SUMMARY

OF THE

SURFACE GEOLOGY

OF

MICHIGAN.

BY

ALFRED C. LANE.

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LETTER OF TRANSMITTAL.

OFFICE OF THE STATE GEOLOGIST,
LANSING, MICHIGAN, May 15, 1908.

To the Honorable the Board of Geological Survey of the State of Michigan:

HON. F. M. WARNER, *President.*
HON. D. M. FERRY, JR.
HON. L. L. WRIGHT, *Secretary.*

Gentlemen—I beg to submit the following report as an introduction to the surface geology of the State and its bearing on the study of the soils, surface deposits and physical geography, for the use of our public school teachers and their pupils, and as a key to the large scale maps of the surface geology which we are preparing.

Very respectfully,
ALFRED C. LANE.

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SURFACE GEOLOGY OF MICHIGAN.

INTRODUCTION AND ACKNOWLEDGMENTS.

The writer does not pretend to have made a special study of the surface geology of Michigan, upon which others, especially Mr. Frank Leverett, are better qualified by their labors to write. These labors give to the maps which this report is to accompany most of their value, but Mr. Leverett is just now in Europe, and the writer's very lack of familiarity with the detail and technical points may help him in preparing this general report for popular use. Of course he has been more or less familiar with both parts of the State and the surface geology thereof for a number of years; he trusts enough so to interpret the work of others. It will not be necessary to give a long historical introduction, because Mr. Leverett has done that in a review of the glacial geology of Michigan published by the Michigan Academy of Science in 1904, sixth annual report, page 100. He has also given an account of the surface geology of the Ann Arbor region in the Ann Arbor folio, recently issued by the U. S. Geological survey, which is of value for the whole Lower Peninsula.

It may be well, however, to say for the benefit of teachers and others who wish to look up even later results that they will be found in Michigan, Wisconsin, Minnesota, United States and Canadian Geological Surveys, in the Journal of Geology, in the Bulletin of the Geological Society of America, Proceedings of the Michigan Academy of Science, Science, and the Michigan Miner. Among the names of those who have been actively working may be mentioned Frank Leverett, Frank B. Taylor, J. W. Spencer. T. C. Chamberlin, R. D. Salisbury, W. F. Cooper, J. W. Goldthwait, W. M. Gregory, A. C. Lawson, C. D. Lawton, W. H. Sherzer, M. S. W. Jefferson, C. A. Davis, and J. Harlan Bretz. One can not forbear to single out from the older names cited by Leverett the names of the Winchells among those who had given thought and study to surface geology.

The study of the surface geology and the soils is intimately connected. The United States Department of Agriculture, Bureau of Soils, under Milton Whitney, have prepared soil maps of certain areas in the State, to wit: Owosso, Allegan, Alma, Munising, Pontiac, Saginaw and Cass, which can be obtained from the department, and other notes on soils will be found in the reports of the Upper Peninsula Experiment Station and the reports by Prof. C. D. Smith.

IMPORTANCE OF SURFACE GEOLOGY.

While the deeper geology of Michigan, implying as it does a study of salt, coal, oil, gypsum, copper and iron, is of great importance, the importance of the knowledge of surface geology may be estimated when we consider its relation to agriculture, to the clay industries, to the development of peat and cement factories. All these depend largely for their material upon surface deposits. Road materials are also largely surface deposits. And the study of such deposits, their origin, extent, and the way they occur, is the field of surface geology. But besides this, questions of water supply, the kind of material to be met in railroad cuts, canals, tunnels and foundations for dams, and other engineering works, all depend for their satisfactory solution upon knowledge of the surface geology.

PRE-GLACIAL HISTORY.

The deposits of Michigan are separated into two classes by a very sharp line, which corresponds to a very long interval of time during which the State was eroded. Geological history has been divided into four great divisions, the Archeozoic, Paleozoic, Mesozoic, and Cenozoic. During the first two of these periods the harder rocks, including those which contain copper, iron and coal were laid down. They are the bony frame work, so to speak, of the two hand-like peninsulas of which Michigan is composed. The oldest of these rocks are found somewhere northwest of Marquette. This may be called the negative pole of the state, from which the hard rocks dip. The positive pole would then be the Saginaw Valley, towards which the rocks dip in every direction, under which the beds lie like a pile of saucers decreasing in size to the middle. This might be considered the hollow of the palm of the Lower Peninsula. But after these rocks were formed the State appears to have been above sea level, and the rocks cut and worn into hills and valleys (Plate VI) by streams, the general aspect of the country being perhaps much as Arkansas or Tennessee at the present date. This seems to have been the condition during the whole of Mesozoic and all but the extreme end of Cenozoic time. The elevation which carried the State above water seems to have carried it to a higher elevation than at present, for we find caves, river valleys and channels in the ancient rock surface which go quite below sea level. The most important of these valleys in the rock surface seems to have passed west from Saginaw, past Alma, and then turned somewhat northward and to have passed beyond our tracing beneath Lake Michigan somewhere between Manistee and Ludington, where the bed rock surface is beneath sea level.

ADVANCE AND CAUSE OF THE ICE AGE.

As long as elevation continued erosion naturally also would continue. But at the close of the Tertiary a great ice sheet overspread Michigan (Fig. 4) coming from centers lying at first northward from the west of Hudson's Bay and then from east of Hudson's Bay. This sheet of ice was what is known as a continental glacier, such as now buries Greenland. Other glaciers are found in Alaska, the Rocky mountains, especially the Canadian Rockies and in Switzerland. As to the fact of this great ice sheet overspreading a good part of North America (see figure 4) geologists are now entirely agreed. There is no such agreement as to the cause, and a discussion of possible causes will be found in Chamberlin & Salisbury's recent Geology. A number of causes may have helped to produce the ice sheet, and once started there are a number of causes which would tend to make it grow. In the first place a greater height of land would promote precipitation as snow rather than rain, and the minute the snow fall, which even now often lingers in the Huron mountains until the first of June, lingered so as to accumulate from year to year we have conditions for steady growth of the ice sheet. After once the surface of the country is covered by white

snow throughout the year there will be so much more heat reflected that the mean annual temperature will be much lower. At the time of the ice age in Michigan there seem to have been large lakes out west, and anything which would tend to increase the amount of snow fall in the winter would tend to promote the ice age. As the ice age seems to have extended widely over the world, and there were great ice sheets in Europe at about the same time as America, it is almost certain, however, that no mere local conditions contributed to bring about the ice age. One may imagine that the sun gave out less heat. It is even more probable that the capacity of the atmosphere to retain the heat has varied greatly from time to time. The air has a power of acting like a mouse trap in letting the heat from the sun in, as visible or radient heat, but checking its outgo. In this last respect it varies very greatly from time to time. A clear, dry air, free from carbon dioxide lets the heat escape back again very freely, as it does when we have the frosts of a clear cold night. On the other hand by building fires we check this escape, not to any appreciable extent by the heat given out by

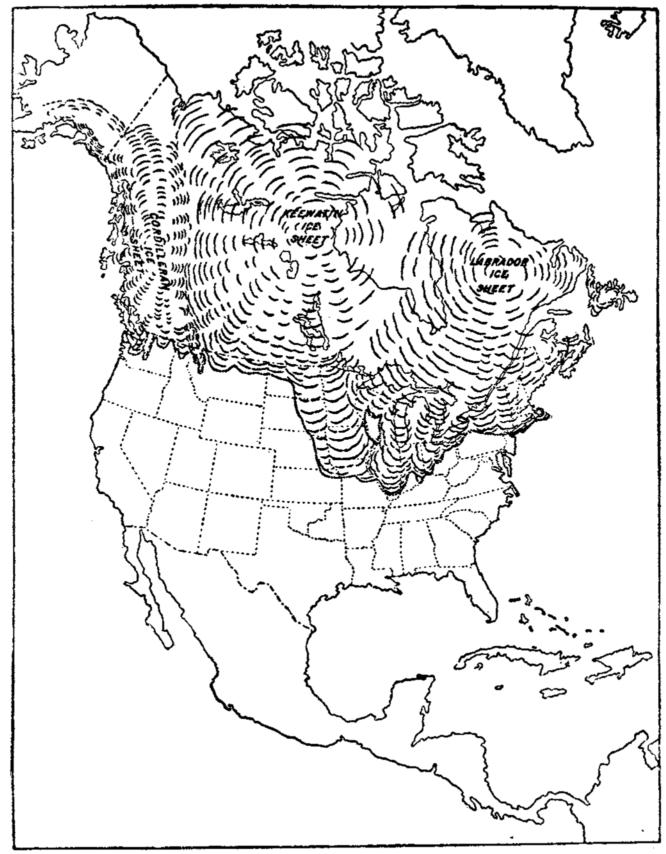


Fig. 4—Sketch map. Extent to which the ice sheet covered North America, after Chamberlin & Salisbury's Geology.

the fire, but rather by the carbon dioxide, vapor of water and smoke which are thus introduced into the air and act as a blanket. Now if by any cycle of geologic activity carbon dioxide were taken away from the air it would tend to promote the ice age as a clear night promotes frost, and this is perhaps, as Chamberlin suggests, the cause of the oncoming of the ice. It is worth noting, that if the ocean were colder it could and would absorb much more carbon dioxide than it does at present. Great increase in vegetable life also tends to abstract carbon dioxide, as do those plants like Chara, and animals like corals, which deposit carbonate of lime.

Changes in the relation of the earth's orbit to the sun have also been appealed to. Sometimes the earth's orbit is more nearly circular than at others. At present the northern hemisphere has its winter when its pole is turned away from the sun at the time the earth is nearest the sun. In some 10,000 years or so the earth will be nearest the sun in the summer of the northern hemisphere, and an attempt has been made to connect the ice ages with these astronomical changes. But even the advocates of these factors concede that the course of the ocean currents and amount of heat transferred north by the Gulf Stream, etc., must be taken into account in order to give any adequate explanation of the ice ages. When we consider the number of factors involved, *all* of which must have *some* effect, and when we consider what a difference an earthquake or the building of a coral reef which should appreciably narrow the Gulf Stream might have on the climate of Europe, and what a similar disturbance of the Japan Current might do in the Pacific Ocean, we shall, I think, find it wise not to teach too positively the exact combination of causes which produce an ice age. It is well, however, to get two or three things in mind. The climate need not have been severely cold. Such extreme cold regions as Siberia, where the ground is frozen for many feet are not covered with glaciers. These on the other hand extend down the Swiss valleys into a relatively mild climate. What is required is a great precipitation of snow. In the second place, before the ice age the country was higher than at present. When the ice came upon it, it was depressed. As soon as the ice left it felt the relief and started rising again. The causes for the apparent depression of the land beneath the ice are not simple. The center of gravity of the whole earth must have been displaced toward the ice, but the effect must have been very slight. If the ice front rose like a wall or cliff the direct attraction would be not inconsiderable so that a line of levels would rise toward the ice, and the country measured by such a line of levels would appear to be lower. But certainly the direct compressive effect of such masses of ice upon the rocks beneath, measured clear to the center of the earth would be quite noticeable. If the atmosphere were doubled, R. S. Woodward writes me, the effect would be to shorten the radius of the solid earth about two meters, say 6½ feet. This would mean an extra pressure of about 14½ pounds per square inch, or about 30 feet of water. Thus the shortening of the earth's radius would be something like 1-5 of the extra thickness imposed if it were a sheet of water, and so a sheet of ice 1,000 feet thick all over the world would shorten the radius some 200 feet. This will not be true of a limited ice sheet, but of ice sheets several thousand square miles in extent, such as the ice sheet we are now considering, it is likely that the resistance to bending of the rocks around the margin when that amount of bending was only a foot or so a mile would not be a very great factor in keeping up the crust above the point to which it would be compressed by the ice cap as above figured. Moreover if there is a viscous fluid layer anywhere not far down in the earth which can not remain at rest under a state of strain,* then it would begin to move under the extra weight of the ice cap and not come to rest until the crust beneath the ice had sunk down into this viscous fluid layer so that the buoyancy was enough to counterbalance the weight of the ice. If, for instance, the weight per cubic foot of this viscous fluid layer beneath the crust of the earth was three times that of the ice, 1,000 feet of ice would mean a depression of something like 330 feet as a limit.

Then when the ice sheet was removed these effects would be reversed, only it must be noticed that the shifting of gravity and the elastic relief of compression will follow almost immediately after the removal of the ice,† but the uplift due to the buoyancy of the viscous fluid layer now not entirely counterbalanced by the weight of the ice will take place much more slowly.

EFFECTS OF THE ICE ADVANCE.

So much for the general attitude of the land during the ice age. As the ice advanced it swept over the surface removing more or less of, and mixing up the previously existing soils, tearing off or plucking the sharp and loose ledges and reducing the form of the bed rock surface to one of smooth round outlines and curves of least resistance. Outcrops of rocks which had thus been smoothed by the ice have been likened to sheeps backs, and to the curves of a canoe turned bottom side upwards (Plate VII.) Besides this the ice did considerable cutting in the hard rock. Just how much is a serious question. Where the limestone, or sandstone or other hard cap was left as a table land on top of a hill of soft shale the ice seems to have in many cases pushed it clear off. This seems to be the explanation of those huge masses of limestone which Winchell has described,‡ in which limestone quarries have been actually started. Moreover, when we find a fresh surface newly exposed since it was beneath the ice we find it covered with lines, or striæ as they are called, which may vary in size from fine hair lines to considerable grooves (Plate VII A). These have been scratched on the rock by the ice passing over it, or more properly perhaps by the sand and stones held in the ice. Now every such scratch means the removal of a little rock flour, and the results of this removal we have in the clays laid down under the ice or in pools in front of it—our glacial clays. It is said that 60% of the mixed material thus found comes from within a few miles. The average thickness of the glacial material scattered over Michigan has been computed by Cooper§ as about 300 feet. If this be so then perhaps an average of something like 180 feet may have been removed by glacial erosion. A good part of the balance certainly has come from across the lake in Canada, where there is very much less drift and the rocks are nearly bare, while on the other hand we find numerous varieties of Canadian rocks in this state. On the other hand something should be added for Michigan material carried farther south, but it must not be forgotten that this thickness represents not merely the matter removed from fresh rock, but also all soil and decayed rock which may have been there before. Still the limestone flour which makes up 25% of our clays is not soil or decayed rock, but the direct effect of glacial erosion.

*At about 30km. according to Prof. Wiechert, Science (1908), 27, p. 76.
†There may also be permanent compression, and set, as well as elastic.
‡Proc. A. A. A. S., 1875, 24, p. B 36.
§Ninth Report Michigan Academy of Science, p. 140.

DEPOSITS OF THE ICE AGE.

The various deposits of the ice age including those both directly and indirectly due to the ice have been quite elaborately classified by Prof. T. C. Chamberlin. A summary prepared by him for the International Congress of Geologists at Washington in 1891 is given below, but we have for our present purposes omitted those which either do not occur or have not been recognized as important in Michigan, and we may simplify this classification somewhat as follows:

1. *Material produced by direct action of the ice.*

This is characteristically unassorted so that in the same handful of clay, sand and gravel may be mixed. The resultant soil will be sandy gravelly loam. At the same time the mixture is not perfect, and the general grade depends a good deal upon the kind of rock from which the ice derived its material. If, for instance, it has been passing over sand rock there will be a large proportion of sand and little or no clay, and if on the other hand it has been passing over soft shale deposits there will be a great deal of clay derived from the shale and comparatively little coarse material. All this material is grouped together as till, or as it is sometimes called, boulder clay, or as well drillers have called it, hardpan.

(a) *Moraines.*

When this is piled up or carved into smooth hills of lenticular shape whose curves are lines of least resistance, such hills are called drumlins. Some authors would confine the use of the term drumlin only to hills which have been built up, and not those which have been carved in drumlin shape, but Prof. Russell in our reports for 1904 and 1906 applies the term to hills which he thinks have been carved into their lenticular shape (Plate VII B). Mr. Leverett thinks that the evidence is clear that some of the Traverse Bay drumlins have been built up layer by layer. In a good many cases it may be difficult, and from the shape alone impossible, to tell what is the true origin of such smooth, till covered hills.

At the margin of the ice there is a great accumulation of material borne on top of, or within them, to be deposited at the margin or let down by their melting. When this makes a well defined belt it is known as terminal moraine. When the ice projects out into a long finger, the moraines at the margin are known as lateral moraines. When two such fingers or lobes project close together so as to mingle their moraines, the combination is often known as interlobate moraine.

Very commonly these ridges are not due simply to the dumping, but the front of the ice has actually pushed the material up into irregular ridges. On the other hand when the water was ponded in front of the ice or a strong current swept along it, the waterlaid moraine may be reduced to a simple line of boulders—a so-called boulder belt.

(b) *Till plain.*

The till that is laid down beneath the ice in a smooth shape or slightly undulating is known as till plain.

2. *By ice and water combined.*

A much greater variety of formations are produced by the combined action of the ice and the waters running in, on, or through it. In fact it is doubtful if these can ever be wholly separated. Many hills which should be classed as till will show in well sections streaks of waterlaid sands or clays, and it is not uncommon to find the covering of unassorted material derived directly from the ice lying as a veneer on top of assorted waterlaid material.

This shows that the ice at that place had readvanced upon the waterlaid material without plowing it up.

a. *Eskers.*

The well known Indian ridges or hogsbacks, of coarse, sandy, not very well rounded gravel, which occur in very many parts of the state are characteristic products of streams in, on, or under the ice, which cut deep canyons or tunnels and then filled them in with gravel. These were confined in walls of ice, which finally melted away, letting the gravel fall down to right and left at as steep an angle as it can repose. These eskers, while they wind like any river valley generally run more or less at right angles to the direction of the ice motion. There is, for instance, a well marked one running from Lansing past Mason to Jackson nearly north and south, while the ice front stood nearly east and west. There is another near Lima on

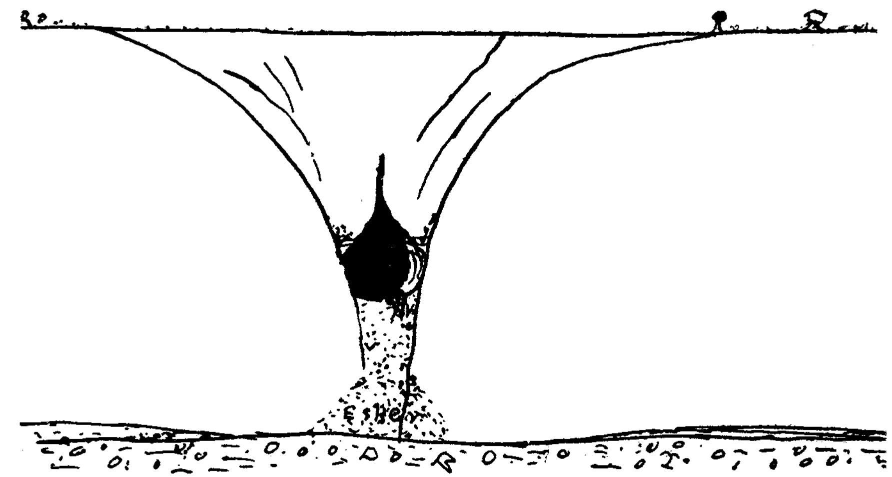


Fig. 5—Illustrating formation of eskers and bordering swamps. The debris from the top of the ice slides down towards the entrance of the cave where the esker is formed and yields less to the ground moraine each side at s–s.

the electric line from Jackson to Detroit, another in Sanilac county, and near Spalding in the Upper Peninsula.

b. *Kames.*

At the margins of the ice, especially at re-entrant angles in the ice front, there are often irregular heapings of assorted drift. These sometimes make the highest points of the surrounding country. The State Tuberculosis Hospital near Howell is on such a hill. They are closely associated with re-entrant angles in the front of the ice and regular terminal moraines of till. On the other hand they may often seem to represent the widening and enlargement of eskers when the ice stood for a long time with its front at a given point, and be really distributed esker deltas. A characteristic feature of glacial deposits, both of moraines and of these kames, is the presence of undrained hollows, or other hollows which have no surface line of drainage. This is due in many cases to the irregular heaping up of the material.

c. *Outwash aprons.*

Just outside the ice front there is a general accumulation of overwash apron, as it is called, which may be made up of material of any fineness—

gravel, sand, or silt—but is generally coarse and slopes gently away from the old ice front.

In these pitted gravel plains there are the same undrained hollows, but they are probably due to another cause, namely, the presence in the original gravel plain when laid down of huge masses of ice, remnants of the waning ice sheet covered by dirt and protected from the melting action and preserved,* while the gravel plain was left around them. Then later they melted out, leaving the pitted gravel plain, which is one of the characteristic features of the accumulation of gravel, just outside the ice front.

3. *Formation produced by water of the melting ice after its issue from the ice sheet.*

(a) *Glacial rock flour.*

In some cases the melting water from the ice was able to run away directly. In that case it could make mighty rivers whose channels would be lined with sand and gravel, taking their origin at the margin of or beneath the ice. This has been known as valley drift extending at the terminal moraine. Where these streams were very broad and large with comparatively small grade thick deposits of fine material differing from clay in one respect, that it contains a great variety of minerals and really should be called rock flour, may be formed. At the same time this rock flour may be as plastic as any clay, and many of our Michigan clays are of this type.

(b) *Gravels.*

In Michigan especially, however, the ice sheet was often margined by lakes in which were deposits of this general clay type. There are also the lake shore line gravels, the so-called "lake ridges," which are often important sources of road material, to be considered. These lakes in turn had outlets, and the streams draining them would give much the same deposits as the streams directly over the ice, only somewhat less turbid with rock flour.

WALLED LAKES.

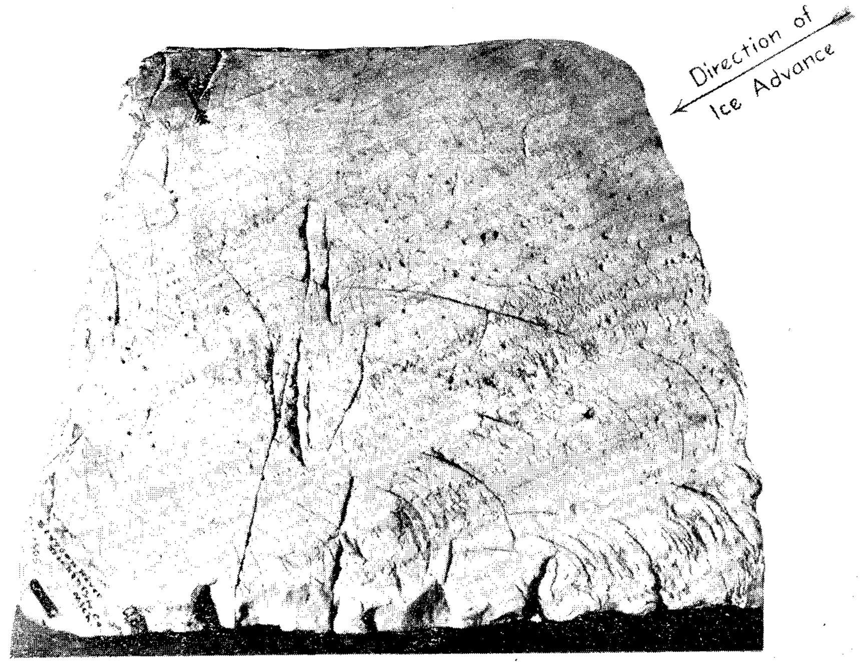
So far as we at present know the salt ocean never reached the region of Michigan, and that class of deposit need not be considered. But not only were there, unquestionably, ice bergs in these old lakes, from the ice front, but the lakes were frozen themselves in the winter, and so in the midst of lake clays we are liable to have occasional stones, though their general bedded character is quite different from that of the boulder clay. Moreover, around the edges of the lakes ridges are pushed up and boulders worked to the shore, as they are at the present day, forming the so-called walled lakes. The interesting stone wall in Sanilac county is a relic of such a former walled lake, and in many places a fairly continuous line of boulders marks the former shore line.†

As these walled lakes attract considerable local interest, and often call forth fanciful explanations, it may be well to say a few words regarding them and their cause. Rather than use my own words I will translate the interesting early description given by H. Credner in 1870.‡

"Many lakes of Michigan, Wisconsin and Iowa, and probably also Canada, are surrounded, if they are shallow, with gently shelving shores, with a regular wall of boulders more or less frequently broken by gaps.

"The walls follow exactly the contours of the basin, and may reach a height of as much as 8 or 10 feet. They consist of sand, pebbles and boulders a

*Ice buried and protected from the direct rays of the sun may last for years.
†See Volume VII, Part 3, Plate IV.
‡Zeitschrift ges. Naturwiss. (1870) 35, p. 30.



A. STRIATED QUARTZITE WITH CRESCENTIC CRACKS.

B. DRUMLIN.

foot or more in size, of granite, porphery, diorite, quartzite, etc. In many places there are only piles of these latter. Such walls have an even crest, and from this slope off on both sides toward the lake and toward the land.

"By their uniform course on the strand side of the lakes, their height which may be uniform for long stretches, and accordingly their summits almost exactly level, they may give the impression that they are artificial constructions. For such they are often enough taken by the hunters frequenting those districts for beaver and otter.

"I found all these peculiarities of these walls surprisingly plainly marked in one place particularly, to wit, Lake Antoine.

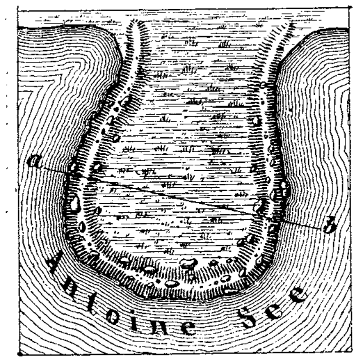


Figure 6—Boulder wall around a spit in Lake Antoine, after H. Credner.

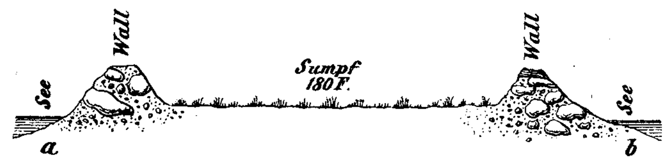


Figure 7—Cross section of the same boulder wall, after H. Credner.

"Lake Antoine spreads its expanse in the middle of the Wilderness which covers the Upper Peninsula of Michigan, some miles east of the Menominee river, in a depression between two chains of hills some hundreds of feet high. The geologic foundation of the region is formed by Huronian quartzites, limestones, iron bearing rocks and chloritic schists, is however mainly heavily covered with sand and boulders of the drift. Only here and there do outcrops of the hard rocks appear.*

"From the low flat north shore of Lake Antoine a tongue of land only a few feet above the water level runs out into the lake.

"Upon approaching the same the temptation is strong to consider it an old Indian fortification. Its outlines are determined by a fine horseshoe

*Herrm. Credner, die Vorsilurischen Gebilde der Ob. Hab. v. Michigan. Zeitschr. Deutsch Geol. Gesell. XXI, p. 516.

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formed boulder wall, closed toward the lake, open toward the land. Near the shore it is only a few feet high, but increases in height the farther away it gets, up to eight feet, the maximum which it reaches in the crescent shaped bend just mentioned. Its slope toward the lake is about 40°, toward the tongue of land within about 50°. On the crest is an almost exactly flat surface on an average three feet broad. It is made up of sand, pebbles, cobbles and erratic blocks up to three feet across.

"The last are not confined to the lower part of the wall. They often form its highest points.

"This wall encloses a level, swampy piece of ground whose level is only ½ to 1 foot above the lake level. Its longest diameter is 220 feet; its shortest, 180.

"The swamp enclosed as well as the top and inner slope of the wall are covered with young birches, poplars, cedars, etc.

"This horseshoe shaped wall must be regarded as a part of the girdling wall of erratics such as surrounds other lakes in more complete fashion.

Figure 8—Cross section of boulder wall, after C. H. Gordon, Volume VII, part 3, Fig. 2.

"In answering the question how these boulder walls around many lakes come to be, three facts must be kept in mind.

1. The boulder walls are confined to lakes with flat shores.
2. They occur only in a district covered with scattered erratic boulders.
3. They belong to regions which have very cold winters.

"These circumstances indicate the following explanation of the origin of the boulder walls.

"The bottom of the lakes in this drift covered region is strewn with erratic blocks like the rest of the neighborhood. In such lakes, when they are shallow during the severe northern winter very strong ("grund eis") anchor ice forms between the pebbles at the bottom. By the ice forming between the erratics those lying near the margin of the lake, upon which the pressure works one-sidedly are shoved toward the bank, if it is flat, and little by little piled up into the shape of walls. The origin of the isolated horseshoe shaped wall above described is explained by the former existence of a shallow sandbank projecting from the steeper north bank of Lake Antoine sloping off equally in all directions, on whose flanks the shoving up of the walls took place in the fashion described.

"That these are not terminal moraines of former glaciers is shown by the fact that the walls girdle the lakes in closed circuits."

A further discussion of the walls is given by Gordon in the report of Sanilac county,* with a figure here reproduced (Fig. 8), showing the conditions for the formation of boulder walls by ice expansion. One thing that needs to be added to Credner's clear description is that it is not necessary to assume ground or anchor ice. The surface ice may have the same effect in a variety of ways.

First, during the extreme cold winter it cracks and the cracks are refilled with ice. Then as spring approaches, and in fact with every warm spell, the whole mass of ice approaches the melting point, and expanding exercises a powerful shove and thrust on the sides, evidences of which are often seen. Any boulders whose tops project near enough to the water level to be fastened to the ice, which may be several feet thick, will be affected by this.

*Volume VII, Part 3, p. 20.

Secondly, during the extreme cold season the level of the lakes is low. It rises with the melting of snow in the spring and boulders frozen in the ice may be buoyed up by it and moved toward the shore.

BOULDERS.

A word may well be given to the boulders themselves. These are popularly known as hard heads, field stone, and the like. They have some value themselves, and it is worth something to get rid of them from the farm. They are used very commonly for underpinning, but rarely for stone walls such as are so characteristic of New England. They often command a price of something like $4.00 per cord. Many very handsome buildings have been constructed from them. The lower story of the new medical building at Ann Arbor and the Baptist Church in Lansing are good illustrations of buildings made from these boulders. Their origin has often excited local interest. In many cases their peculiar character is such that we can almost beyond question tell from what region they came. For instance, there is a peculiar conglomerate of white sand with bright bits of red jasper which strikes the eye almost at once and is widely scattered throughout the drift of Michigan, especially that ice which came through or across Saginaw Valley. A rock precisely like this is found in what is known as the original Huronian area which lies near Thessalon, east of the "Soo" and north of Georgian Bay, and there can be but little doubt that these pebbles were largely derived from that region. There was a singular rock with eye-shaped or orbicular balls in it discovered by H. P. Parmelee of Charlevoix and figured by J. F. Kemp, whose original resting place, however, we do not know. This is not surprising since among all these hard heads of boulders there is a very great variety. Prof. Alexander Winchell collected at Ann Arbor specimens of over 100 distinct varieties of rock. In fact probably samples of every rock to be found in Canada between Lake Huron and Labrador could be found among these boulders. This would indicate of course the Nipissing mining district, and samples of considerable value in themselves, of lead, iron, gold, and other ores, and mica and other valuable substances have been sent into this office for determination. Such samples are, however, of no more worth than the sample itself. They are no sign of paying accumulations in the same region of anything similar.

Very frequently these boulders have very queer shapes and as such have attracted the admiration of residents and are set up around houses. It is easy to see that no ordinary process of rolling or battering could ever get the rocks into such shapes and a little careful study will show that the projecting ridges which tie together these grotesque shapes are veins of quartz or some other material chemically more resistant than the rock as a whole, and that the shape of the boulders is due to chemical corrosion. Anyone who will study parts of the northern country which are so lightly glaciated that the original weathered surface still remains—this is true of a part of Mt. Homer in the Huron Mountains*—will readily recognize the origin of these pebbles. The same grotesque, deeply pitted surface bound together by harder projecting lines, like the veins of one's hands, is characteristic

*See also C. A. Davis, Ninth Report Michigan Academy of Science.

of many of the weathered non-glaciated outcrops north. These freak boulders then represent the remnants of the old, chemically corroded surface of the rocks which have been plucked and torn away by the ice, but not shaped by it. When boulders are shaped by ice or by currents of water in or under it, they are rounded and more or less smooth but scratched. Illustrations of boulders will be found in the annual report for 1905, Plate XV; the annual report for 1906, Plate VII, and the Monroe county report, Volume VII, part 1, Figure 1. This is no definite limit known to the size of these boulders. The one figured from Monroe county is 20 x 4 feet. An equally large one is found near Swan Creek in Saginaw county, Sec. 31, T. 18 N., R. 3 W., and as we have said, limestone quarries have been opened in some of the larger limestone slabs, which seem, however, to have been, in some cases, simply the displaced table land cappings to hills of soft shale outlying and fringing the main exposures of limestone.

Besides the use of boulders or field stone for building, especially for underpinning, they have also been crushed for road metal, for which they are excellent if not too many limestone pebbles are included. Large ones have also been used for monuments.

RECENT DEPOSITS.

We have of course also to consider the deposits now forming; the gravels and sands along the shore—the clays deposited along the deeper water, or in the case of the St. Clair river carried down from Lake Huron and deposited in the delta of St. Clair flats. We have deposits of bog lime or marl in many of our lakes,* which have been of much importance in cement manufacture. We have also deposits of peat more fully described in a special report on that subject by Prof. C. A. Davis.†

It is well to remember that all these deposits are associated not merely with the present lakes and rivers but may also be associated with higher water levels either of the Great Lakes system or of other lakes which have shrunken or disappeared with the passing away of the great ice age.

LAKE DEPOSITS.

It will be shown that the east side of the Lower Peninsula up to an elevation of 200 feet and more above the lake has been washed by the glacial lakes, while on the west side the same belt is much narrower, being only from 100 feet above the lake down. It is worth while to consider the characteristics of these soils.

These glacial lakes were muddy with a very slowly settling rock flour, which would be called clay in fineness and plasticity, but is not at all kaolin. In fact it corresponds more to the dictionary, not the factory, definition of marl. Usually about a quarter is dissolved by acids and may be classed as a limestone or dolomite flour‡. There is also a large amount of finely divided quartz and feldspar and other minerals. Every once in a while in these glacial clays a big stone or pebble may be dumped from the melting of an ice cake. But very often they are quite free from any coarse grit, and very well bedded in thin layers.

*Volume VIII, Part III.
†Annual report for 1906.
‡Annual report, 1903, pp. 184-188. Also Vol. VIII, Part I.

POLISHING POWDER.

Even when free from coarse grit these glacial clays always contain, however, a large proportion of sharp fine particles, so that they may be used for brass polishing. As the water level dropped it was in shallow water for a longer or shorter time, and then coarser, sandier deposits accumulated. These are sometimes quite thick, but in general it is characteristic of the old lake bottoms that they have stiff clays overlain by more sandy clays, and sands which may very often be shallow. Throughout the whole lake bottom region the sands will rarely be so deep that trees or alfalfa can not get near enough to the bottom to get water, and very many excellent orchard sites are found on the old sand ridges.

These lake clays are often brick clays. But owing to the amount of lime they will not generally burn hard or very red. They are white to light orange or buff.

The lime has, however, often been leached out of the upper few feet, which then makes a redder brick.

While they may be of value for pottery, brick and tiles, experience so far goes to show that they are *not fit for* making Portland cement. For this purpose there must be a uniformity in composition with low magnesia, which they do not possess. Nor will they generally make face, front, or paving brick.

ROAD GRAVELS.

The road gravels are the old beach lines, especially the very highest lake borders, where they cut and concentrate the gravel from stony till, and the overwash gravels, kames, eskers and valley trains connected with the ice front. These gravels deposited in powerful swift flowing streams in or from the ice are on the whole the best, and are deposited in almost all parts of the state. In all our gravels there is enough binder.

The great channel that comes down by Mecosta, that around Grand Rapids, the upper valley of the Cass, the esker that runs from Mt. Hope cemetery, Lansing, south, are but conspicuous examples. The Tecumseh gravel is shipped clear to Central Ohio. The U. S. Department of Agriculture have furnished us copies of their soil maps on which gravel pits are indicated. The Miami gravel is the prevailing formation.

BOG LIME.

Bog lime or Marl, shell marl as it is often called, is fully described in our especial report on it.*

With all the lime in the clays that we have mentioned it is no wonder that the waters of Lower Michigan, especially the spring waters, are hard. In fact it may almost be said that they are normally saturated with bicarbonate of lime or its equivalent. That would mean .238 ounces $CaCO_3$ per cubic foot of water.

Where this water is exposed to air and sunshine whether in lakes or standpipes it is rapidly decomposed and the carbonate of lime thrown out. Shell producing animals do a small part of the work, but by far the greatest part of the work is done by lowly lake weeds, especially vine-like forms of the Chara family. Others like Schizothrix take part. But this latter makes more or less firm coatings with a fibrous cross fracture over bits of stick and dead shell, and makes the pebble-like bodies known as marl biscuit. The soft

*Volume VIII, Part 3.

white or blue slime which fills some of our lakes to a depth of very many feet is the Chara-lime as Davis has shown. Probably one-third of the 5,000 or more lakes of Michigan have more or less bog lime, and there are very many bogs which were once lakes that have been filled with it.

It is often covered over with peat. It is most frequent:

In the upper chains of lakes.

In spring fed lakes with cold water.

In lakes of the higher parts of the state in the morainal regions.

PEAT.

This has also received special treatment.* In the broadest sense it includes all accumulations of nearly pure vegetable matter. Muck is not so pure. Davis distinguishes a number of classes according to their origin. But, since the higher and southern parts of the state have been longest exposed, there has been the greatest length of time for the accumulation and decomposition of peat deposits there. Moreover there are the divides where the drainage is most uncertain. There too are the old glacial dumping grounds and the abandoned channels of the waters draining them.

This then is the region of our greater deposits of peat. Some peat is also found back of the old beach ridges especially the very highest ones, and those of Algonquin and Nipissing time. It very commonly fills up small lakes and may build out over deposits of Chara bog lime. The oldest, blackest, and most decomposed is in the south part of the state along the old glacial drainage channel system from Niles northeast toward the Thumb (Figures 10–12).

RIVER SILTS.

Most Michigan rivers overflow their banks—of late years more than ever. In certain cases, and particularly in Saginaw county around Shiawassee Lake, miles and miles of country are naturally thus covered.

When the muddy waters of the swollen streams thus spread over their flood plains a deposit of mud takes place which is heaviest and coarsest near the main channel, finer and lighter at the margin. Thus the flood plains are built up and are normally somewhat higher next the stream. Along the margins of the flood plains next the bluffs is likely to be a swampy belt.

These flood plains are well stratified, but in irregular layers. We do not find the enormously thick beds without apparent break which are so characteristic of the glacial clays. They are generally very fertile, and their fertility is ever renewed.

Of the same general character but liable to be coarser are the deltas which form where any stream suddenly widens into a lake. The greatest of these is the St. Clair flats, described by Cole.†

CONNECTION OF SURFACE DEPOSITS AND SOILS.

It is obvious that there is a close connection between the various kinds of surface deposits and soils. Dune sand is a kind of soil, and at the same time a particular kind of deposit. The fact is a classification of soils and surface deposits deal with the same material but from a different point of view. The surface geologist is studying them in the first place to see how they came to be, the soil expert to see what they are good for agriculturally.

*By C. A. Davis, annual report for 1906.
†Volume IX, Part I.

But if there is any difference in two soils there must have been some difference in their origin and hence the surface geologist, if he has an economic factor in view, can always make some distinction between soils which would be separated by a student of soils simply from the view of the Department of Agriculture. The geologist has also other uses in view. On the other hand some knowledge of how the soils were formed would be of the very greatest assistance in mapping different kinds and helping one to look out for important factors. Two soils of equal fineness may both pass for clay, but if one were a very fine rock flour with a great variety in chemical composition, while the other was almost entirely hydro-silicate of alumina, the agricultural value of the same, I think, would be very different. While all of the factors could be found out by sufficient detailed chemical and physical investigations, yet one can not analyze every foot, and there is often great need in soil mapping of knowing the geologic history.

TYPES OF MICHIGAN SOILS.

The United States Department of Agriculture have so far mapped the following soil areas, which are sufficient to give us a fair idea of the types of the soils in the Lower Peninsula, though an area in the Grand Traverse region is urgently needed, and one to give us some clue to the soils of the western part of the Upper Peninsula, and thus there are still important types of soils which they have not touched. The areas mapped are mentioned on p. 9. The following descriptions of their soils are taken from the United States soil survey field book. It will be noticed that the most important factor in their classification is the relative proportion of grains of different fineness in the soil and subsoil. There are a few types to which no locality name is given. These are as follows:

"*Dune sand.*

"The dune sand consists of loose, incoherent sand forming hillocks, rounded hills, or ridges of various heights. The dunes are found along the shores of lakes, rivers or oceans and in desert areas. They are usually of no agricultural value on account of their irregular surface, the loose, open nature of the material, and its consequent low water-holding capacity. The dunes are frequently unstable and drift from place to place. The control of these sands by wind-breaks and binding grasses is frequently necessary for the protection of adjoining agricultural lands. In certain regions, where levelled and placed under irrigation, the dune sand is adapted to the production of truck crops and small fruits."

The dune sands occur around the edges of the present lakes and also along the lines where the lakes formerly existed. They are nearly pure silica, and the softest waters in the state have been obtained from them. In fact, near East Olive, the excessive softness of the water is supposed to have something to do with a hoof disease. The sand is also shipped from Port Crescent in Huron county for furnace linings. There is, however, quite a little difference in the sharpness of the dune sands in the different regions. The longer it has been handled of course the more rounded it gets, and in many cases it is derived from sands already rounded.

Muck, Peat and Meadow.

The term muck as used by the Department of Agriculture is practically the same as peat, being, however, applied to the more decomposed varieties, such as are found for instance around Kalamazoo, and are used very extensively in this state to grow celery, peppermint, etc. It occurs in the more extensive swamp areas especially those south of Saginaw Bay. Further north the material will be more commonly classed by them as peat. In the maps, Plate XII, by Mr. Nellist this variety of soil is not especially indicated except by the swamp symbol. It may overlie to a varying depth any of the other soils. It is particularly likely to overlie also what is known as marl or bog lime, which occasionally occurs in this state in what might be called a formation by itself as described below. The peat overlying bog lime is not so likely to be sour, whereas many other peats contain sulphate or other organic salts of iron, and in that case are very likely to be sour. Such beds are very likely to be underlain by hardpan of quite a different nature from the till to which the term is also applied. This hardpan is cemented together by iron, and may pass gradually into deposits of bog iron ore, which may also contain considerable quantities of manganese. Small deposits of bog iron ore are found in various places in the state, as in Branch county, as well as in the Upper Peninsula, but are of no present commercial value. The soil book of the Department of Agriculture describes muck and meadow as given below. Meadow is generally a term applied to various kinds of bottom land.

PEAT.

"This is vegetable matter consisting of roots and fibres, moss, etc., in various stages of decomposition, occurring as turf or bog, usually in low situations, always more or less saturated with water, and representing an advanced stage of swamp with drainage partially established."

MUCK.

"This type consists of black more or less thoroughly decomposed vegetable mold, from 1 to 3 feet or more in depth and occupying low, damp places, with little or no natural drainage. Muck may be considered an advanced stage of peat brought about by the more complete decomposition of the vegetable fibre and the addition of mineral matter through decomposition from water and from æolian sources, resulting in a finer texture and closer structure. When drained, muck is very productive and is adapted to corn, potatoes, cabbage, onions, celery, peppermint and similar crops."

MEADOW.

"This term is used to designate low-lying, flat, usually poorly drained land, such as may occur in any soil type. These areas are frequently used for grass, pasturage, or forestry, and can be changed to arable land if cleared and drained. The present character of meadow is due to lack of drainage, and the term represents a condition rather than a classification according to texture. Textural variations frequently occur in meadow areas on a scale too small to permit of detailed mapping. In many areas the term "meadow" has also been used to represent small bodies of bottom land occasionally or frequently subject to overflow, which are normally placed under cultivation and constitute land of high value for the production of various general farm crops. Within these bottoms the soils vary frequently in texture, even within small areas, and on account of occasional overflow the character of the soil at any one point is subject to change. The use of this term should be avoided whenever it is possible to separate such areas into distinct soil types."

FINE SOIL DIVISIONS OF DEPARTMENT OF AGRICULTURE.

In a general map of the state it is not possible to go into the numerous fine divisions—some 20 more or less—of the soils made by the Department of Agriculture. On the map prepared by J. F. Nellist, Plate XII, are but six main divisions outlined. All the finer sandy soils are grouped together in one pattern, and they are generally overwash either from the ice directly or more or less rehandled by lake action. Then we have the gravel plains, the outwashed apron from the ice front. We have also gravel ridges, either old beach lines or eskers which are good road material; then we have the morainal soils which are generally hilly and more or less stony; then we have the till plains which occur between the moraines. Finally we have the purer clays of the old lake bottoms. Thus in one pattern (the yellow color) we have soils separated by the Department of Agriculture as Miami sand, the Miami fine sand, Saugatuck sand, the Miami gravelly sand, and the Clyde fine sandy loam. The green color of the old lake bottom covers generally a very good group of soils. The typical soil is perhaps the Clyde clay with sandy streaks or ridges, or with faint sand streaks with a small quantity of sand as Saginaw sandy loam, the Clyde sandy loam, the Clyde loam, and the Clyde silt loam. The typical soil of the gravel pattern (brown color) is perhaps the Miami gravel, but it will also include areas of Miami gravelly sand, the Miami fine sandy loam, the Miami sandy loam, and the Miami sand, the Clyde sandy loam, the Clyde sand, the Clyde gravelly sand, and Clyde stony and sandy loam, and the Marshall loam. The typical soils of the morainal areas (colored red) are the Miami clay loam, the Miami stony loam, and Miami clay, but the Plainwell stony loam, which is the same as the Miami stony sand and the Kalamazoo gravelly loam, which is the same as the Clyde gravelly sand, will also generally be included under these heads. Under the blue or till plain color the type is perhaps the Miami fine sandy loam, but almost any of the Miami series of soils can be included. These are about all the soils which have yet been determined in the lower part of the state, but the Volusia series derived from a slight reworking of the shales should unquestionably be found in the Grand Traverse region, and probably some slight representation of the Dunkirk series. In the Upper Peninsula there is at least one important soil to be added to the list. This is the Superior clay, which is the lake bottom of the former extension of Lake Superior, or possibly of a lake that existed between the ice ages. Then too in this region there will be areas which will have to be defined as rock outcrop, absolutely bare and rough and stony land where timber alone could grow. In a general way it may be said that almost all the soils of the Lower Peninsula and of the Upper Peninsula around Green Bay contain very considerable quantities of limestone rock flour.* In many parts of the Lower Peninsula there is a very considerable amount of gypsum, or land plaster, mixed with the soil, all of which are fertilizing ingredients of value. Even the Lake Superior sandstone, devoid of fertilizing power as it may seem in some instances runs up to as much as 7% of potash, which is, however, present in the shape of feldspar, and can only very slowly be put in shape to be available for agriculture.

With regard to these soils it should be said that the Departme nt ofAgriculture divides each general group into a series passing from coarse sandy soils to clay soils, that the Miami series which is a glacial soil has a generally

*Analysis of clays and soils bring out the fact will be found in Volume VIII, Parts 1 and 3; also in previous annual reports, 1901, pp. 26 and 27; 1903, pp. 184–188; 1904, pp. 73, 94; 1905, pp. 393, 557, 562; 1906, pp. 73, 80.

light surface soil, the Marshall series is darker, while the Clyde series and the Dunkirk series have both been reworked considerably since the ice age. We copy from the soil survey field book the descriptions which apply to the various soils found in the state. They divide the grain of which the soil is composed into seven classes, and it is by the proportions of these that they divide each series into eleven classes from sand, through loam to clay, as is shown by the following table:

U. S. SCHEME OF SOIL CLASSIFICATION, BASED UPON THE MECHANICAL COMPOSISION OF SOILS.

1 mm. = about 1-25 inch.

Class.	1. Fine gravel. 2–1 mm.	2. Coarse sand. 1–.5 mm.	3. Medium sand. .5–.25 mm.	4. Fine sand. .25–.1 mm.	5. Very fine sand. .1–.05 mm.	6 Silt. .05–.005 mm.	7. Clay. .005–0 mm.
Coarse sand.	More than 25% of.... 1 + 2					0–15	0–10
	More than 50% of 1 + 2 + 3.					Less than 20% of 6 + 7.	
Medium. sand.	Less than 25% of 1 + 2.					0–15	0–10
	More than 20% of 1 + 2 + 3.					Less than 20% of 6 + 7.	
Fine sand.	Less than 20% of 1 + 2 + 3.					0–15	0–10
						Less than 20% of 6 + 7.	
Sandy loam.	More than 20% of 1 + 2 + 3.					10–35	5–15
						More than 20% and less than 50% of 6 + 7.	
Fine sandy loam.	Less than 20% of 1 + 2 + 3.					10–35	5–15
						More than 20% and less than 50% of 6 + 7.	
	Will pass through 10-mesh sieve.	Will pass through 20-mesh sieve.	Will pass through 40-mesh sieve.	Will pass through 80-mesh sieve.	Will pass through 200-mesh sieve.		

Sieve tests of tills will be found in Russell's report for 1904, p. 73, and 1906, p. 80, and it will be noticed that while a fourth to a half passes through the 200-mesh sieve, a very noticeable proportion of up to 38% remain at the same time on the 50-mesh sieve, thus bringing them in the class of sandy loams.

Numerous other analyses of clays may be found in our reports* and peat

*Especially pp. 48–62 of Volume VIII, Part 1.

and muck analyses will be found in Davis' peat report* and Livingston's report,† and the reports of the Board of Agriculture. A series of tests of sands will be found in Ries & Rosen's molding sand report, which precedes this.

The following are the United States Department of Agriculture descriptions of our soils:

Clyde clay.—"The soil, from 6 to 9 inches deep, is a silty clay loam of a brown or black color. Where the proportion of organic matter is highest, the soil is darkest and more loamy and friable. The subsoil is a bluish or drab-colored clay, very tenacious and practically impervious to water. The type is derived from glacial lake deposits, and occupies low, wet, level areas, some of which were originally covered with peat. With good drainage the soil is well adapted to sugar beets, as well as to general farm crops."

Clyde fine sand.—"The soil consists of a dark-gray to black fine sand, varying in depth from 4 to 20 inches. The subsoil has about the same texture as the soil, but contains less organic matter and is lighter in color. In some instances the subsoil contains layers of peat. The surface of the type is nearly level and natural drainage is generally poor. The type has been formed by the reworking of the glacial sands and their deposition in former lakes. The soil is greatly improved by artificial drainage. The crop value of this soil depends much upon the proportion of organic matter present and its drainage conditions. It is suited to small fruits, being an ideal soil for strawberries. Fair crops of corn, oats and potatoes are produced."

Clyde fine sandy loam.—"The soil, from 9 to 12 inches, is a very fine sand loam of a brownish-gray or brown color, homogeneous in texture, friable and easily kept in good tilth. The subsoil is a brown or yellow fine sand or fine sandy loam to a depth of 2 feet or more below the surface, overlying a clay similar to the subsoil of the Clyde loam. But soil and subsoil are entirely devoid of gravel. Portions of the type seem to be the result of delta formations, subsequently modified by wind and wave action, while other portions occur in the form of low ridges as wind-blown beach deposits. The surface is slightly undulating and rolling, and drainage varies largely with local topography. Besides general farming and dairying, sugar beets, beans and potatoes are important interests, and to a less extent, chicory, apples, grapes, pears and vegetables."

Clyde gravelly sand.—"The soil is medium-textured, light to dark brown loamy sand or light sandy loam 10 inches deep, carrying a large percentage of gravel. The subsoil is a rather coarse incoherent gravelly sand, usually grading into a mixture of coarse sand and fine gravel at a depth of from 24 to 30 inches. Clay is often found at from 4 to 8 feet below the surface. The type is generally well drained. The topography varies from gentle slopes to gently rolling ridges representing old beach lines or terraces. The soil is the result of beach or shallow water deposition, in places influenced to some extent by local wash from the higher lands. Fairly good yields of corn, oats, wheat, rye, timothy, clover, and buck wheat are secured, and some special crops, such as sugar beets, beans and potatoes are grown. The soil is also adapted to fruit and truck crops."

Clyde gravelly sandy loam.—"The soil to a depth of from 8 to 15 inches is a coarse to medium black sandy loam, rich in organic matter and containing a varying percentage of gravel. The subsoil to a depth of 36 inches

*Annual for 1906.
†Annual for 1903.

consists of a mixture of medium to coarse sand, with a high percentage of gravel. The surface varies from nearly level to gently rolling and the drainage is good. This soil has been formed by the reworking of glacial material by water and its deposition in lakes. It is well adapted to potatoes and produces fair crops of grain, hay, onions, carrots and sugar beets."

Clyde loam.—"The soil ranges from a moderately friable loam to a rather heavy, compact loam of a dark-gray, brown, or black color, from 8 to 12 inches deep, resting upon a drab-colored sandy or silty clay somewhat streaked and mottled with iron stains. On account of former inadequate drainage much of the soil is still in a puddled and compact state, sticky and impervious when wet, and very hard when dry. This condition is emphasized by low-lying areas that have been cultivated only a short time. In its natural state the soil possesses marked clayey properties to within a few inches of the surface, where there is an accumulation of organic matter. In the better drained areas the soil is mellow, and the subsoil, too, is more friable and not pervious to water. The type is derived from glacial lake deposits that have not been modified to any extent by subsequent stream action. Its almost level surface with occasional low knolls and swells and intervening shallow depressions naturally cause poor drainage. When properly drained and cultivated, large crop yields are secured. The principal crops grown are corn, oats, wheat, hay, and sugar beets. It is considered an excellent soil for the latter crop."

Clyde sand.—"The soil consists of 12 inches of black medium to fine loamy sand, underlain by sand to a depth of 30 inches, which in turn is generally underlain by clay. The type occupies low, flat areas and is generally swampy and poorly drained. It is composed of reworked glacial sands with the addition of organic matter. When well drained the soil produces good crops of corn, wheat, grass, oats, rye, and all kinds of truck crops. It is a fair soil for sugar beets."

Clyde sandy loam.—"The soil is a dark gray or brown mixed-textured sandy loam from 8 to 12 inches deep, resting on material of similar texture, but lighter color, which is underlain at 18 inches by a drab or brownish mottled sandy clay, sometimes tending more toward a sticky sandy loam. The soil carries a fair percentage of organic matter, and is easily brought into good tilth. The type has been formed by the reworking of glacial material as beach or shallow water deposits. The surface is level to gently rolling, and upon the whole the drainage features are fairly good. This is a good soil for general farm crops, sugar beets, beans, potatoes, and orchard fruit.

Clyde silt loam.—"The soil is a light to chocolate-brown silt loam 10 inches deep, resting upon a similar silt loam of a lemon-yellow color, containing little or no organic matter. The texture is very homogeneous at a depth of three feet, and gravel is entirely absent, but there are some boulders strewn over the surface. The soil is very friable and easily kept in good tilth. The type seems to be derived from material carried by streams and deposited in the glacial lake. It is somewhat rolling in topography, and the drainage is fairly good. The soil is well adapted to grain and hay, and is used for general farm crops and for the production of chicory."

Clyde stony sandy loam.—"The soil is a dark-brown, medium textured gravelly sandy loam, 18 to 24 inches deep, underlain by a sandy loam or mottled brown clay loam containing a small amount of gravel. A noticeable characteristic is the large number of boulders strewn over the surface and occurring to a less extent below the surface. These boulders are mainly

of granite, and range from cobbles to angular fragments 2 to 3 feet in diameter. With these stones removed from the surface the soil is a good friable sandy loam, and produce fairly good crops. The type is of glacial or lacustrine origin, has level or gently rolling topography, and for the most part is fairly well drained. The crops grown are corn, oats, wheat, sugar beets, beans, potatoes, hay, etc."

Marshall gravel.—"The soil is a dark brown to black sandy loam, containing a high percentage of fine gravel. At 15 to 24 inches it grades into a bed of gravel and coarse sand. With the exception of some pasturage afforded early in the season it has little agricultural value, and crops being small and easily affected by drought."

Superior clay.—"A heavy, compact, and almost impervious red clay, with no apparent difference in color or texture between soil and subsoil. When wet it is of a brick red color, and quite adhesive and gummy; when dry cracks an inch or more in width are common on the surface, and the soil breaks up into cubical blocks. Sometimes there are small fragments of rocks in both soil and subsoil, and usually upon new ground there is an inch or so of vegetable mold. The type occurs generally in broad and flat areas, with surface inclinations toward streams, and is very retentive of moisture. The soil is lacustrine in origin. It is adapted to timothy and clover. It improves with use and good crops of potatoes, peas, beets and other root crops have been grown."

Superior sandy loam.—"A gray to reddish sand or light sandy loam, of medium texture, varying in depth from 12 to 24 inches. Sometimes the surface is strewn with small rocks and boulders in such quantities as to interfere with cultivation. The subsoil is a stiff, tenacious, impervious red clay similar to the material forming the Superior clay, and it is sometimes interstratified with thin layers of fine sand. The sandy soil is the result of wash from higher lying sandy land. The type usually occupies level and gently rolling areas, with sufficient elevation to secure good natural drainage. It is a warm soil, easily tilled, and adapted to a variety of crops. The crops grown are clover, timothy, potatoes and small fruits. The original timber growth is pine."

MIAMI SERIES.

"The Miami series is one of the most important, widely distributed, and complete soil series that has been established. The series is characterized by the light color of the surface soils, by derivation from glacial material, and by being timbered either now or originally. The heavier members of the series are better adapted to wheat than the corresponding members of the Marshall series, but they do not produce as large yields of corn."

Miami stony sand.—"The soil is a loose yellow or brown sand or light sandy loam 8 inches deep, underlain by yellow sand of varying texture to a depth of three feet or more. Stones and large boulders, constituting 20 to 70 per cent of the total mass, are scattered on the surface and mixed with the soil and subsoil. The type is derived from morainac material and occupies large, rounded hills and ridges. Corn, rye and buckwheat are grown to some extent, but the yields are low."

Miami stony sandy loam.—"The soil is a gray or brown sandy or fine sandy loam from 6 to 10 inches deep, underlain by brown or yellow sandy loam or heavy sandy loam. Both soil and subsoil contain from 20 to 70 per cent of stones and gravel, consisting of granite, sandstone and limestone. The type is derived from the weathering of glacial material, occupies the rolling and level uplands, and is usually well drained. The soil is not very productive. Beans, corn, wheat and oats, and grasses are the main products. Truck and fruit do fairly well."

Miami stony loam.—"The soil consists of a gray to brown loam about 10 inches deep, underlain by a yellow loam or heavy sandy loam, which is in turn underlain locally by beds of consolidated gravel or bed rock. There is from 20 to 60 per cent of rounded and angular stones on the surface and mixed with both the soil and the subsoil. The stones vary from 1 to 8 inches in diameter. The type generally occupies large, rounded hills and table lands and gently rolling lands at lower levels. It is chiefly derived from moranic material. The soil is very productive, and produces good crops of corn, wheat, grass, oats and fruit, particularly apples. The type also affords excellent pasture."

Miami gravel.—"The soil is a medium grade sandy loam about 12 inches deep, containing 50 per cent of gravel from ½ inch to 2 inches in diameter. The subsoil consists of cross-bedded sand and gravel, the latter often coated with calcium carbonate. The type occurs only in small areas and is the outcrop of reworked glacial gravels in river cliffs. For the most part it is uncultivated and is of little value for farming."

Miami gravelly sand.—"The soil is a brown gravelly sand of medium to coarse texture, 9 to 12 inches deep, grading through a lighter brown gravelly sand into a mixture of coarse sand and fine gravel at a depth of about 3 feet. In some places the underlying gravel comes within a few inches of the surface. The type represents mainly old beach lines, and is formed by material deposited by wave or stream action. Its usually rolling or ridgy topography insures good drainage. The type is best suited to truck and fruit crops."

Miami gravelly sandy loam.—"The soil to a depth of 8 inches is generally a light brown sandy loam containing a high percentage of gravel and frequently small stones. The subsoil varies from a sticky sandy loam to a gravelly sand, and is often underlain at a depth of 2 to 3 feet by a bed of gravel. The surface is rolling and the type often occurs as rounded knolls or hills, generally composed of stratified and unstratified sands, clays and gravels. It is of glacial origin, and often represents moranic material. Where cultivated, the crop yields are only fair. It is not adapted to general farming, though fairly well adapted to light farming and the production of small fruits. In favorable localities peaches do well on this soil."

Miami gravelly loam.—"The soil is a brown or reddish loam 12 inches deep, containing 15 to 30 per cent of rounded gravel. The soil is underlain to a depth of 24 inches by a stiff, tenacious clay loam, which is in turn underlain by gravel. The type occupies level or gently rolling river terraces, and is composed of original glacial material worked over by the streams. This is recognized as fine soil for general farm purposes."

Miami sand.—"The soil is a coarse to medium loose, incoherent sand, underlain by yellow or reddish sand of about the same texture. This is the prototype of the Norfolk sand of the Atlantic coast, and Fresno sand of the Pacific coast, and is a typical truck soil. The type may be either of glacial or alluvial origin, modified by wind action, and has a level or rolling topography."

Miami fine sand.—"The soil is a fine yellow or light brown sand 6 to 12 inches deep. The subsoil consists of a fine orange or yellow sand. The type is free from stones and often occurs as dunes. It has good natural drainage and is easily tilled. The principal crops are corn, potatoes, berries, and, of less importance, wheat, oats, grasses and cabbage. The soil is best adapted to truck, potatoes and small fruit."

Miami sandy loam.—"The soil is light gray to brown sandy loam 8 to 14 inches deep, underlain by a sandy loam or sand, sometimes containing fine gravel. The type is of glacial origin and occupies level or gently rolling areas, and sometimes rounded hills with kettle like intervening depressions. In some areas the soil is adapted to corn, wheat, grass, rye and oats; in others mainly to fruits, small fruits and truck crops."

Miami fine sandy loam.—"The soil consists of a loose, loamy brown sand or sandy loam from 10 to 30 inches deep, the sand being from medium to fine in texture. The subsoil is a clay loam or sticky sand loam. This type differs from the Miami sandy loam in having the heavy subsoil within three feet of the surface. The type is of glacial origin, occupies rolling country, often occurring as rounded hills and ridges, and has good drainage. The Miami fine sandy loam is a good corn soil. Wheat yields from 15 to 30 bushels, oats from 35 to 75 bushels, rye from 15 to 30 bushels, and hay 1½ to 2 tons per acre. The soil is used for general agriculture, but is especially adapted to medium and late truck crops and fruit."

Miami loam.—"The soil consists of a light brown to dark gray rather mellow loam about 12 inches deep, sometimes becoming lighter in color with depth. The subsoil is a compact yellow sandy clay, frequently carrying stones and gravel. Often at a depth of from 14 to 25 inches gravelly material is encountered. A few boulders and pebbles usually are found on the surface. The type occupies level to rolling upland, and is fairly well drained except in some of the level areas. The soil is especially suited to corn and potatoes, while small grain and grass are grown with a fair degree of success. Small fruits, such as strawberries and raspberries, do well."

Miami silt loam.—"This is a light brown or yellow to almost white silt loam from 8 to 12 inches deep, underlain by a compact silt loam or silt clay of a yellowish color. The type occupies rolling to hilly areas and was originally timbered. Its origin is due to the deposition of loose over glacial till. The soil is not as productive as the Marshall silt loam, but produces good yields of wheat, corn, clover, and timothy hay."

Miami clay loam.—"The soil to an average depth of 10 inches consists of a yellowish gray to light brown somewhat silty loam, underlain by light brown to yellow, sometimes mottled, stiff silty clay loam or clay, which is in turn underlain by boulder clay at depths varying from 5 to 10 feet. Stones and erratic boulders are found on the surface, but in no great quantity except in small areas. The type occupies uplands and the surface is level to gently rolling, except near streams, where it becomes hilly and broken. The flat interstream areas generally require artificial drainage. The soil is fairly good for general farming, and is especially adapted to small grains and grass crops."

Miami black clay loam.—"The soil is a black clay loam 10 to 12 inches deep, underlain by a tenacious drab clay. The type is of glacial origin, is generally level, and the natural drainage is poor. When thoroughly drained this soil is very productive, particularly for corn. It is also well adapted for grass and wheat."

THE ICE RETREAT.

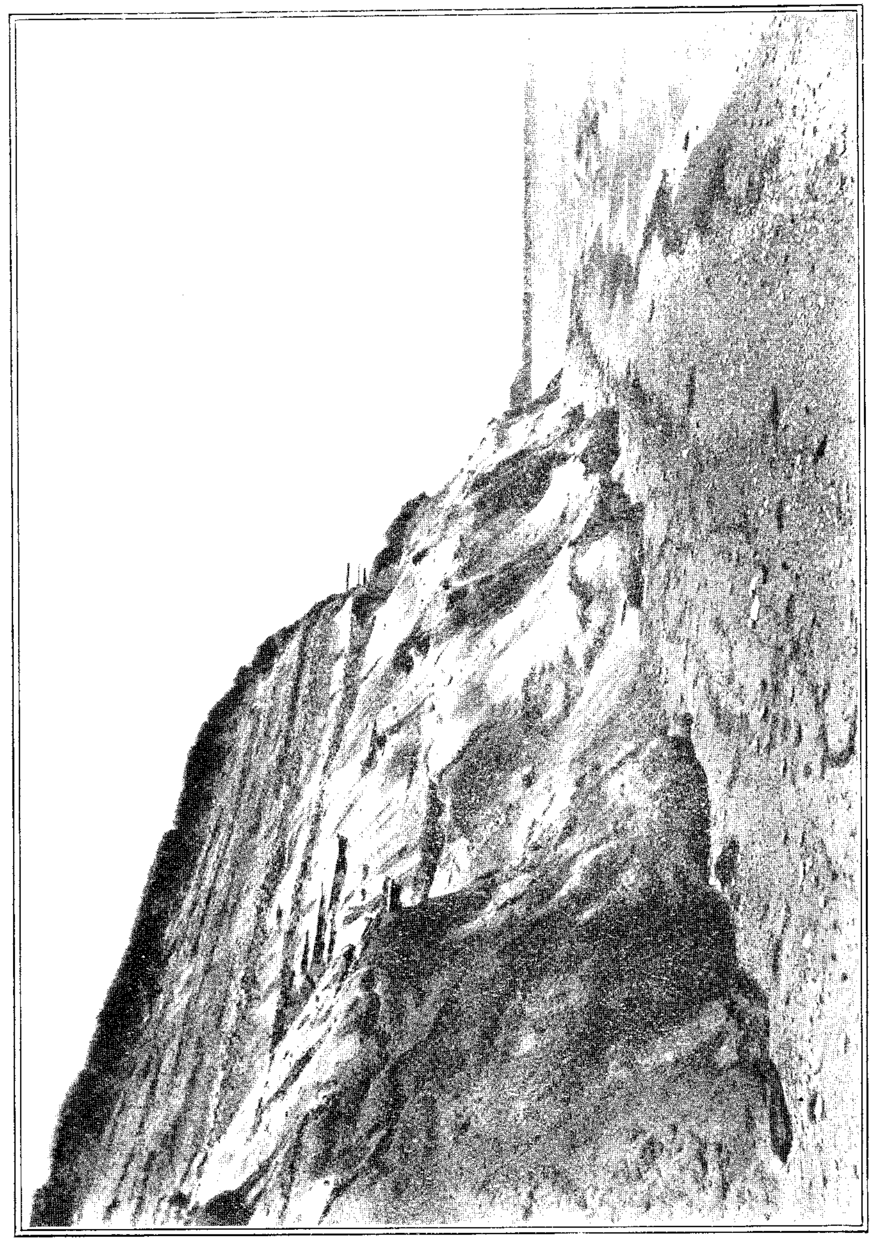
We have said at one time Michigan was covered by a great ice sheet moving from the north. This did not, however, move steadily out from one center until it reached its extreme size and then retired steadily backward. That is not the way glaciers do at present. A series of winters with extra snow and cool summers will push them forward, and the accumulated effect of a series of hotter years will cause them to retreat though the effect on the glacier lags some time behind the weather.* So it was with the great ice age. There are a series of advances followed by very marked retreats. This is, of course, especially conspicuous in the states to the south of us, but it seems also that the ice at times retired so far as to leave Michigan uncovered, and indeed it is quite possible that the ice entirely disappeared. Some, indeed, have supposed alternate glaciation, first in the northern hemisphere and then in the southern. The signs of these oscillations as we find them are:

1. Beds of soil or wood which have been encountered in sinking wells and shafts.
2. The difference in the hardness of the drift. The older, having been overridden by the ice, is notably more compact.
3. The difference in the direction from which it received most of its material.
4. The weathering (including the erosion, the bleaching, reddening and leaching out of the lime) of the older till deposits during the time the ice retired, which marks off the older till from the younger.
5. In a few cases, especially around Toronto, marine clays with shells have been found between the different drift sheets. The fullest list of stages of the ice age made out which will be found in Chamberlin & Salisbury's Geology, Volume III, page 383, is as follows:†

I. The sub-Aftonian, or Jerseyan, the earliest known invasion.
II. The Aftonian, the first known interglacial interval.
III. The Kansan, or second invasion now recognized, from west of Hudson's Bay.
IV. The Yarmouth, or Buchanan, the second interglacial interval.
V. The Illinoian, the third invasion, from Labrador.
VI. The Sangamon, the third interglacial interval.
VII. The Iowan, the fourth invasion, from west of Hudson's Bay and Labrador.
VIII. The Peorian, the fourth interglacial interval.
IX. The Earlier Wisconsin, the fifth invasion, from Labrador and Hudson's Bay.
X. The fifth interval of deglaciation, as yet unnamed.
XI. The Later Wisconsin, the sixth advance, from many centers, lobate.
XII. The glacio-lacustrine sub-stage.
XIII. The Champlain sub-stage (marine).

Of these stages probably not more than six can be even guessed at at present, so far as Michigan evidence is concerned. There is, however, distinct evidence of ice motion from the northwest, scattering bits of native copper toward the southeast and making striæ in that direction. Whether this is Kansan or Iowan I would not pretend to say. Probably during the interval between this and the motion of the ice from the Labrador cen-

*See Sherzer's report on the Selkirk glaciers for the Smithsonian Institution, 1908.
†Compare also Leverett's list page 4 of the Ann Arbor Folio.



BEACH DEPOSITS, GRAVELS, ALGONQUIN BEACH GRAVELS, EXPOSED BY PRESENT CUTTING.

ter, a lake may have existed in which the red clays so abundant around Lake Superior were laid down, and the clay and till of this ice age may have been carved into drumlin form by later invasions. Then came invasion from the northwest from the Labrador center. Around Ann Arbor on the Huron just below Ypsilanti, and at other places cuts have been made down into hard, dark, older looking till which have been thought by Leverett's

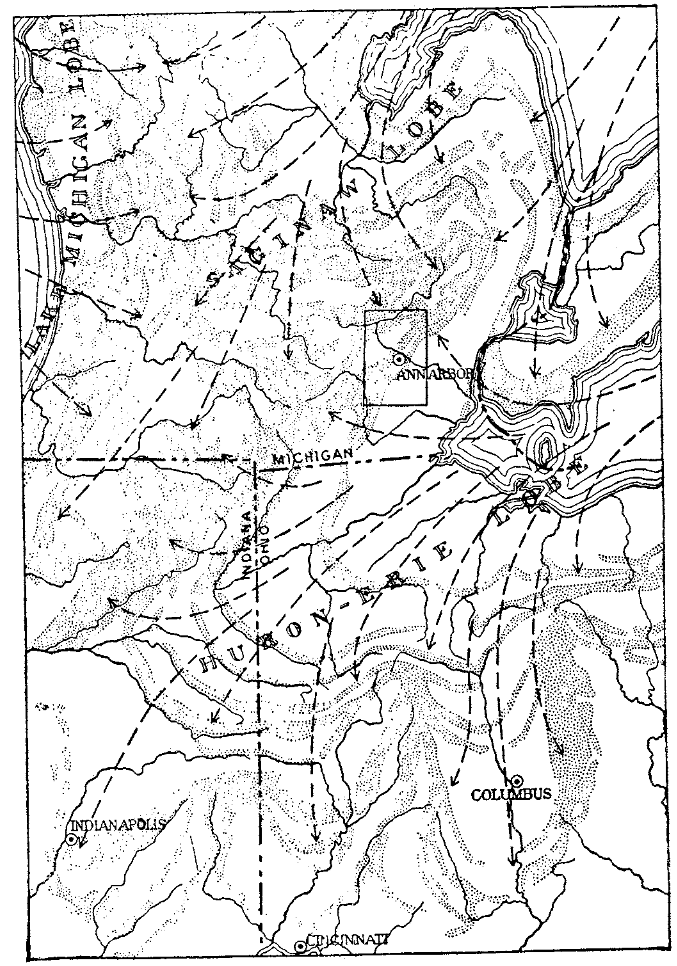


Figure 9—Sketch map of moraines of till left in its retreat from the Ohio River by the Erie-Huron ice lobe. This was formed by the currents of ice that followed the valleys of these lakes. After Fig. 5, Ann Arbor Folio, U. S. G. S. See also Monograph XLI.

perhaps to represent the Illinoian stage. It does certainly seem as though it were quite a little older than the till lying on top, and we know that drift of the Illinoian stage came across Michigan to Illinois from the Labrador ice fields at that time. "It is also probable that this state was covered by ice at the Iowa stage, for the Iowan drift sheet is well displayed on the west side of Lower Michigan outside the limits of the Wisconsin drift." We may expect, therefore, to find remnants of these earlier till sheets here and there where, owing to some favored condition, they have not been eroded away by the later ice sheet. But to identify these sheets one would have to be very familiar with their characteristics and also have samples. Very few borings or drillings record the character of the drift beds encountered between the surface and the bed rock with sufficient care to even guess at any such separations. In fact the drillers rarely recognize till and very rarely keep samples of the "surface," so that while we can be pretty sure of the earlier till sheets it is quite impossible as yet to determine the same or to tell how and in what directions the ice may have retired or advanced.

The last, and to us the most important, movement of the ice was that of the Wisconsin ice sheet. This came to us mainly from the northeast, in a general direction from Labrador, and was, we may believe, not very thick, at least during its waning time, for at that time it seems to have been guided very largely by the greater valleys of the surface of bedrock beneath, shown in Plate VI. One great tongue spread down Lake Erie, meeting one from Lake Huron. Another great tongue reached down Lake Michigan. A shorter one considerably checked by the hard rocks which cross the neck of Saginaw Bay is called the Saginaw lobe. As its farthest extent the ice reached as far as the Ohio river, (Fig. 9), and then the general trend of the ice motion was from the northeast but as the ice waned the lobes more and more appeared and the course of the ice was shifted, the direction of the ice motion as indicated by the scratches on the rock, by eskers, etc., being always at about right angles to the margin of the ice. Thus as the ice waned and the ice front came less and less far south the ice scratches veered, instead of being from the northeast, and the general rule will be found to be that they veer from northeast so as to be more nearly up the general rock slope. The ice spread out by way of the great valleys now occupied by the Great Lakes and thence rolled as it were up on to the higher lands of the rock surface.

Thus the ice front was composed of a series of curves marked by moraines between which were sharp points or reentrants pointing north. Into these reentrants streams from the ice tended to wash great quantities of stratified drift. In retiring from its position on the Ohio the first place where the ice front reached Michigan was near South Bend and Niles (Fig. 10). Here an early line of drainage followed the Dowagiac and upper St. Joseph rivers and went past Buchanan and South Bend into the great Kankakee marsh and sand area.*

On the west side was the Illinois ice lobe coming down Lake Michigan. The moraines at the edge of the lobe Leverett calls the Valparaiso moraines. They run almost parallel to Lake Michigan up as far as Grand Rapids. On the other side were moraines from the Saginaw Valley in which fragments of coal occur quite abundantly.

THE GLACIAL LAKES.

When the ice had thus retired from its frontage on the Ohio, and Mississippi and Missouri valleys so far north that, as the land *then* stood, there was a slope toward the ice front, lakes were formed along the edge of the ice (Figs. 12 to 16). These drained over the lowest point or points to the south where discharge could be obtained. As the ice retired they flowed together by channels opened up next to the ice until at one time a great sheet of water covered most of the Great Lakes region.

*Leverett, The Illinois Ice Lobe, U. S. G. S., Monograph XXXVIII, Plate XV, p. 342.

When two lakes thus flowed together one of the outlets might be deserted[1] entirely, or the lake might and often did have two outlets at once. Sketch maps showing successive stages in some of these lakes have been prepared by Taylor and Leverett and are here reproduced.[2]

THE RETREAT IN LAKE MICHIGAN.

It will be impossible to follow the retreat of the ice front, which is what really determined our surface geology, everywhere all at once. It will be convenient to take it in Lake Michigan first, both because it has been recently and carefully studied there by Goldthwait and because Lake Michigan so lies from north to south as to make the story except in its later stages much more simple and readily understood.[3]

LAKE CHICAGO.

When the ice retired from the Valparaiso moraine on the west side of Dowagiac a lake soon formed in front of it, which discharged through the recently reopened Chicago outlet and has been called Lake Chicago. A number of minor ridges of the retiring ice have been recognized by Leverett.[4]

Around and about these ridges Lake Chicago extended. But in a number of cases, back of St. Joseph, South Haven, New Richmond, etc., there may have been earlier and separate lakes, the exact histories of which will make pretty problems for local students.

(a) Glenwood 60-foot beach.

The highest level of Lake Chicago is shown by a stony beach just east of Holland on the south side of Black river at 60–65 feet (640 A. T.). This beach has been called the Glenwood beach. Higher water level signs around Vriesland and Overisel may be due to one of the smaller earlier lakes.

The extensive sand plains in Allegan county back of the Valparaiso moraine seem to be a delta deposit in this lake and run from 70 to 90 feet above the lake.

While this 60-foot stage lasted the ice retreated at least as far north as Sheboygan and Manistee, perhaps farther, but if so it returned and wiped out the beaches made.[5]

The lake may then have fallen in level materially during the retreat of the ice, possibly even lower than its present level. River channels are found to have been cut in the till to lower levels than the present bottoms. It very possibly connected at times with Lake Nicolet (Fig. 16) at the head of Green Bay.

(b) Calumet 40-foot beach.

With the readvance of the ice the channels which may have been opened to drain off the lake to a low level, probably somewhere on the eastern side of the Lower Peninsula were plugged up and the water once more escaped to the south, finding its way to the south to the Desplaines and Illinois rivers by a slightly different outlet—at Summit instead of three miles south.

It did not rise so high as before by about 20 feet, and this 40-foot beach

[1]If one of the outlets was so much lower than the others that it could carry the discharge of all the lakes without being raised enough to have even its top higher than the bottom of some of the other outlets.

[2]Chamberlin, III, pp. 390–400. Also Ann Arbor folio, No. 155, U. S. G. S.

[3]Goldthwait, J. W. 'A reconstruction of water planes of the extinct glacial lakes in the Lake Michigan basin." Journal of Geology, Vol. XVI, (1908) p. 459.

[4]Monograph XXXVIII, U. S. G. S., p. 386, to wit: The outer ridge from east of Benton Harbor through Baroda to Three Lakes. The Covert ridge from Hutchinson Lake, northern Allegan, through E. Saugatuck, South Haven, Covert, St. Joseph, etc., only a mile or two from the lake. The Zeeland ridge or May Hill just north of the Pere Marquette track between Grand Rapids and Holland. These ridges are clay or clay loam—typical till.

[5]Goldthwait, Abandoned Shore Lines of Eastern Wisconsin, Wisconsin Geol. Sur. Bull. 17, p. 42.

is known as the Calumet beach. During this second stage the ice lay in the north end of the lake, extending from time to time as far as Manistee and Manitowoc, and wiping out the beaches that may have formed along the shore during its recessions and building heavy moraines now cut into by the lakes. (Fig. 12).

When the ice withdrew finally from the region of Manistee and Muskegon there was a great drop from the Calumet beach, very likely even below the present water level and the drowned river valleys now occupied by the "daughter lakes," which fringe Lake Michigan so conspicuously may have been carved. But this was due to the blending of Lakes Michigan and Huron (and for that matter Superior too) in one great expanse of water which has been called Lake Algonquin, and the story of Lake Algonquin

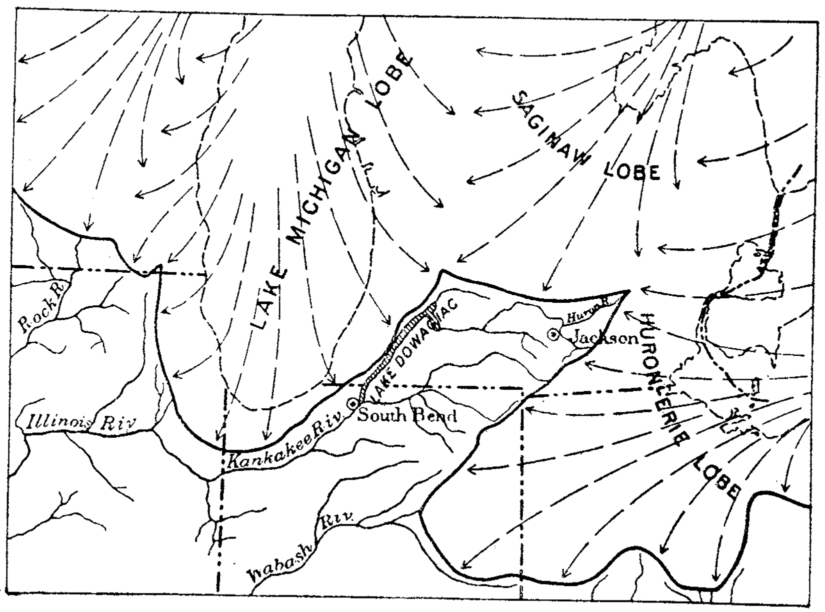


Figure 10—Course of drainage from Southern Michigan by way of the Kankakee, after Leverett. Fig. 6, Ann Arbor Folio, U. S. G. S.

must be postponed until we have brought down the story of the other lakes of which it was composed.

One final comment. So far as we now know the beaches of Lake Chicago contain few or no shells. Lake Algonquin contains more. This may be because the earlier lakes were filled with ice water, clouded with glacial silt, and were thus unfavorable to life, whereas toward the end the ice had but little frontage on Lake Algonquin.

RETREAT OF THE ICE TO THE SAGINAW VALLEY.

We have said that the ice front first reached Michigan near South Bend and the sand burdened waters drained off to the great Kankakee marsh. The moraines from the reentrant angle circle Lake Michigan in one direction and curve about Saginaw Bay in the other (Fig. 10).

As the ice returned the reentrant worked north. Its position as marked by the gravel plains around and south from Kalamazoo when the reentrant angle was in the great ridges southeast of Gun Lake.

Another position (Fig. 11) was when the great kame of Dias Hill (T. 5 N., R. 11 W.) in the south part of Kent county was piled up, the drainage following Gem river to the south, and making the Green Lake outwash plain.

Another retreat brought the reentrant back to Plainfield north of Grand Rapids, and the gravels upon which Grand Rapids is built were washed out in front of the moraines, the hill around East Paris being formed by ice that came from the Saginaw Valley. The waters ran into Lake Chicago and built up the sand plains of western Allegan county—"Saugatuck" sands.

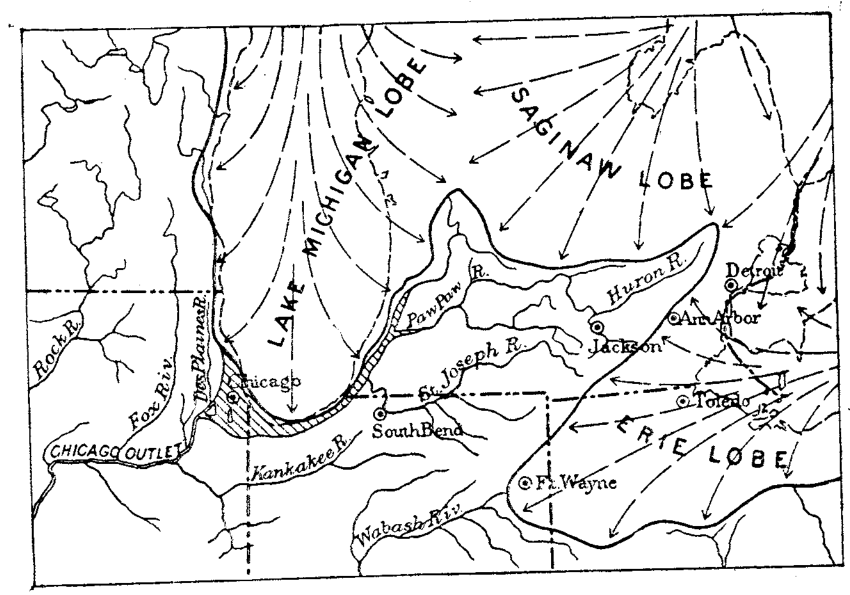


Figure 11—Course of drainage from Southern Michigan by way of Lake Chicago, after Leverett.

In melting back from this the next stand Leverett notes is near Cedar Springs, whence the ice front went to the southeast toward Alto, while to the southwest it passed near Englishville, helping to pile up a belt of high rolling land just west of Grand Rapids, and thence towards Hastings and Mason.*

In the meantime the rivers in the southwestern part of the state, the St. Joseph and Kalamazoo, had been developing. Fed and started at first by floods of waters from the melting ice, they often flow in heavy gravel plains. Their valleys are notably of two kinds. They may be valleys between moranic belts of till, which are very often covered with outwash gravels. Or they may be valleys, where mighty streams coming from the ice have cut through the moraines, either preventing their formation or washing them away. They are very often followed by railroads. The Michigan Central from Lawton to Niles, the Grand Trunk from Battle Creek to Charlotte are good illustrations.

*See annual report for 1901, pp. 84, 85.

As the ice tended to occupy the lowlands a peculiarly unnatural form of drainage was produced, and there has doubtless been rearrangement in very many places. The upper parts of the Kalamazoo, and the St. Joseph, and the part of the Grand River that lies about Jackson or even Eaton Rapids are much older than the lower parts. Indeed it seems that parts of the head waters of the Huron river in Oakland county, and even of country now draining into Lake St. Clair once drained first past Jackson, then past Eaton Rapids to the southwest.

Two things to be noted are the relatively rapid disappearance of the ice in its waning stage of glaciation from the higher parts of the rock surface, and the relatively little vigor with which the ice pushed over the Saginaw Valley. This may be attributed to the fact that right across the neck of the bay from Huron county to Arenac county through the Charity islands is a rock ridge.

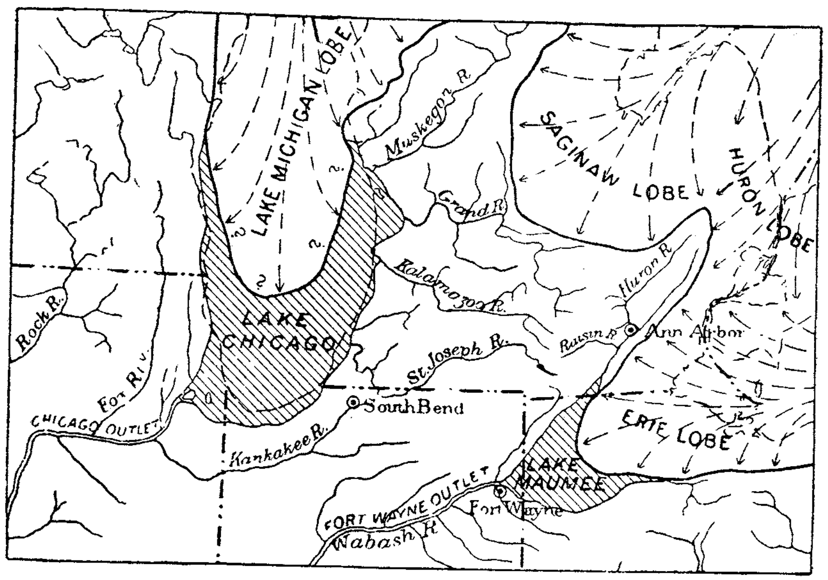


Figure 12—Course of drainage from Southern Michigan by way of Lake Maumee and Lake Chicago. After Leverett.

Though Michigan is full of lakes they must have been much larger, and many large lakes which once existed have ceased to be. This process is indeed now going on. There is opportunity for indefinite and very attractive outdoor local work in tracing out the history of individual lakes and regions and placing them so far as possible in the general succession of events, as here outlined.

EARLY LAKES ON THE EAST SIDE OF THE LOWER PENINSULA.

Lake Maumee.

(a) Van Wert Stage (793 A. T.).

As soon as the ice in its retreat passed the divide between the Maumee and the Wabash in Indiana, near Huntington, not far from Ft. Wayne, a lake shaped like an arrow head began forming in front of the ice and the marginal moraines formed by it. The Huron and Raisin soon found their way into this (Fig. 12).

A well marked moraine has its apex near Defiance, Ohio, and thence passes northeastward through Adrian, Michigan, between Ypsilanti and Ann Arbor, and so north to a reentrant angle between the Lake Erie and Lake Huron ice tongue and the Saginaw Valley ice somewhere in Lapeer county.* (Plate IX.)

When the ice ceased to reach the Defiance moraine the waters of the Lake worked around in behind it (Fig. 13) leaving it in islands, and of course the water was at first at the same level. But as this beach is traced north it is found at present higher and higher up. This is a phenomenon we find over and over again repeated and must be due to an uplift, increasing to the north, combined to some extent with the readjustment of lines of equal level, as previously explained. From 793 feet at Adrian it rises to 800

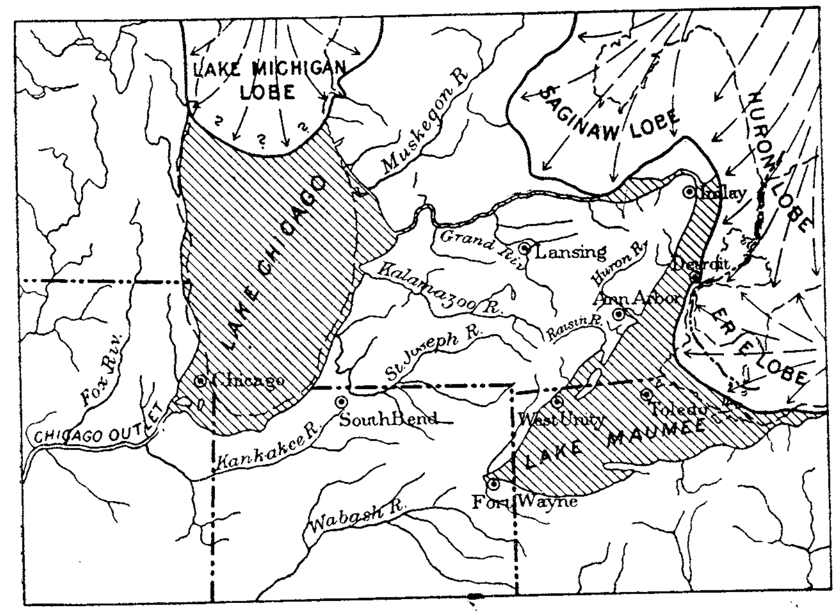


Figure 13—Course of drainage by Imlay outlet and Grand River valley (Pewamo outlet) after Leverett.

or 812 feet A. T. at Ypsilanti, and Ann Arbor, and reaches 850 and perhaps more further north. The addition of a second outlet lowered the level of the lake and of the water in the first until the outflow reached a balance.

(b) Leipsic stage (Second Maumee Beach).

Finally the ice front retreated far enough so that a channel was opened in Lapeer county (see Plate IX,) by way of Imlay City and the Flint river drainage down to a lake which had formed in the Saginaw valley and was discharging by way of the Grand into Lake Chicago. In order to balance this extra outflow the discharge by way of Ft. Wayne was cut off by drop of the lake level so that the Ft. Wayne outlet from being 15 to 20 feet deep was only 5 or less, a mere regulator or waste weir, the main channel being that of Imlay City. These channels are clearly

*Annual report for 1901, Plate VI.

brought out on the map of surface geology, being bottomed with sand and gravel or swampy, and not till. Plate XII.

The beach is 15 or 20 feet below the upper one, being about 825 feet A. T. at the Imlay outlet.

With the next retirement of the ice the lake spread so as not merely to cover the flat area southwest of Erie and Huron, but absorbed the Saginaw Valley as well, and thus has received a special name.

A third beach 20 feet lower yet may mark the culmination of a recession between the times of the first and second, and seems to have been washed over by readvances.

Lake Arkona—Arkona Beaches. Defiance Moraines

When the ice left the moraines in the northern part of Wayne county it seems to have retired quite rapidly and to a distance that left open complete water communication around the Thumb.* Of course this was by degrees, and water channels opened across the Thumb. Of these there are many, some of which may have begun work at this time, others certainly later. Lake Arkona, like Lake Warren (Fig. 15), then covered a good part of Lakes Erie and Huron and stretched from the highlands of Arenac county to the highlands back of Buffalo. There thus seem to be two, rarely four, beaches belonging to Lake Arkona, and whether these are due to the gradual opening of channels across the Thumb, to cutting down of Grand river outlet, or whether even there were outlets opened in New York state† is not fully determined.

The next step in ice history was very interesting. The ice front readvanced. Lake Superior was cut off by itself once more; the Pt. Huron moraine wiped out part of the beaches, while near the point where they were wiped out and facing the moraine great strong beaches remain.‡

RETREAT OF THE ICE FROM THE NORTHERN HIGHLANDS.

During the time of Lake Arkona and the retreat of the ice front the reentrant between Lake Michigan and Saginaw Bay must have gone back so as to leave all the great highland north of Saginaw Bay uncovered. The readvance at the close of this time in Lake Huron reminds one of the readvance of the ice in Lake Michigan to the Manistee moraine. One is tempted to speculate if the retreat went so far as to open some passage to the north where the land was then depressed and drop the water level even below the present. Signs of some such interruption by a great drop of water level during the existence of Lake Chicago have been noted. In that case the recognized Arkona beaches would mark certain late stages in the readvance of, and the higher levels of Lake Arkona. The lower ones would be wiped out or inextricably worked over and into the series of later beaches.

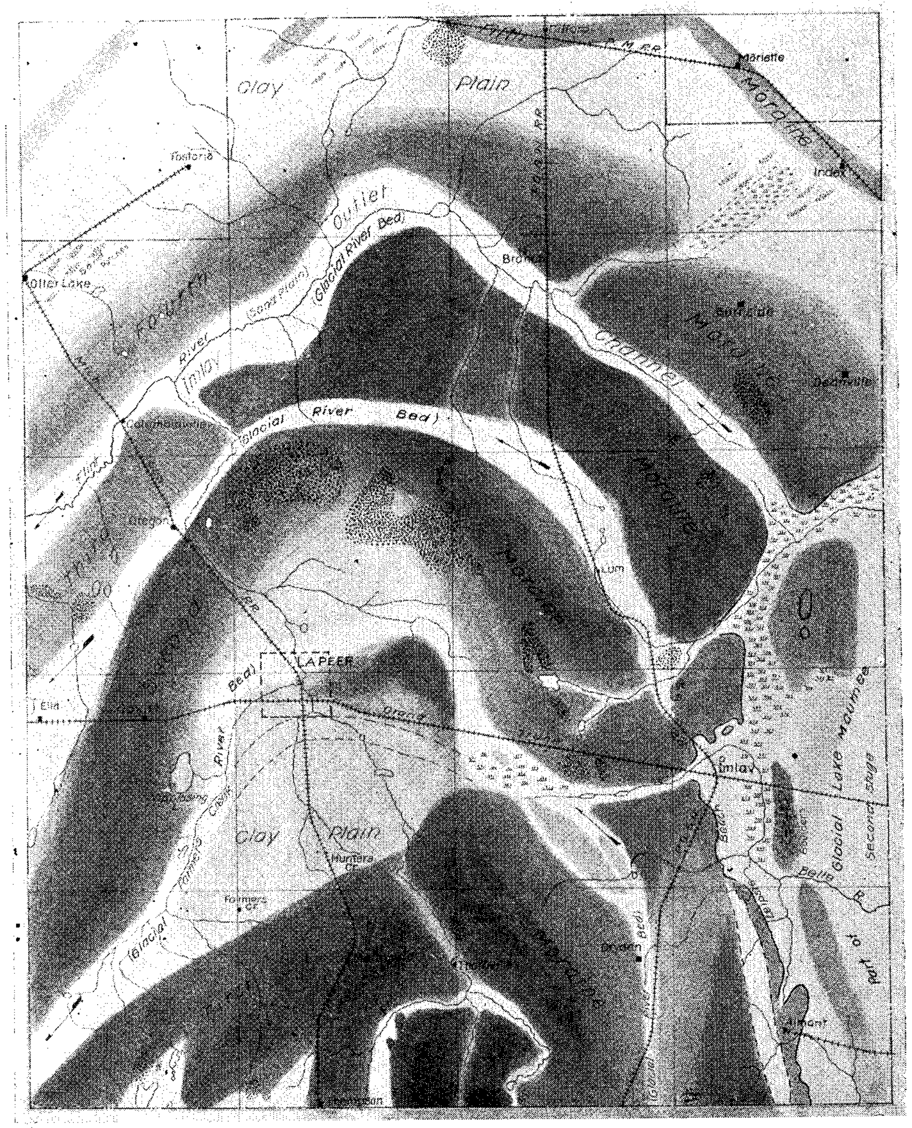
We had followed the retreat of the angle between the Michigan lobe and the Saginaw lobe back a little way north of Grand Rapids. So far it had been a rather sharp and definite point. But in retiring farther past the high land in the Lower Peninsula (1722 A. T.) near the junction of Osceola, Wexford and Missaukee counties, it probably ceases to be so defi-

*Taylor. Seventh Report Michigan Academy of Science, pp. 32–33.

†Fairchild, H. L., Glacial Waters in Lake Erie Basin, N. Y., State Education Department, Bulletin 393, Feb., 1907, being Bulletin 106 of the N. Y. state museum.

Fairchild, p. 42 and 64, 75, believes that the ice front did not retire so as to let Lake Arkona reach N. Y. state at all, but if there was a drop between the two stages of Lake Chicago to a level below that of the present lakes, there may have been an even greater retreat and lower beaches of the Arkona interval.

‡Taylor. Seventh report Mich. Academy of Science, p. 32.



SURFACE GEOLOGY OF LAPEER COUNTY.

nite. The ice tongue coming down the Lake Michigan valley moved out against an irregular "knobstone" topography and a double escarpment made by the harder beds of the Lower Carboniferous and Marshall sandstones and the Upper Grand Rapids or Bayport limestones, and the eastern margin of the ice tongue against the high land was broken into spurs.

Floods of sand and gravel were washed out from the ice and when readvance came scraped up from these extensions of the lake shores formed during the times of especial retreat. Thus the *very moraines themselves became sandy and gravelly*, and a broad area was formed between the side moraine of the Lake Michigan tongue and that of the Saginaw ice, in which the drift was piled hundreds, yes in places probably over a thousand feet thick. The rise from 700 or 800 foot contours to 1100 or 1200 A. T. is very sudden, and Cooper* has called attention to the relatively large percentage of territory between 1100 and 1300 A. T., nearly twice as much as there is between 900 and 1100 A. T.

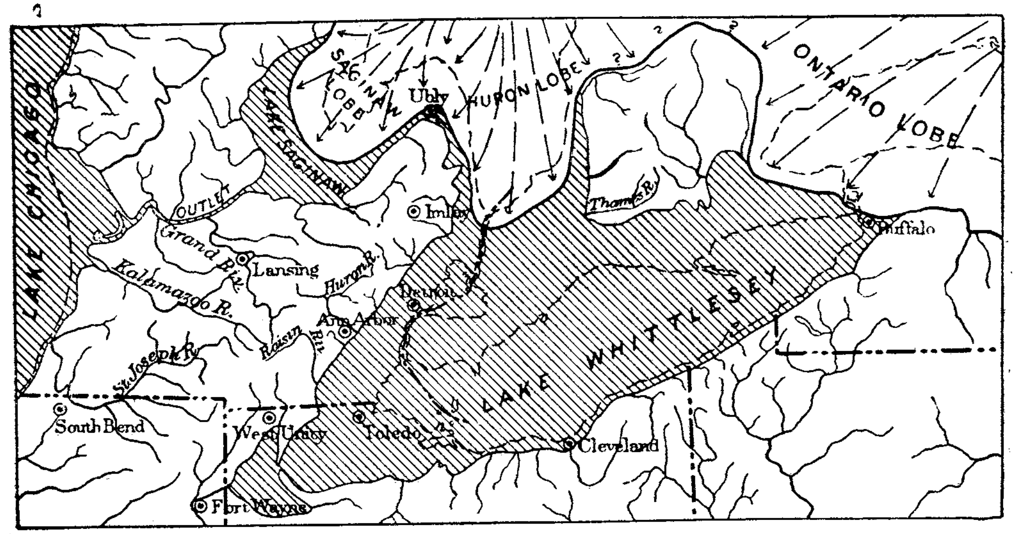


Figure 14—Lake Whittlesey and the Ubly outlet, after Leverett.

The course of the moraines and the position of gravel and sand plains is shown in Leverett & Nellist's (Plate XII) maps.† But it must be remembered that the moraines of this area are of relatively light and sandy material. Numerous undrained lakes and hollows probably mark where fragments of stagnant ice were left buried in the gravel in the relatively rapid retreat of the ice front. The area was drained by the Muskegon, into which flowed parts of the AuSable and Manistee.

LAKE WHITTLESEY. BELMORE BEACHES.

With the cutting of Lake Arkona in two parts by the readvance of the ice front, the name Lake Saginaw is once more applied to that part of the Saginaw valley, but that east of the Thumb has been called Lake Whittlesey.

*Ninth report Academy of Science, p. 140.
†Fuller details of the stages of retreat will be given by F. Leverett in a forthcoming monograph.

This latter drained into Lake Saginaw by channels (Fig. 14) across the Thumb leading down into the Cass river valley, channels out of all proportion to the present size of the streams in which they can scarcely maintain themselves. The one past Ubly is the strongest, and the water line was there 809 A. T.

Lake Whittlesey extended from the Thumb to Marilla, N. Y., a village south of Buffalo. That this readvance was one of some duration is indicated by the persistence of the so-called Belmore beach, made at the time.

Around to Birmingham the level of the Belmore beach is quite flat, the crest being 739 A. T. At Lake Ridge in the northeast corner of Lenawee county the elevation is 736 A. T. Thence the beach is found at higher and higher elevations, owing either to the ice attraction or to the depression of the crust of the earth under the extra load of ice and water. Both explanations must be true to some extent. Fairchild finds in New York a similar rise at a rate up to 2.1 feet per mile in 26 miles, but in 74 miles 1.64 feet per mile.*

In Michigan a rise of (809–739) 70 feet is mainly concentrated in 60 miles. At one stage in the existence of Lake Whittlesey, before it broke fairly open to the Lake Saginaw valley, it may have reached clear around the point of the Thumb, the last holding ground of the ice determining higher levels being the moraine north of Mud Lake, Grant township, Huron county. Around Bad Axe at 774 A. T. the shore lines belonging to this naturally merge with the shore lines belonging to the next stage.

LAKE SAGINAW.

The exact relations between Lake Whittlesey and the Arkona beaches and those corresponding to the Belmore beach in the Saginaw valley have not been worked out. As the outlet of the lake in the Saginaw valley was all the time the same, through the Grand Maple river channel or Pewamo outlet as it has been called, which rests at Ionia and elsewhere on a rock sill, there is no reason why in the Saginaw valley there should have been any material change in height of shore through all the time of Lake Arkona, Whittlesey and the beginning of the succeeding Lake Warren. If the up grade near the ice was as usual it would tend to raise the water level somewhat when it advanced, and there may have been a clearing out of the till on the floor of the Grand River channel. A heavy set of beaches shown on the map start at 760 feet A. T. or so, where they merge in the heavy gravel deltas of the Ubly outlet of Lake Whittlesey around Cass City, and decline toward the Pewamo outlet, grazing the S. E. corner of Saginaw county at 728 A. T. and below. The highest part of the Pewamo or Grand-Maple river outlet is not over 80 feet above Lake Huron, 660 A. T., but this outlet must have been quite deep at first, as it may have carried a stream comparable to Niagara. It is also quite likely that its bottom was at first glacial drift, and slowly cut down, somewhat as the St. Clair river is now doing at Port Huron, until it reached a bed rock sill near Pewamo and Ionia, which would then be the fulcrum from which the tilting of the beaches would be reckoned.

LAKE WARREN. FOREST AND GRASSMERE, BEACHES.

When the ice retired finally from the Port Huron moraine after the Belmore beach was formed, the water level in the Lake Erie-St. Clair valley dropped back to that of Lake Saginaw, and the outlet by the Grand river valley was

*Loc. cit. Glacial Waters in Lake Erie Basin, pp. 77, 78.

for a while the only one for a vast lake extending from the highlands north of Saginaw Bay to New York state (Fig. 15).

This retreat, like the retreat during the time of Lake Arkona, may very likely have gone back so far that other outlets than the one by Grand river, either around the north end of the Lower Peninsula or across the state of New York, past Syracuse and down the Mohawk valley to the Hudson, were opened. But if so they were closed by the readvance of the ice, and the waters rose to the highest shore line of this lake.

The higher shore lines are called the Forest shore lines* and skirt the Thumb of Michigan, from a little north of Bad Axe and at an elevation of about 774 A. T. to 744 A. T. declining where they leave the county, to 729 A. T. to 757 A. T. These are unquestionably connected with the Grand river outlet and that alone.

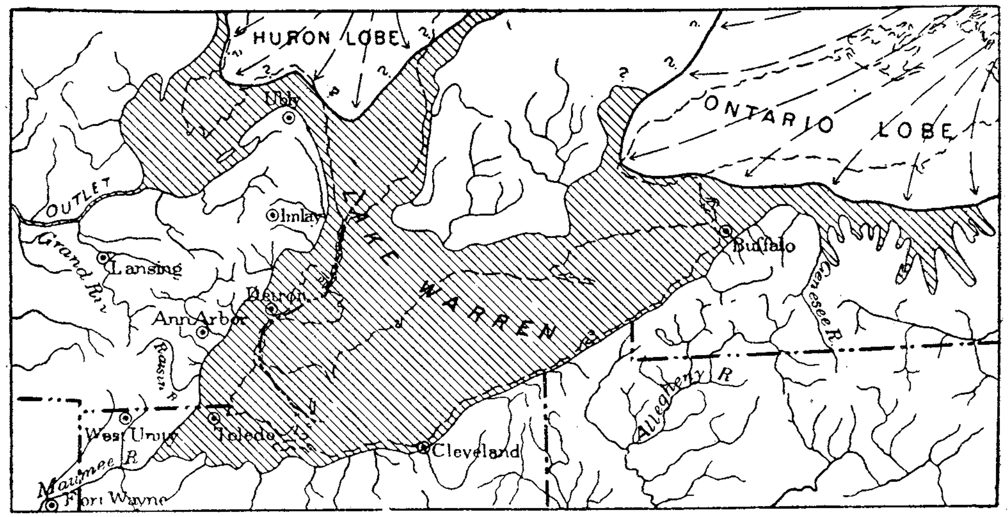


Figure 15—Lake Warren according to Leverett. N. B.—Earlier writers, C. G. Lawson, used the term in a broader sense.

The shell marls associated with these levels indicate rather severe conditions.†

Another group of beaches, which I have called the Grassmere beaches, are on the Thumb 680 to 700 feet A. T., and do not seem to decline so much to the south as the higher beaches‡ and may well represent a relatively stationary level of Lake Warren after the Pewamo outlet had cut down as far as it conveniently could (or was acting as a spill way to some other outlet), and after the ice had retired so far that its effect in making the beach rise to the north was less noticeable.

*See U. S. G. S. Water Supply Paper, 182, Pl. V

†Huron county report, Mich. Geol. Surv., Vol. VIII, Part 2, Chapter X, Sec. 2.

‡Compare the Woodland Avenue beaches in Cleveland, and Fairchild's table on p. 65 of the "Glacial Waters of the Lake Erie Basin." If we take, as Fairchild's table suggests, 70 feet below the Whittlesey or Arkona beaches in Lake Saginaw we shall get the Grassmere, which *may* be what has been called the Lower Forest.

LAKE DANA. ELKTON, ETC., BEACHES.

The next drop was a marked one to a level in Huron county 647 A. T., the Elkton beach. There was a marked sharp halt at this level and then a drop to a level sharply but faintly marked at 635 A. T., at the Thumb.

For the Elkton beach the Pewamo channel can hardly have been an outlet. This must unquestionably have been to the east along a line south of the N. Y. Central down the valley of the Mohawk to the Hudson. A magnificent series of channels running in this direction along the edge of the ice front have been mapped by Fairchild and the lake called Dana.*

The ice front which had been holding the lake up to a level of the Pewamo outlet retired, and somewhere near Marcellus, N. Y., retired so far that water (standing at 880 A. T.) began to find its way around the ice front from Lake Warren into the Mohawk valley. For a short time there would have been two outlets, the amount carried through the Pewamo channel decreasing and the water level there lowering until the amount of the new channel by the ice was balanced. This is just the sort of thing indicated by the Grassmere beaches.

The shore lines at 647 A. T. and 635 A. T. are sharp as to elevation, but relatively weak. It is impossible to connect them with any particular channels as yet.

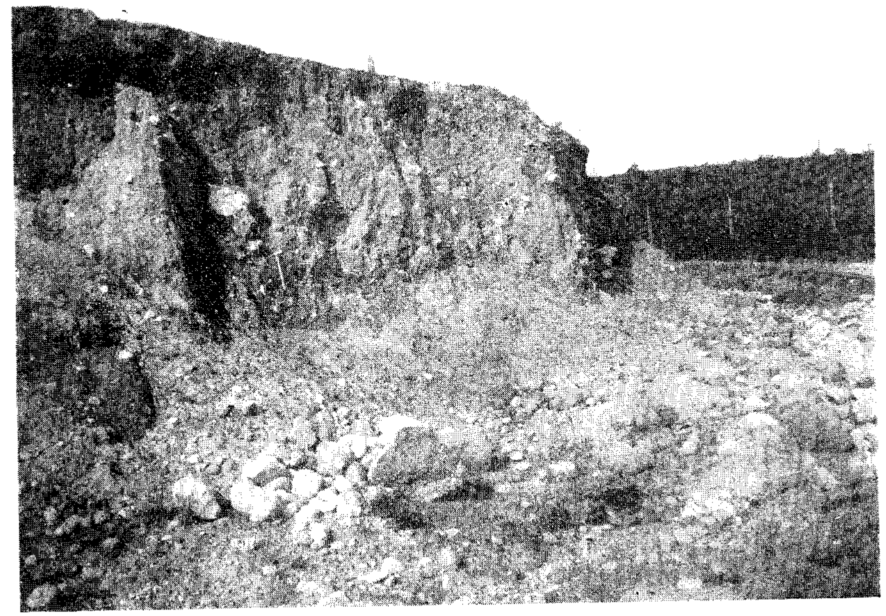
In Bay county where at this time there seems to have been relatively rapid building of sand ridges the record is more complete, and as given by Cooper† we find the following beaches with their respective elevations;

Grassmere, 688 A. T.
Section 5, Garfield, 667-674 A. T.
Section 16, Garfield, 660 bottom to 669 top.
Elkton, 642-650 Williams township.
Saganing, 625 bottom, 633 top, very persistent.
Section 19, Kawkawlin, 610 bottom, 620 top.

LAKE ALGONQUIN. TOLESTON BEACH, ETC.

While the ice was retreating from New York and the Mohawk valley it was also retiring from Lower Michigan. The resultant lake extended into Lake Superior, Lake Michigan, Lake Huron, and would also have covered Lake Erie, but as soon as the ice front retired far enough the water in the Ontario basin dropped to the level of a lake known as Lake Iroquois, Niagara began to work, Lake Erie drained that way and was even lower than at present perhaps at its west end. The upper lakes would have drained about as at present, but that soon after the Mohawk valley opened there was probably an outlet to the Ontario valley (Lake Iroquois) by way of the southeast corner of Georgian Bay, the "Trent outlet" which was so depressed, though now it stands 875 A. T., that the water for a while flowed that way and may have been lower than at present in the south ends of Lakes Huron and Michigan. However, the land around this outlet was rising as the ice retired, and the water soon found its way once more to the south, past Chicago (the Toleston Beach) and past Port Huron. The St. Clair river is cutting down its channel. The Algonquin beaches are being studied by J. W. Goldthwait. His result‡ up to date is that about

*Bull. G. S. A., X, 1899, pp. 27-68.
†Bay county report. Annual report for 1905, pp. 344-348.
‡Abandoned shore lines of Eastern Wisconsin. Bull. XVII, Wis. Geol. Survey. Am. Assoc. Adv. Sci., meeting Dec.-Jan., 1907-08.



TILL OR BOULDER CLAY.

the south end of the lakes the highest Algonquin shore line is nearly horizontal, and the crest of the beach 25 feet above the lake, and is the Toleston Beach of Lake Michigan. In the Saginaw valley faint swells of the surface laid down by the ice under the waters of Lake Saginaw, with beach spits upon them, cut off from the main expanse lakes like those at the ends of Lakes Erie and Superior at present, and there are numerous other lakes,* which began their existence in the same way.

Benches in front of the cut Algonquin shore line are often only 17 to 18 feet above the lake so that the highest *water* level is, say about 600 A. T.

This vast lake had an extremely well marked beach line, which in contrast to those preceding contains shells† (Unio, etc.), in such abundance as to show that the ice had relatively little effect upon the waters. In fact the ice front may have touched it, for at least a good part of its considerable duration, only in one relatively narrow tongue north and east of Lake Nipissing where the Nipissing outlet later to be used was still filled with ice. The Trent outlet was probably soon uplifted and ceased to work. The means of discharge were then reduced to the Chicago outlet, which probably carried but a small part of the water, and the Port Huron outlet, much as at present. During the life of Lake Algonquin the St. Clair delta may have begun to form.‡

As the uplift to the north continued a series of water levels and beaches were produced which converge toward the Port Huron outlet. If the Trent and Port Huron outlets were at first so low that the Chicago outlet did not work at all, the low beaches down at the south end of Lake Michigan could be covered over so that the Toleston beach may not represent really the oldest beach there.

Each distinct uplift would make a new water line and at Mackinac Island and St. Ignace there are some ten of them from 812 to 760 feet A. T. Then at 716 feet A. T. is a well marked Battlefield beach. Then from the 680-foot beach down are a lot belonging to the Fort Brady group. The lower beaches are not tilted so much, and all converge so that by the time we get down to Manistee they are together. South of this signs of tilting do not appear. Some years ago I called attention to one sign of this recent northward elevation of practical importance in the fact that the streams north of a line through Port Huron and Frankfort have a steep grade and water powers near their mouth. An elevation of the outlet at Port Huron seems also to be indicated by the "drowned" or dead water state of the streams south of this line and of some streams like the Saginaw which flow toward the direction of uplift.§

These uplifts presumably took place during the retreat of the ice front after the time the Trent outlet was opened, and the waters on both sides of the Lower Peninsula flowed together. One reason perhaps why there is so little sign of tilting in the south part of Lake Michigan is that that part of the earth's crust had been uncovered much longer during the time of Lake Arkona and Whittlesey and had had time to get well settled once more.

*Rice lake, Huron county, lakes near Pt. Tawas.

†See Huron, Bay county, and other reports.

‡This may have taken from 1,000 to 10,000 years. It is (see Part 1 of Volume IX) 14 feet deep and about 128 square miles in area, or contains about 49,000,000,000 cu. ft. A single summer storm Cole measured to bring down .033 to .04 ounces per cu. ft., and as the discharge is about 234,000 cu. ft. per second that will mean 430,000 to 510,000 cu. ft. a day. Wheeler estimated that 4,000,000 cu. ft. came down in a three-day storm. It would then take only between 100,000 and 10,000 such storms to build up the delta. As the storm Cole mentioned was not an exceptional summer storm, the precipitation being .60 at Port Huron, .78 at Detroit and .78 respectively, it might be safe to assume one a month for 10 months, 71 out of 104 summer months (March to October) having storms with greater 24-hour precipitation. Wheeler's storm may have been more exceptional.

§See Jefferson, M. S. W.; Bulletin, G. S. Am., 18, pp. 347–349.

Before the ice retired so far as to leave an outlet for the Lakes above Port Huron directly by way of Lake Nipissing and the Ottawa, which was the next great event, the uplift of the northern region was so great that no very great drop was made.

LAKE NIPISSING.

Finally the ice disappeared altogether from the basin of the Great Lakes. At first surely this must have caused some drop (30 feet or more) in water level, and probably the Port Huron outlet may have been deserted for a short time. But the progressive elevation of the north country would, and soon did, bring it up again so that the Port Huron outlet was once more used. But it did not rise to the same elevation because since part of the water went another way, not so large a channel was needed and by the time the elevation went so far that the Nipissing outlet was abandoned the Port Huron outlet had been cut deeper. So that the highest shore line of this lake is something like 10 ft. below the Algonquin and only 14 feet above the present lake on the Thumb and near Port Huron—the water level then not over 10 or 11 feet above the present lake level.

This vast sheet of water covering the great Lakes after the opening of the Nipissing outlet is known as Lake Nipissing. At first it had an outlet only to the north, but later, and probably soon, the Port Huron outlet was opened and probably for a very considerable time both worked conjointly. With the continuing uplift the volume of discharge was slowly shifted from the Nipissing outlet to the Huron outlet. With the final abandonment of the northern outlet the era of development of the present lakes may be said to have begun which has just closed with the reopening of the Chicago outlet and other modifications due to man.

The duration of Lake Nipissing is said by those who have studied it to be the longest of all the stages of lake development, judging by the amount of work done, the cutting of cliffs—the building of bars and sand plains.

This may be true in the northern part of the region but in the southern part where the Algonquin levels are bunched, say around Saginaw Bay, I should give the preference to the Algonquin. Taken together certainly the work done in Algonquin and Nipissing time and since seems far greater than that done at any higher levels. Around Northport the elevation of the Nipissing crest is 606 ft. A. T., at Charlevoix 612 ft., at Harbor Springs the base of the cut 613 ft., at Mackinaw City 627 ft. A. T., at Sugar Island 672 ft., A. T., according to Goldthwait.

RECENT LAKE SYSTEM. RECENT SHORE LINES.

Between the Nipissing shore lines and the present there are numerous shore lines due to the gradual cutting down of the Port Huron outlet and the continuance of the northward uptilting which according to careful observations is still going on.

Of course in the southern part of the basin where the interval between the Nipissing beach crest and those of 1886, 1838, etc., is less than 10 feet no farther divisions can be very well made out. Farther north where the beaches are separated by the uptilting there are shore lines at 8 or 10 different levels and one horizon, the "Algoma" 20 feet above the lake at Mackinac, has received an especial name.

With the artificial reopening of the Chicago outlet a new era may be said to have begun.

It is doubtful if the lakes will ever again reach the levels they touched in the past century. High water of 1838, formerly taken as 584.34 is now taken by White as 583.26, by the U. S. Engineers as 584.69. In June, 1886, there was another high water, 583.13 A. T., that is 1.21 below the 1838 high water, and this 1886 beach ridge was very well marked in 1895, when I was doing my Huron county work, being 4 or 5 feet above lake level then. The lake has since risen somewhat, but the 1886 ridge is still identifiable.

CHANGES NOW TAKING PLACE.

The shore line of these recent lakes is a well marked one, especially south. Cliffs at present lake level have, where cutting is going on, often cut away the traces of previous beaches, and apparently cut as deep a notch as any previous.

These changes are going on with a good degree of rapidity. Along the east shore of Huron county* rates of cutting from 2 to 6 feet a year were observed, averaging perhaps 3 feet a year, and at Point Aux Barques† (Plate XI), the recession of a bluff seemed to be something like 2 feet a year, 115 feet between 1835 and 1897. In Sanilac county a careful survey of a half mile of somewhat rapid erosion‡ gave a loss of 27.25 acres in 79 years, 4.18 feet per annum, 1823–1859, and 7.2 feet per annum, 1859–1902, or 5.7 feet per annum. In extreme cases the cutting has gone on at the rate of a rod a year. Quite similar figures have been found as the losses along the Lake Michigan shore.

The clay bluffs along the Lake Superior shore from the Michigan boundary to Clinton Point are very rapidly retiring, if one may believe reports many feet in the past few years.

Now as to gains. Local accretion at the foot of Huron Avenue, Lexington, Sanilac county, was found to be 244 feet in 20 years. In other places it was from 10 to 30 feet a year.

The Harbor Beach breakwater has caused in spots 100 feet accretion in 20 years, and the engineer's blue prints show the stages.

Tawas Point is adding something like 60,000 square feet a year.§

Around Mackinaw City, though modified no doubt by improvements, as reported the terrace west of the dock has advanced 143 feet in 24 years prior to 1907, 250 feet in 35 years, 6 or 7 feet a year. The growth of St. Clair delta has been already described.

From such figures as these compared with the total amount of work at present levels one comes to estimates of this *recent* time of a few hundred years, and of all Nipissing time as possibly 3,000 years or so.

Records of the rate of such recent changes are of scientific value and are very gladly welcomed by the State Geologist.

The upward tilting of the north has been spoken of, and its signs in drowned river mouths in the south part of the basin and rapids and water powers in the north part of the basin. Moseley has studied these signs around the Toledo end of Lake Erie‖ at Cedar Point, and concludes that the rise of the lake Erie level due to the uptilting of the other (the outlet) end is about 2.14 feet per century, or at a rate of about 1 foot per century per hundred miles if the direction of rise is north northeast.

Between Milwaukee and Port Austin Gilbert found an apparent rise, cor-

*Volume VIII, Part 2, p. 80.
†Annual report for 1902, p. 14.
‡Annual report for 1901, p. 286.
§Annual report for 1903, p. 303.
‖Seventh Annual report Michigan Academy of Science, p. 39.

recting his figures, of 0.068 feet from 1876 to 1896.* Comparing gage readings at Milwaukee with those at Saginaw† may also give some results. Around Saginaw Bay in Bay county the shore line in many cases is close to the original meander posts, and this shore is so flat that any material change in level would be readily recognized. This is close to a line at right angles to the supposed direction of uplift, through the outlet, and shows no change in water level.

The following table prepared by W. H. Sherzer may serve as a review and guide to the position of the beaches on the easily accessible strip from Ann Arbor to Detroit.

PREDECESSORS OF GREAT LAKES.

Name of Lake.	Beach.	Outlet.	Location of Beach on Electric Ry.	Elevation.
Maumee, 1st stage	Van Wert	Ft. Wayne & Wabash R.	1 mi W. of Ypsilanti	812 ft.
Maumee, 2nd stage	Leipsic	Ft. Wayne & Imlay City	Water Tower	794
Saginaw	Arkona	Grand River	Dentons	708–694
Whittlesey	Belmore	Cass River Valley	Wiards	736
Warren, 4 stages	Upper Forest		Canton	680
	Lower Forest[3]	Grand River	Wayne	655
	Grassmere	Around Lower Peninsula[3]	Inkster	635
	Elkton	Mohawk[3]	Dearborn	610
Algonquin	Algonquin	Trent; Chicago Outlet; Port Huron	Detroit	590
(Lowering of Mohawk bed brought Lake Iroquois into existence, over the present site of Ontario, and gave birth to Niagara River and Falls.)				
Lakes Nipissing	Nipissing	Ottawa & Mattawa R.; Port Huron.	Detroit	580
(Detroit river out of commission and only waters of Lake Erie going over Niagara Falls, cutting the narrow part of the gorge.				

The elevation of land in Ontario shifted the outlet from the Ottawa to the Detroit river and raised the level of the water in it and Lake Erie.

The withdrawal of the ice from the St. Lawrence valley opened up the present outlet and gave rise to the present system of lakes.

THE ICE AGE IN THE UPPER PENINSULA.

The main principles and course of events during the ice age in the Upper Peninsula are the same as in the lower.‡ In both the ice followed the great main valleys, spread out and covered the highlands, and spread south. Then in retiring it left lines of unassorted material known as till at its margins, great sheets of gravel washed off in front of it, where the slope was away from the ice, and lakes and lake deposits where the slope was toward the

*Huron county report, Volume VII, Part 2, p. 36.

†Michigan Miner, June, 1900. Annual report for 1905, p. 368.

‡The literature and history of the ice age in the Upper Peninsula can not be separated from that of other states, especially Wisconsin, and is not covered in the list by Leverett already referred to, Mich. Acad. Sci., 1904, p. 109), the work of Chamberlin & Salisbury and other pupils in Wisconsin, a popular account of which is given by Case, Wisconsin Geology and Physical Geography, 1907, and a resume in their recent geology, the original being in their geology of Wisconsin, should be consulted.

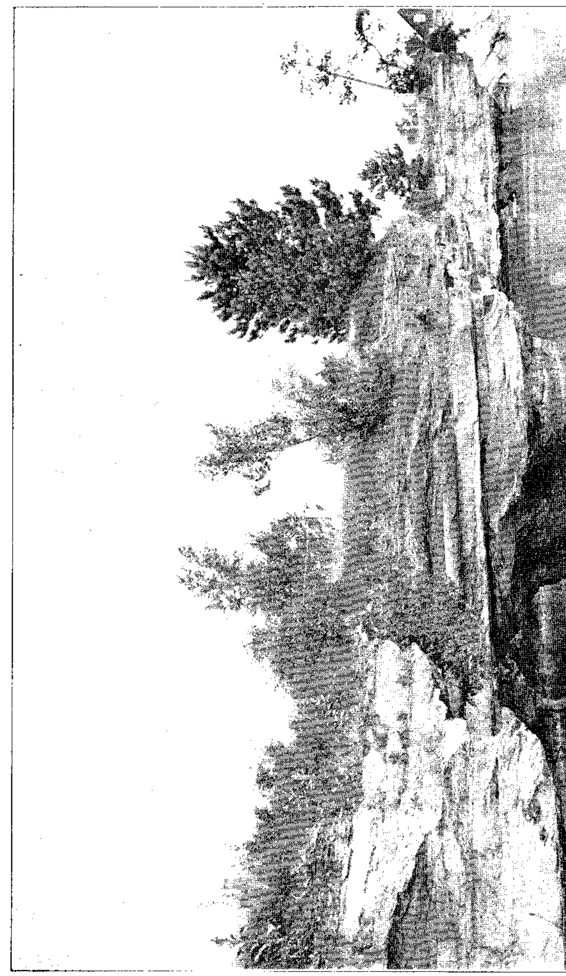
There are the two reports by I. C. Russell in the annual reports of the Board of Geological Survey of Michigan for 1904 and 1906, various papers by Taylor, mainly in the American Geologist, especially Vol. XII, 1894, p. 365, numerous papers by Upham (see especially Vol. VI, Bull. Geol. Soc. Am.), and an important paper by Lawson in the 20th Annual report Minn. Geol. & N. H. Survey. The bibliography given by J. W. Goldthwait, Bull. 17, Wisconsin Geological Survey, mainly covers Lake Michigan and not the Lake Superior papers. I have had the help of more recent papers read before the A. A. A. S.

N. H. Winchell did some work around Green Bay for the State Survey, never properly published, of which some results will be found in the A. J. S., 1871, pp. 1 to 4.

Agassiz's "Lake Superior," 1850, is practically inaccessible outside the large libraries, and covers only the north side of the lake and the general theory of ice action.

The earlier geologists of the D. Houghton survey have some notes, and their reports, as well as those of Jackson and others in Ex. Doc. No. 5, 31st Congress, 1st Session, Message N, 1849, pp. 391-935, and descriptions by Foster & Whitney (and Desor) in their report on Lake Superior are of historic interest. Rominger, in Volumes I, pp. 15–20, IV, p. 2, and the writer in Vol. VI, Part 1, Chapter VII, add a few facts.

Dr. C. A. Davis was with Russell and hopes to continue his work. A preliminary paper by his pen has appeared in the 9th report Mich. Acad. Sci., p. 132.



UNDERCUTTING AND RECESSION OF ALGONQUIN TERRACE LEVEL AT POINT AUX BARQUES.

ice. Also here again the ice front broke up into lobes and scallops in its waning stages. The main lobes are indicated in Figure 16.

One feature of difference however, is connected with the pre-glacial topography and that is the region where the ice was thin.

THE THINLY COVERED AREAS.

The areas colored Laurentian and Archean on the geological maps of the older rocks are relatively high. The hills are often more than 1800 feet above sea level, and the general aspect is that of a series of knobs and hollows 200 to 300 feet up and down. On the other hand Lake Superior is over 1008 feet deep, and a large part of the bottom is below sea level. We have thus a protuberance on the south side of something like 3000 feet.

Moreover, just south in Wisconsin, not over 150 miles from Lake Superior, is an area which was never reached by the ice. Now what is known of ice slopes and the thickness of ice sheets would lead us to expect that over such protuberances so near to its margin the ice could hardly extend. Ice did, however, at one time or another during the various epochs of the ice age seem to have covered all the high areas, but the main ice movement rose out upon them from the low land around as a river might rise over some mound in its flood plain in time of freshet without doing appreciable erosion.

Knobs and projecting hard points, crystals for instance of chiastolite in a chiastolite schist are smoothed and polished with scratches, but not cut down to the general level of the rock.

The old weathered soil seems to have been carried off or washed away, but very little foreign material has been brought in, and large areas are composed of bare rock knobs, slopes lined with blocks of the same stuff and swamps in the valleys.

THE ICE LOBES.

The following main streams of lobes of ice have been recognized (Fig. 16) though they doubtless flowed together and merged when the ice was at its greatest advance.

1. The Lake Superior lobe: running down the main line of the lake toward Duluth.

2. The Chippewa lobe: separated from the first by the peninsula that projects out and terminates in the Apostle Islands, and on the other side by Keweenaw Point, which, however, it over rode at one time, extending into the Ontonagon valley.

3. The Keweenaw lobe: following up Keweenaw Bay, separated on the east by the Highlands of the Huron Mountains which it wrapped around and on the west by Keweenaw Point. The Keweenaw lobe and the Chippewa lobe very likely flowed together at early stages, but even then the main threads of the ice current seem to have been present. The Keweenaw lobe seems to have felt a push from the Chippewa lobe where the Copper Range is cut through by the valleys of the Ontonagon, Flint Steel and Fire Steel, etc., which deflected it to the southeast; for while the Copper Range was last very strongly overridden around Houghton and northward by ice which moved a little north of west, heavy interlobate accumulations begin just south of Houghton and from about half way between Portage Lake and the Ontonagon river south the strong and recent motion is southeastward, and moraines are piled on the southeast side of the range and drift carried in that direction. At the south line of the state Russell* found the

*Annual for 1906, p. 50.

dividing line between the blended Chippewa-Keweenaw lobes (which laid down heavy moraines of gray till) and the ice from the east about six miles east of Crystal Falls and Stager. This gray till overlaps that from the east. In Wisconsin the Keweenawan lobe has not been recognized as a separate body.

4. The Green Bay lobe: This was to some extent a branch of the Lake Michigan ice, but probably, as N. H. Winchell suggested, at certain stages received some ice from Lake Superior by way of a valley running north from Bay de Noc to Au Train. With this lobe one may in a broad way include

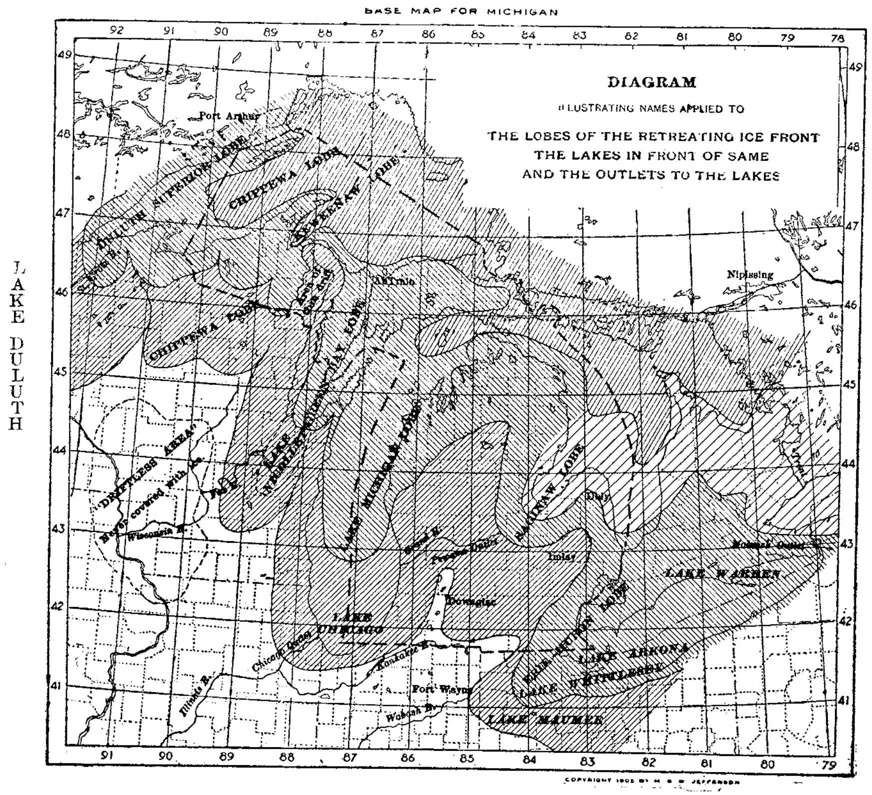


Figure 16—Diagram to illustrate the naming of the lobes of the retiring ice sheet and the lakes and outlets in front of them.

all the ice that wrapped around and over the iron ranges and Huron Mountains from the east as far even as Crystal Falls, and moved into Wisconsin along the axis of Green Bay. It is separated from the main Lake Michigan lobe by the escarpment of Niagaran limestone which forms the north wall of Lake Michigan and crosses the mouth of Green Bay in a series of islands. On the steep north or west side of this scarp (cuesta) the rock drops off steeply 200 to 500 feet, though the old preglacial valley in this soft shale of the Utica and Lorraine is often filled 300 feet and more.

In the Green Bay lobe there may thus at one time or another have been a commingling of three currents, one coming down from the north, one following the lowlands north of the Niagara escarpment, while a third spilled over from the main stream of ice in the Lake Michigan valley, at the mouth of Green Bay.

It does not, however, follow so broad or well marked a valley as the other lobes, even in Green Bay, and was not so pronounced a current of ice. Though it extended as far as Crystal Falls it must have been very thin, deposited little till and early retired and was broken up into separate glaciers in the valleys.

The red color characterizing its till may be due to the red Superior sandstone in part, and also to red residual clays it picked up, and to oxidation since the ice left.

5. The Lake Michigan lobe we have already mentioned. Its westward north border followed the course of the Niagaran escarpment except perhaps a few places where preglacial valleys gave it a chance to get through.

The general arrangement of these lobes and their relations to the Lower Peninsula lobe is given in Fig. 516 of Chamberlin's geology, and also in the sketch given herewith, Figure 16.

THE FIRST AREAS LAID BARE.

It is possible that even at the greatest advance of the ice, knobs here and there may have peered through, small islands in the sea of ice, nunataks as they are called in Greenland. None have yet been found, but it is quite clear that large areas were only thinly clad with ice. As the ice front retired and drew nearer and the ice itself became thinner, they would peer through here and there and then might even serve to some extent in the winter as gathering grounds for snow and ice to replenish the tongues of ice which would remain and wind in between them. Just such features are well shown on the Menominee range, and have been described by Russell.[1] Little moraines cross the valleys that trend east and west, and once lay at the ends of tongues of ice that ran out almost at right angles to the main trend of the ice sheet. Various little lakes were formed, connected and drained by channels, now abandoned, like that at Norway described by Russell.[1]

This retreat of the Green Bay lobe was probably early in the stage of the ice retreat until it got back as far as a belt running north and south along the west side of Menominee county. This position may have been held quite persistently while the Huron Mountains were being cleared, since the elevation of the moraines here is only from 700 to 800 feet up and well marked moraines bank up around the Huron Mountains at about 1150 A. T., and the grade between would be quite reasonable. Where these moraines cross the Menominee range they are nearly 900 ft. A. T., and in the Metropolitan district over 1,000 ft. A. T.

LAKE JEAN NICOLET.

As the area only thinly covered with drift running from Iron Mountain north to and including the Huron Mountains was cleared of ice first along the front of the ice, using portions of the Peshekeme, Escanaba, Menominee, Michigamme and Menominee rivers the waters issuing from the ice on three sides worked southward, deposited those large sand plains which are so conspicuous a feature on the Lower Michigamme river and of the Menominee as far down as the Wisconsin and Michigan R. R. bridge at Fisher, and drained into the driftless area of Wisconsin or skirted the ice front till they reached

[1]Report for 1906, pp. 49-53.

a large lake of which Winnebago is but a remnant. This, Upham has called Lake Jean Nicolet. By way of the Upper Fox river reversed it emptied into the Wisconsin river at Portage, and so down to the Mississippi valley.

In view of its nearness to the extreme limit of the ice and the relatively blocked channel over which it went there is little doubt that the Green Bay lobe retired at first much faster than the Michigan lobe, and that the drainage of the thinly covered Archean area into the driftless area was well organized while yet the great lake basins were occupied with ice.

By and by the ice retired in Lake Michigan, and Lake Michigan and Lake Jean Nicolet merged, but may have been separated again by readvances. But the probabilities are that the line of moraine on the east edge of Menominee county was held pretty persistently or frequently, and would hardly be abandoned until the ice was well out of Lake Michigan, though at the same time the ice may have been retiring and clearing off from more of the highland to the north. Well marked moraines lie on the north side of Huron Mountains up to about 1150 feet A. T. Thus we may imagine Lake Jean Nicolet beginning earlier, but lasting until merged into Lake Chicago.

LAKE DULUTH.

In the meantime the ice retired from the west end of Lake Superior, and water ponded in front of the Superior lobe is called Lake Duluth. It passed by way of the Bois Brulé river and St. Croix river into the Mississippi.* The water level at the outlet was at its highest some 550 feet above the present lake 1150 A. T.; the sill itself, however, is only 1070 A. T. and Upham assumes it has been filled 20 feet. Allowing for the usual rise to the north this would bring the water level 600 ft. and more along the north side of the Gogebic range, and as a matter of fact we find a distinct base level and sea bench at about 1230 ft. A. T. in that region. From the D., S. S. & A. R. R. north to within less than 2 miles of the lake the general level of the country where streams have not recently cut down is over 1100 ft. A. T. Around the Ontonagon valley where pass streams through the Keweenaw range, are very well marked beaches up to 1167 A. T.

TRANSITION FROM LAKE DULUTH.

As Lake Duluth enlarged and the ice retired and melted lower water levels would be found. But nothing below 1050 A. T., say 450 feet above the lake, could be referred to this outlet, and so far as there has been relative uplift since not even as low as this. But such uplift is believed to have occurred.

Thus while the beaches found by Lawson at 535 feet above the lake at Duluth, and at 607 feet at Mount Josephines may be referred to this St. Croix outlet, the heavier beach of the Duluth Boulevard† must be the last stage of this lake before a new outlet opened. By the time the ice retired from Thunder Bay and the neighborhood of Port Arthur and exposed Isle Royale, however, Keweenaw Point was exposed as a string of islands broken through by narrow straits, where now are the Ontonagon, Flint Steel and Fire Steel valleys, Portage Lake, the Allouez Gap, etc. The highest recorded beaches thence north on the north shore of Lake Superior are about 413–418 feet above the lake, 1020 A. T., and belong to Lake

*Upham. Geol. Minn. II, p. 643. Bull. G. S. A., II, p. 23.

†(At 473 ft.); Mount Josephine (at 509.5 feet); just grazing Isle Royale, around Portage Lake, and one north on the east side of Keweenaw Point a marked feature down to 490 feet above the lake. Also down to the 500 ft. contour in the Porcupines. Wright, Ann. Rep. B. G. S., '03 and '05.

Algonquin, being at the same level as beaches north of the Sault. As soon as the ice withdrew from the Huron Mountains there was clear sailing to the Lake Michigan Basin.*

It seems probable that the outlets south through or around the Huron Mountains were very temporary, and possible that these beaches at about 500 feet or less are to be correlated with an outlet to the north not far from Port Arthur as suggested by Taylor.

LAKES IN THE ONTONAGON VALLEY.

With the retirement of the ice the water must have found its way into the valley of the Ontonagon. Yet from this area there is no outlet directly south which would serve as a channel of discharge to Lake Duluth.

To work out the retreat and separation of the Keweenaw lobe from the Chippewa lobe, would even if it were known be a matter of detail which would be tedious and out of place in this preliminary sketch. The interlobate area of heavy drift which comes to a sharp point in the great kame hill of Wheal Kate, (1508 A. T.) which overlooks Portage Lake on the south, broadens as we go south, and its eastern limit follows Houghton county. No doubt along the south line of the state, between the Menominee and Montreal rivers a large area now full of lakes was once even more so, and head waters of the Black, Presque Isle and Ontonagon rivers once found their way southward. In this area, as in other such areas lying like eddies between the main channels of ice, the ice was relatively stagnant, and as it retreated huge masses were left swathed in gravel which melted only slowly and left basins without outlets, which are sometimes of large size.†

But the Keweenaw lobe, deflected by the Ontonagon spur of the Chippewa lobe hung, as we have seen, more persistently to the west side of the first opened, thinly covered area than did the Green Bay lobe to the east side, and when it retired still kept its side against the Huron Mountains, which are flanked by a crowded series of lateral terminal moraines, till terraces. Thus when the Ontonagon spurs of the Chippewa lobe retired so as to let the waters of Lake Duluth in on both sides of the Keweenaw range there seems to have been no drop of the lower Lake Duluth waters. The lake clay plains around Mass City are but little below the Boulevard Beach level.

South of the Copper Range there must have existed at one time lakes, early extensions of Lake Gogebic, whose water levels were considerably higher than Lake Duluth, and their drop may have been the other way. They may have dropped to the level of Lake Duluth. The exact point and stage of blending remains to be made out. It is west of T. 50 N., R. 40 W. We may thus be sure that during its closing stages Lake Duluth was held by the ice on the one side on the shore not far north of Isle Royale, and on the other side on the Huron Mountains, while the ice front may very likely have touched and been cleft by the northeastern ends of Isle Royale, and Keweenaw Point. When it retired further north other outlets may have been opened over the water shed into the Hudson's Bay region as suggested by Upham and Lawson.‡

*The higher lake terraces on the north side of the Huron Mts. are at 835 ft., 840 ft., 860 ft., levels, and correlate with Goldthwait's highest Algonquin shore line, which is found at the same level well marked just south of Newberry and at intervals on the hills beyond. But the valley that runs from Lake Superior over to Green Bay is a good deal lower than this, and would naturally have served a short time as an outlet channel as suggested by Winchell.

†Notably in the Perch Lake Topographic Sheet at the corner of Baraga, Houghton and Iron counties.

‡20th Ann. Rep. Minn. Geol. Sur., pp. 288–289. Height of Lane Portage south of Long Lake, 1102 A. T. Northeast of Michicipoten Harbor, 1042 A. T.

More careful examination of the Huron Mountains may yet disclose enough of a spill way from the west side to the east somewhere to justify treating the lake on the west as a separate unit.* It is probable that there was open connection across by Au Train to Lake Michigan before it opened farther east. This is suggested by the striking fact that back of the Pictured Rocks, within a few miles of Lake Superior, the drainage is toward Lake Michigan. It seems, too, that this channel had been kept so clear as an outlet for discharge from what was left of the Green Bay lobe that there was no material difference in the level at the two ends, and thus no separate beach lines for this part of Lake Superior. Of course something depends on what has been the tilting since.

THE WESTERN END OF LAKE ALGONQUIN IN LAKE SUPERIOR.

The highest levels that we must refer to this lake are Lawson's on the north side, 1018 A. T.† and they presumably slope off to the southwest, until they make a series of terraces of from 210 feet to 380 feet‡ above the lake which are well marked along Keweenaw Point. As Goldthwait makes it out Lake Algonquin seems to have had at one time or another three outlets, and the partition of these beaches among them is a problem of the future. So is the question how the ice influenced their altitude.

There is a fine delta of Dead river near Marquette at Forestville, and others of Swedetown and Huron Creeks near Houghton, belonging to Lake Algonquin. The Algonquin series of beaches is divisible into two series along the Michigan shore of Lake Superior, a higher one 326 to 200 feet above the lake, and a lower, probably more nearly horizontal, whose heaviest building and cutting seems to have been at about 137 ft. above the lake, and may be the Fort Brady group.

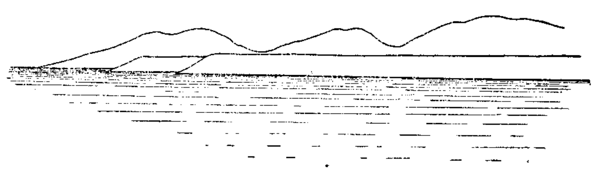


Fig. 17. The Porcupine Mountains from the mouth of Black Rivers.

The lowest level that can certainly be assigned to Lake Algonquin is the very strong shore line which, beginning just a little below 100 feet above the lake is a most marked feature all along Keweenaw Point,§ and Isle Royale as well (Fig. 17). This runs so level that we may be sure the depressing effect of the load of ice was far removed and the topographic base levels at 150 to 100 feet are so pronounced that we may be sure that the stay of the water at this level was relatively long.

*My examination of the north slope of Huron Mountain would indicate water levels there not above 935, A. T., and stronger at about 860 A. T. Such levels might well be those of Lake Algonquin.

†Jack Fish Bay, 418.3 A. L. Compare Sault Ste. Marie, 413.9 A. L., Mt. Josephine, 413.3, Isle Royale, 380 A. L., Thunder Cape, 392.3 A. L., Beaver Bay, 313.9 A. L.

‡Mt. Josephine 226 to 313 A. L., Lawson. Isle Royale 203 to 315 A. L., Vol. VI, p. 190. Valley of Flint Steel 335′ A. L.

§Foster & Whitney, Part 1, p. 105, 95'. Figure; Gordon, Ann. Rep. 1906, p. 420, 100' in 1904. Figure; Wright, Ann. Rep. 1903, p. 38, 100'; Rominger, IV, p. 2, 85' at Marquette; Jackson's report; the plates of cross sections of Porcupines, near p. 897, show the 500–600' level, and the 100–150' level also; p. 885 Hubbard; Lane Volume VI, Part I, p. 191, 192, most marked level 137'.

Less than 100 feet above the lake and above the heavy beach assigned to the Nipissing which is generally not over 63 feet above the lake, a couple of beaches* are sometimes noted which may perhaps be attributed to the transition time when the Nipissing outlet was just opening.

THE EARLY LAKE SUPERIOR.

When the ice retired so far that the outlet by way of North Bay, Lake Nipissing and the Ottawa river opened there was probably a rapid drop of 30 feet or more, which might have left Lake Superior separate, but as the rise of the land to the north continued until the Port Huron outlet came into play once more there soon came a time when Lake Huron and Lake Superior once more connected freely at the Sault.

This period of rise of water upon the shore would be checked when the Port Huron outlet came into play, and turned into retreat of the water, for the northern part of the lake at least, and when the sill at Sault Ste. Marie rose so high that it fixed the water level, if the tilting still continued the water would still continue to retreat on the north shore while the south shore would be submerged. Thus for the Michigan shore we may imagine the water rising, falling a little and then rising again.

The drowned character of the mouths and lower valleys of many of the rivers on the south side of Lake Superior is well known.† The excavation of the drowned river valleys may well have begun immediately at the close of Lake Algonquin, and have been interrupted by the rise of Lake Nipissing. The highest Lake Nipissing level is 49 ft. above the lake 651 A. T., at the Sault, 672 ft. A. T. at Sugar Island, about 663 feet,‡ around Port Arthur and Isle Royale and thence declines southward, the strongest work along the Michigan shore being at 25 to 30 feet. That the rise of this level was fairly slow is shown by the heavy filling at Au Train Bay, and along the north side of the Huron Mountains up to about this level, and the shore line cut by it was also recognized and mapped by the surveyors of the first Michigan Survey. Along the west shore of Keweenaw Point only patches of the bluffs cut at the high stages of Lake Nipissing, and the terrace flats in front of them have been left by later erosion but Freda Park, the outing place of the copper country, is one of them. The filling in at the head of Keweenaw Bay, where the D. S. S. & A. R. R. runs on a Nipissing terrace for six or eight miles, is conspicuous. The delta of Dead river back of the Powder Works north of Marquette, the site of Munising and the Sault are other notable features.

If, as seems probable, the sill at Sault Ste. Marie has cut but very little since that outlet was last established, and the direction of tilting is such that the Michigan shore is not at present rising as fast as that outlet, then it follows that all work at the higher levels than that which the lake can now reach in high water at stages of storms, say 15 feet or so above the mean lake level should be referred to Lake Nipissing shore lines, the work at about 30 feet above the lake particularly.

*Between 85' and 75' above the lake; Goldthwait and Leverett make the Nipissing on Sugar Island at 672'.

†Dead River, near Marquette, note the name. Black River, Annual for 1906, p. 160. Annual for 1903, p. 37.

‡61.3, Lawson.

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A BIOLOGICAL SURVEY

OF

Walnut Lake, Michigan.

BY

THOMAS L. HANKINSON.

WITH CHAPTERS ON THE PHYSIOGRAPHY, GEOLOGY AND FLORA OF THE REGION BY CHARLES A. DAVIS; AND A PAPER ON THE AQUATIC INSECTS OF THE LAKE BY JAMES G. NEEDHAM.

A REPORT OF THE BIOLOGICAL SURVEY OF THE STATE OF MICHIGAN, PUBLISHED BY THE STATE BOARD OF GEOLOGICAL SURVEY AS A PART OF THE REPORT FOR 1907.

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