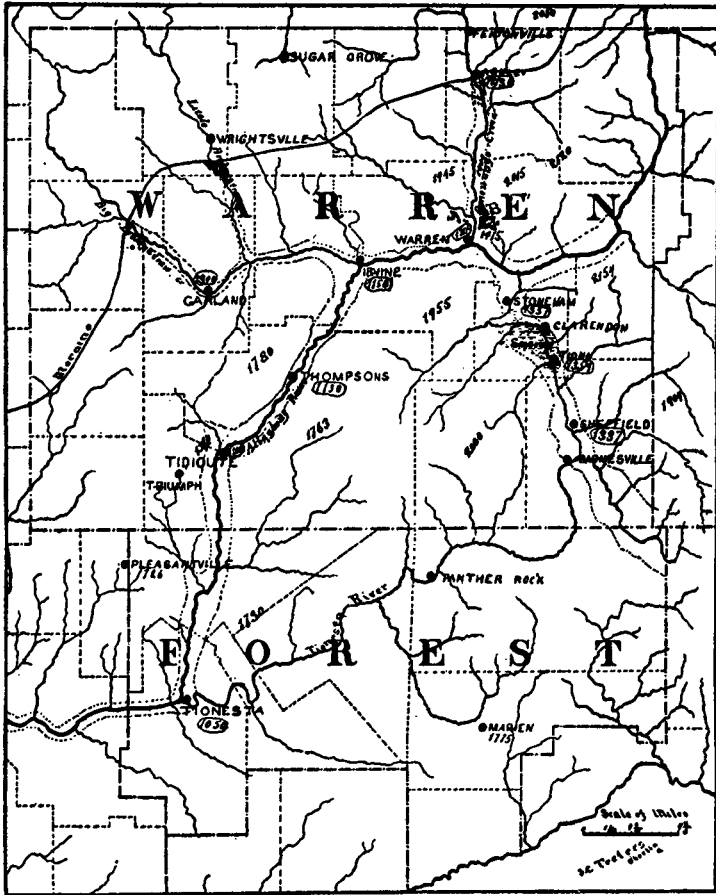


FIGURE 2.—Map of the Vicinity of Warren, Pennsylvania

depth of water and direction of flow. At one time there were two forces acting near Warren in opposite directions—the first, from upstream, filling in the north end of the valley; the second, from the Brokenstraw, filling the other end. These met about half way between Warren and Irvineton. At that time I think the col which formed the highest water and made a flow past Clarendon had not been degraded, but after it had been cut down there began the action of the forces that finally made the present Alleghany Valley.

"At Warren the drive-pipes of oil wells in many cases have been driven through the gravels from a surface hundreds of feet above the present level of the river to a depth 20 feet below the present water level, showing that the Conewango Valley was degraded before the gravels were deposited, and the river now flows on 20 feet of those gravels, and so 20 feet above the preglacial level of the valley. There is no rock shelf there, but an aggraded valley, with bed 20 feet above its preglacial level."

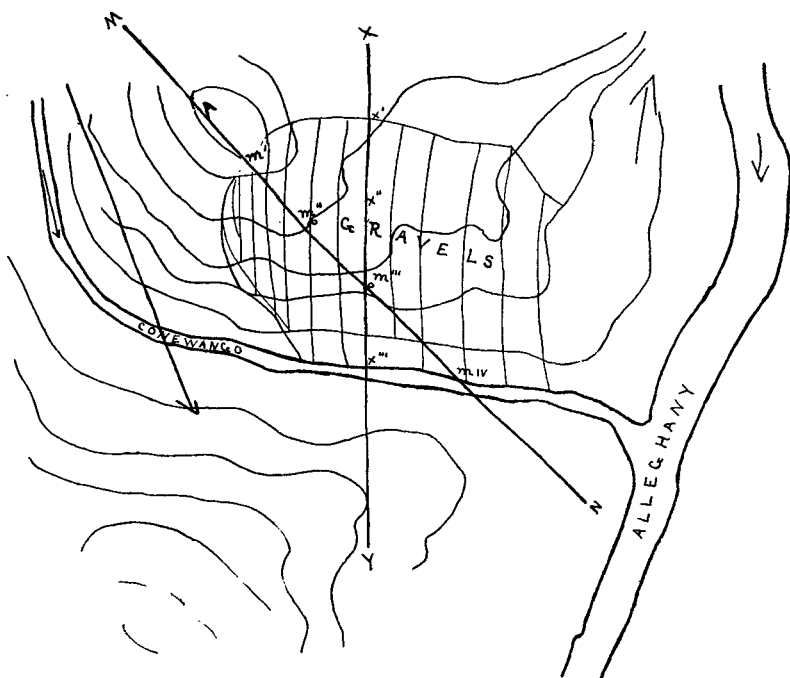


FIGURE 3.—*Topography East of Warren, Pennsylvania*

A is a hill, which deflected the glacial stream down the Conewango; m^I , m^{II} , m^{III} , m^{IV} , and x^I , x^{II} , x^{III} are places where wells have been sunk, revealing gravel as in figures 4 and 5. These high, level gravels at Warren are shown to be deposits of the Glacial age in a valley that was entirely preglacial. The force of the current was such that, while leaving these gravels in the lee of hill A, it scoured them all away from the south side of the Conewango.

SIGNIFICANCE OF ESKER TERRACES

The existence of "esker" terraces has also led, as I believe, both in this country and in Europe, to a great exaggeration of post-Glacial time. Two such series of terraces have come under my observation in Ohio, namely, in the River Styx, in Medina County, between Seville and Wadsworth, and in the Mohecan River, in Wayne County, in the vicinity of Wooster. In both cases these streams flow southward from the water-

shed and occupy wide preglacial channels about 300 feet below the general level of the country. In both cases the bottom of the troughs are about a mile in width and as level as a floodplain, but in both cases the trough is bordered upon the west side by gravel terraces from 100 to 200 feet above the present level of the stream. The readiest explanation of these terraces is that they are composed of gravel deposited by torrents from the melting ice, which flowed at that level between stagnant ice which filled the valley and the sides of the preglacial rock gorge. Russell has published photographs of a stream similarly situated, held at a level 2,000 feet above the sea, between the Malaspina Glacier and the flanks of Mount Saint Elias. Emerson⁵ has thus given a rational explanation of

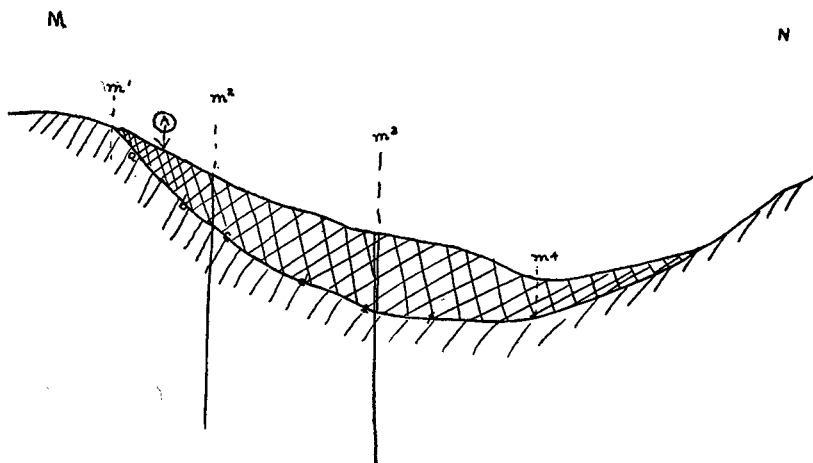


FIGURE 4.—Gravel Accumulations along Section N-M in Figure 3

A, b, c, d, e, f, marks the contour of the preglacial valley

many of the high-level terraces bordering the Connecticut River, which had formerly been explained by Professor Dana as the results of incredible floods in the open trough of the river. An interesting feature in the Killbuck, near Wooster, Ohio, is the occurrence of a deposit of till from 15 to 20 feet in thickness which has been pushed over this terrace without disturbing its bedding. The elevation is here 200 feet above the floodplain of the river. It is interesting to remark, also, that both in the "esker" terrace of the Styx and in that of the Killbuck, paleolithic implements have been reported, but on evidence less exact than is necessary to make them available for public discussion (see plate 11, figures 1 and 2).

⁵ B. K. Emerson: *Geology of Old Hampshire County, Massachusetts*. U. S. Geological Survey, monograph xxix.

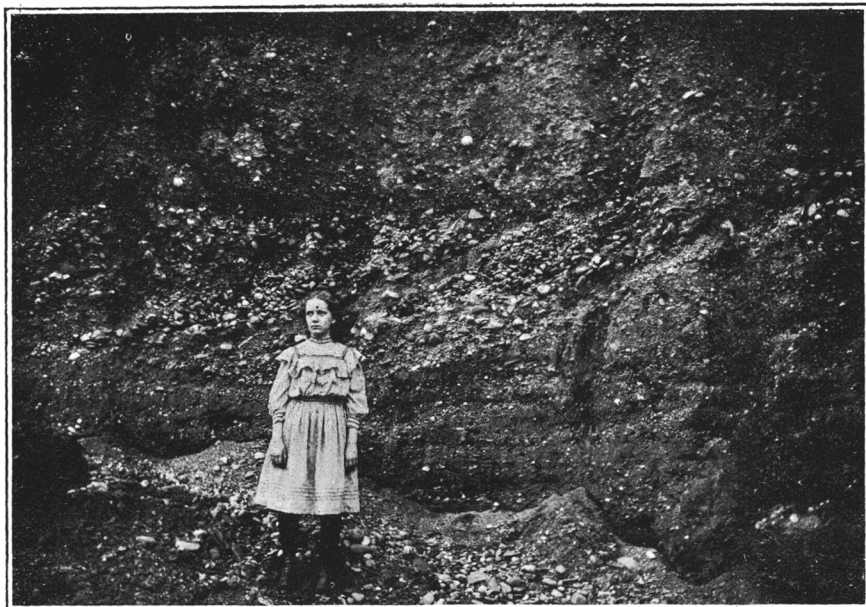


FIGURE 1.—SECTION OF THE ESKER TERRACE ON THE KILLBUCK, SOUTH OF WOOSTER, OHIO
Photo by Prof. J. J. Crumley

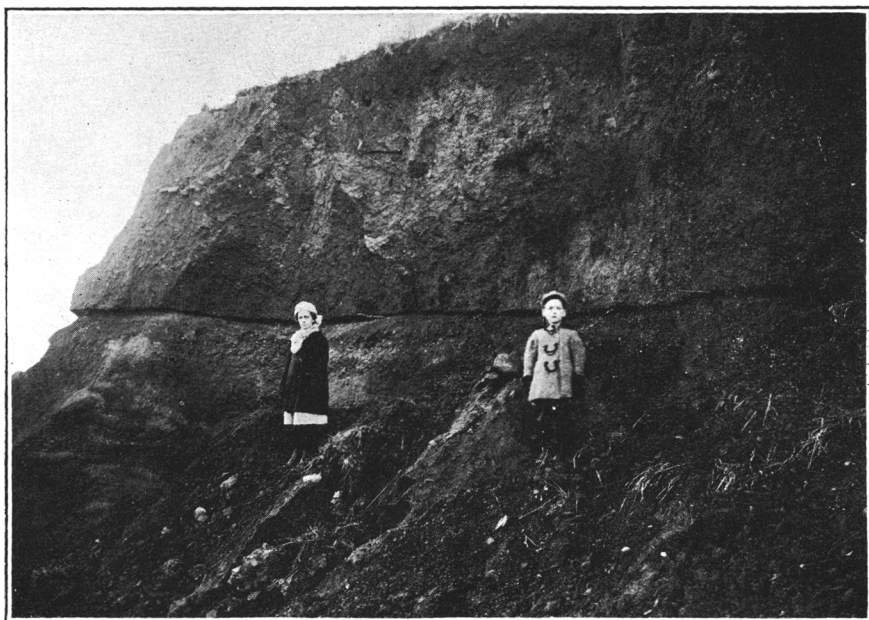


FIGURE 2.—ESKER TERRACE COVERED BY 15 FEET OF TILL

Photo by Prof. J. J. Crumley

ILLUSTRATIONS OF OHIO ESKER TERRACES

These facts become important in modifying the calculations which have been made concerning the age of the terraces in the valley of the Somme, and in those of other streams in northern France and southern England where paleolithic implements have been found. It is by no means necessary to suppose, as has been generally done, that the valley of the Somme, for instance, was first filled with gravel to the height of the 90-foot terrace and then the material eroded by the present small stream from the area occupied by the present broad floodplain. In discussions of the problem in the valley of the Somme, both Dr. Warren Upham⁶ and Prof. E. B. Tylor⁷ have maintained that these terraces were merely marginal accumulations of gravel, but neither of them has taken

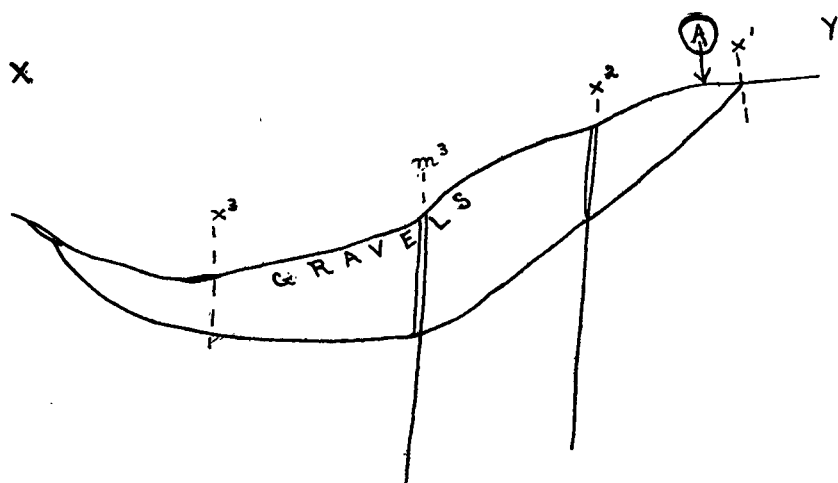


FIGURE 5.—Section X-Y of Figure 3

Showing the depth of gravel which had accumulated in the original valley, whose bottom is indicated by the lower line

advantage of the probable existence of stagnant ice in the valleys acting as a temporary barrier to determine the course of the currents which deposited the gravel.

Other more general problems present themselves in the broader areas of the glaciated region nearer the center of the Mississippi Valley. Over much of this area, as the glacial boundary is approached, the supply of drift was diminished, so that it was less and less able to fill up and therefore to disguise the inequalities caused by preglacial erosion. As good

⁶ American Geologist, vol. xxii, pp. 350-362.

⁷ Proceedings of the Geological Society, London, vol. xxiv, pp. 103-126; vol. xxv, pp. 57-100.

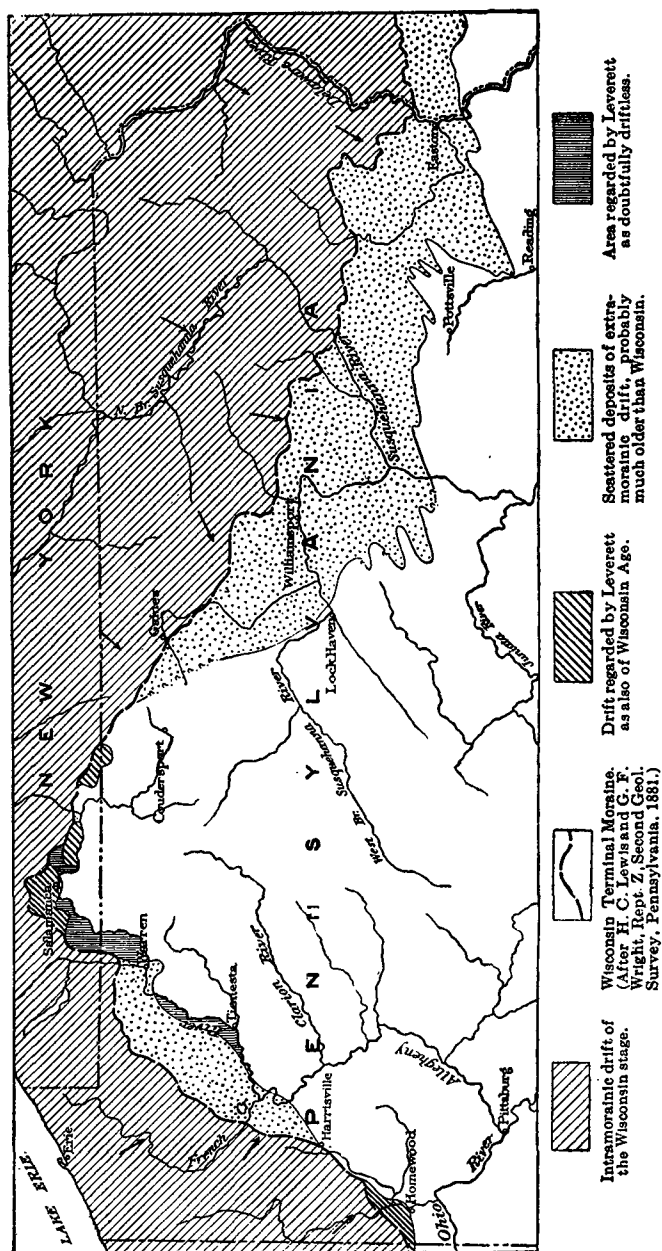


FIGURE 6.—Map showing Distribution of glacial Deposits of Pennsylvania and adjoining Portion of New York
 Arrows indicate direction of glacial striae. Scale, 1 inch = approximately 40 miles. Compiled by Wm. C. Alden, 1901. (From United States Geological Survey)

a place as any to illustrate this point is in the area between the Illinois and Mississippi rivers extending from Galesburg northeast along the line of the Burlington and Missouri Railroad. For a long distance this is a tableland from 300 to 350 feet above the rivers mentioned on either side. The glacial deposits over this area consist of a pretty uniform capping of loess, 10 or 15 feet in thickness, overlying till of about the same thickness on the average, but deepening to a hundred feet or more in the depressions of the old valleys. But in descending on either side one encounters ever-deepening preglacial valleys heading in characteristic amphitheatres in which the evident erosion of the present streams has had comparatively little influence in molding the surface.

POSTGLACIAL OXIDATION

The extent of the oxidation of postglacial deposits has been generally taken as one of the surest measures of the time that has elapsed since they were laid down. There is no question about the increase of this oxidation as we go southward to the glacial boundary, and also as in many places we penetrate older glacial deposits that have been overridden by later ones a considerable distance north of the extreme limit of the ice extension. North of the watershed in Ohio there is a pretty uniform blanket of yellow till from 10 to 15 feet in thickness overlying a less oxidized blue till of much greater average thickness. Moreover, between these strata there is quite likely to be a deposit of gravel, indicating the temporary influence of flowing water. Toward the southern part of the State the thickness of this blanket increases until when we pass the boundary of the so-called Wisconsin deposits the entire mass of till seems to be thoroughly oxidized.

But Prof. E. H. Williams again, in his extensive observations on the attenuated border of glacial deposits in Pennsylvania, has brought to light facts which have apparently escaped the notice of other observers, and which lead to entirely different conclusions from those which have ordinarily been made respecting the age of the so-called Illinoian, Kansan, and pre-Kansan deposits. The facts are that, mingled with this highly oxidized material throughout the "attenuated border" in Pennsylvania, there are pebbles of the same character which are only slightly oxidized, indicating that the mass of oxidized material was already oxidized when it was picked up and deposited by the ice, and is therefore no criterion of the length of time which has elapsed since its deposition. But it is the comparatively unoxidized material mixed with it which indicates the time of the deposit. Furthermore, Mr. Williams observed

innumerable cases where water-worn Canadian pebbles had evidently been oxidized inwards until a core of unoxidized material remained in the middle, when afterwards they had been taken up by the ice and in the process of transportation glaciated on one side until the unoxidized core was almost or entirely exposed on the glaciated side, while the oxidized portion retained its original thickness on the other side. These pebbles therefore indicate that the oxidation had taken place mainly in pre-Glacial times, proving that it is no criterion touching the time of its transportation by the glacier.

Again, the amount of postglacial oxidation of the glaciated surfaces, even over the area covered by the Kansas invasion, is in many instances so small as to forbid the supposition of the enormous lapses of time which are currently made concerning the date of that invasion. In my original observations upon the glacial deposits in Saint Louis, Missouri, which are certainly as old as any, I found extensive limestone areas freshly uncovered near the Botanic Gardens which still retained glacial markings on their surface where not deeply eroded by chemical action. In the enormous lengths of time usually supposed to have elapsed since this glacial action the thin beds of limestone would have entirely disappeared.

Again, Professor Williams' observations upon the mammoth coal vein near Pottstown, Pennsylvania, where its surface had been glaciated in close proximity to the unglaciated area, disclosed the fact that, though the superincumbent soil was easily permeable to water and its eroding acids, the glaciated surface had not been eaten away to any appreciable extent, whereas a short distance beyond, in the unglaciated area, the coal was rotted to a depth of several feet.

I quote from a private communication, giving unpublished results of Professor Williams' observations on the attenuated border in Pennsylvania:

"The outcrop of Oriskany sandstone north of the Blue Ridge shows the coarse-grained variety cemented by calcite and carrying *Spirifer arcuosa* and the cherty band.

"[But] the pebbles of the former can be traced through the moraine of Lewis and Wright and across the great valley of Pennsylvania; thence over the South Mountain, being carried from 250 above tide over the summit at 900 above tide and down the south slope to and half way across the Saucon Valley (average elevation, 400 above tide). These pebbles are mingled with local material, mostly angular. The local stuff is weathered and rotten; but *there is absolutely no difference in color, weathering, or degree of disintegration between the pebbles found on and south of South Mountain and those found in the moraine and even in the Lehigh at the foot of the outcrops.*

"Slate.—The outcrops of slate south of the moraine of Lewis and Wright are under a cover of gravels. Near Slatington workable slate is quarried immediately under these gravels, and there is no difference in appearance between them and the gravels of the terminal moraine.

"Coal.—The gravels at Morea, Pennsylvania, are neither oxidized nor rotten, nor in any manner capable of separation from the gravels of the Lehigh water level or of the moraine. They are abundant in sands, which are like the sands of the Pocono outcrops, or at Glen Summit, Pennsylvania, or above the coal outcrops north of the moraine of Lewis and Wright, and there is nothing to distinguish them either in color, degree of disintegration, or other characteristic dependent on age from outcrops to the north. They are 10 feet thick on an average. Immediately under them are the vertical outcrops of the mammoth bed. Weston Dodson and Company mined this bed and sent every particle of the same to market. Analysis of fixed carbon and ash in samples taken immediately under the gravel and 100 feet underground showed that there was not 2 per cent of difference between the samples and between samples of the same bed, which were flat and not in any manner influenced by surface water. Now, it is a well known fact that samples from the same bed and the same belt in the bed taken 10 feet apart may differ from 5 to 10 per cent in these things, and I have seen in the same mine a bed 11 feet thick of clean coal gradually diminish to a dirt bed 1 foot thick, and that within 1,000 feet. We can, therefore, conclude that the 2 per cent variation shows an agreement between the two samples at the surface and immediately under the gravel, and at depths as great as between any two samples of coal in any anthracite mine.

"On the other hand, 1 mile south of the limit of the 'border' and the mine next to it there is the usual 'peacock' coal in the outcrop, showing influence of weathering and the inclosing rock rotted soft for several feet from the surface, as is the usual occurrence, and this also occurs north of the 'border,' where the ice poured over a ridge and left the outcrops immediately below the crest untouched, as in the 'crag and tail' cases, which are infinite in number and identical.

"Loss of calcite in glacial deposits.—The Hydesville, Pennsylvania, overwash gravels of the moraine of Lewis and Wright are taken as of the latest age. These are cemented by calcite, and the shells in the red sandstone are generally dissolved to form the binding material, as is also the case in the gravels near Warren at both high and low levels, so that there is no difference in the induration from calcite cementation to be seen between the 'hard-pans,' as they are called, before and behind the moraine. The marine shells in the drumlins of Massachusetts have disappeared and their place is taken by sand concretions cemented by their calcite. These are behind the moraine of Lewis and Wright and so of the latest period. In fine there is evidence that generally the calcite in the glacial deposits, in the form of shells, has been leached away either before or since the deposit of the fragments in the drift. This is not always the case, and about Warren, Pennsylvania, cobbles have been found with portion of the shells undissolved in gravels, which can be traced continuously from the alleged 'rock-shelves' to the present levels.

"Now, from these evidences it seems that the times of the 'border' were very

recent; so recent that at the places indicated there can be no distinction made between the transported materials of the border and of the moraine.

"The character of the original material of the glacial accumulations.—We must agree that the ice could not attack the solid outcrops until the soil rotted in place had been removed. The depth of that soil varies according to material, slope, and climate. Agassiz reports soil over 100 feet in depth along the Amazon.

"Before the solid, rocky portion of the outcrops were reached there was pushed before the glacier this oxidized soil without distinguishing characteristic. I have advocated several times the study of the soil of the 'border' under the microscope, as our petrographic knowledge is so sure that it may be possible to detect and distinguish varieties in an apparent homogeneous body of oxidized soil.

"Next.—The glacial scrapings then were mingled with the rotten portions of the solid rock next the outcrops, and these were glaciated, as shown in the pebbles found at Warren among the gravels, where the river action was strong, and also in a cobble of gneiss found west of Irvineton on the top of the hill and several hundred feet above the river. Here the solid nucleus was within half an inch of one side and 3 inches from the opposite surface, showing weathering before rounding, and the rounding was from ice rather than water, as it was above stream action.

"The slate region of the Great Valley of Pennsylvania, from the Lehigh to the Schuylkill and utterly south of the Moraine, which was 30 miles to the north, was a good field for inspiring patience. In the first place the slate was so solid under the thin soil that post holes had to be cut into it for the fences, and the posts had to be wedged in with cobbles collected here and there from a region generally free from such things.

"In this region there was a fresh slate surface, coming sharp and solid under an oxidized deposit of soil, which was not slate soil. On this area there were at times masses of the rocks of the crest of the Blue Ridge moved a mile or more to the south and sometimes as large as a small house. At other times I have followed a section which went to the solid slate, and in the uniformly well rotted and fine soil there was not even a slate flake. Here was evidently the original preglacial soil. After a mile or so of search along a section I have found an Oriskany or Oneida pebble, and it was as fresh as pebbles usually are that are in oxidized soil, and that means a thin yellowing stain on the outside, but not extending inward more than a hair's breadth. Then I would come upon a sporadic deposit of gravelly soil.

"The influence of a rotted soil containing a large amount of iron peroxide is shown in the pebbles (Olenellus quartzite) of the basal conglomerate of the Triassic, just south of the South Mountain, at Hosensack, Pennsylvania. This conglomerate has thoroughly rotted, and its pebbles lie in the red and loose soil and very much resemble a glacial deposit; but the pebbles are as hard as if rolled today and with the steely-blue patina of magnetic oxide. Their section shows that the iron penetrated more or less deeply, and in every case there is no difficulty in picking them from a mixture of Olenellus pebbles from more northern localities.

"Old glacial deposits.—These must show a difference from fresh ones. The characteristics of a fresh deposit are that its oxidized character shall not vary

between the condition at the surface and at any depth if the deposit is the result of one and the same action. Even if there be a terminal moraine which has taken a million years to form, and the ice front has never moved from one spot for that time, and the lower portion be rotten while the top is fresh, if we suppose an advance of a mile, we will have whatever is carried onward mixed up in the carriage and deposited with a generally uniform appearance at top and bottom. We conclude, therefore, that when a deposit shows a similar state of oxidation at top and bottom it is not soil rotting in place, and if it shows no signs of stratification it is not sedimentary unless the conditions of sedimentation were identical during the period covered by the whole of the deposit. The presence of glaciated stones will, however, settle the matter.

"On the other hand, if a glacial deposit, which at the beginning showed the above characteristic of uniformity, lies for ages, say one thousand years, under the influence of weather, frost, rain, etcetera, we can readily see that the surface must begin to show a weathering distinct from that which was shown at all depths by the weathered portion of the original deposit, and this weathering in place will extend to varying depths according to the openness and porosity of the mass; but in every case there never will be a uniformity of weathering between the top and bottom layers of the mass.

"We have, therefore, an infallible criterion for gauging the age of a glacial deposit. There will be three conditions:

"First. There will be a deposit which has been formed by the long continued action of a glacier forming a moraine at a given line of advance. Here the lower part of the deposit is the most oxidized and the fresh and recent material is on the top.

"Second. There has been the formation of a terminal moraine by an advance followed by a continuous retreat. Here the criteria will be of two kinds:

"a. It is an old moraine and the surface is more oxidized than the base, or

"b. It is a comparatively recent moraine and there is a uniformity of oxidation from top to bottom.

"From the latter we see that whether the contents be fresh or completely rotten, the recency is shown by the uniformity of oxidization throughout, so that there may be a recent moraine of entirely rotten and oxidized material if the material was taken from a rotten surface, as well as a recent moraine of perfectly fresh material taken from a well glaciated surface. Again, if we find at all levels freshly rolled material mixed with perfectly rotted and oxidized soil the formation is recent.

"We can deduce the general rule:

"Absolute uniformity in characteristics of a deposit of glaciated material at all levels on a vertical section shows recency of formation, and it is immaterial whether the deposit consist of entirely fresh, entirely oxidized, or mixed fresh and oxidized material."

These various observations certainly nullify the evidence usually adduced to prove an enormous lapse of time since the culmination of the Glacial period, and support the earlier conclusions of Dana, Hitchcock, Upham, and others, that the upper and lower till are quite distinct in

their methods of accumulation. The upper till is for the most part material which was held in the upper strata of the ice, and which gradually accumulated in thickness toward the south as the ice melted and deposited its earthy material upon the lower surfaces which were exposed. During this long exposure this material of the upper till underwent a great amount of oxidation, while the lower till was protected from oxidizing agencies. Moreover, the material which had been oxidized in pre-Glacial time was that which was first picked up by the continental glacier and incorporated in its mass and carried onward far toward the southern limit. When the movement had proceeded as far as to the time of the Wisconsin episode, the surface rocks of Canada had been denuded of this oxidized preglacial material, which readily accounts for the comparatively small oxidation of the Wisconsin till.

One other point should be kept in mind. As the surface of the ice moved faster than the bottom, much of the material which was carried high up in the glacier would be thrown forward upon the margin and become mingled with the material which was underneath the glacier; so, in periods of advance, after a time of recession this would become a part of the ground moraine and be overridden by the ice, thus furnishing a lower stratum of highly oxidized material covered, as the ice advanced, by a later stratum of less oxidized material. Failure to keep these considerations in mind will lead to erroneous inferences concerning the age of deposits of highly oxidized material lying underneath deposits of less oxidized material, for on a little thought it is evident that the two deposits need not be far separated in age, for the earlier oxidized material is constantly being thrown forward, to be overrun by later movements of the ice in close succession. Every pause in the movement of the front, or temporary recession, would be marked by an accumulation of highly oxidized material, to be covered by deposits of less oxidized material that were continually advancing. The complete oxidation of such a basal deposit would be no evidence of great age.

CONCLUSION

While this evidence does not give us any very definite conclusions as to the age of the drift upon the attenuated border of the glaciated region, it is sufficient to throw doubt on the extreme figures made to represent the length of inter-Glacial and post-Glacial time. The physical conditions of the Glacial period were so abnormal that we are not permitted to apply to that period measures which are drawn from present earth movements and rates of erosion and deposition. It is pretty certain that

the departure of the Wisconsin ice-sheet took place not much more than 10,000 years ago, and that the date of the Kansan deposits should be reckoned in tens of thousands of years rather than in hundreds of thousands of years.

DISCUSSION

Mr. LEVERETT called attention to great erosion in the upper Alleghany region which took place between the deposition of the old drift and of the young or Wisconsin drift, and which should be considered in estimating the relative ages of these drifts. Valleys which were filled with the older drift to a height of 200 or more feet above the present streams were largely reexcavated prior to the later or Wisconsin ice invasion. Evidence that they were filled to this height is found in level-topped remnants of the old valley-filling preserved in recesses on the sides of the valleys. Evidence that much reexcavation had occurred is found in the fact that moraines of the later drift pass down into the low valley bottoms instead of terminating up on the surface of the earlier drift filling. Moraine-headed terraces that represent the glacial drainage from the later ice-sheet start at levels only about 50 feet above the present stream. From this it appears that erosion since the last glaciation is but a small fraction of that between the deposition of the old drift and of the young or Wisconsin drift. The aged aspect of the old drift may therefore be something acquired since its deposition. The incorporation of preglacially weathered material, while no doubt a fact, may not have been of sufficient amount to be a dominant feature of the earlier deposit.

Prof. H. L. FAIRCHILD said: The question of the length of post-Glacial time is always interesting, and while we as yet have no yardstick of geologic duration, the maps yet before the audience in illustration of paper 31 will give us a suggestion. How long has Lake Ontario existed? (The replies ranged from 15,000 to 25,000 years.) Let us take 10,000 years for the life of Ontario. Then preceding that was the marine submergence, with the slow lifting of the land and production of the remarkable series of heavy, close-set bars on the marine shore (at one place 42 bars in a distance of $1\frac{1}{4}$ miles and a vertical fall of 165 feet), which may be taken as at least another 10,000 years; then the long-lived Lake Vermont, New York, with its expansive deltas and good beaches; then the briefer Lake Emmons; then the Lake Iroquois. All this in the Saint Lawrence Valley, which represents only the later part of the post-Glacial time, since the terminal moraine was deserted, and which must be at least 30,000 or 40,000 or 50,000 years, and may be twice that.

Dr. J. W. SPENCER said: Professor Wright's determinations of the rapid erosion by weathering, seen on the sides of the Niagara Gorge, is based upon artificial conditions. The railway cut has steepened the natural slope covered with talus; consequently the rate of lateral erosion now found here is excessive. Furthermore, the lower levels of the gorge wall became exposed only after the sinking of the waters to and below that of the Iroquois beach, and, on account of the later exposure of the slopes and the subsequent overdeepening of the gorge, when all the lake waters were turned into Niagara, the lower slopes were excessively steep, and, when exposed to weathering, such would favor very rapid removal of the debris and shales.

Professor WRIGHT's reply: The movements of land level during the Glacial period were abnormal and can not be judged by present movements. The relief furnished by the removal of the ice-sheet led to a rapid reelevation of the land, so that the 1,000 feet may easily have been accomplished in 5,000 years.

The Conewango was never filled with gravel to the height of 300 feet. The deposit at East Warren is a dump in the lee of a rocky projection, while on the west the glacial torrent scoured out the channel.