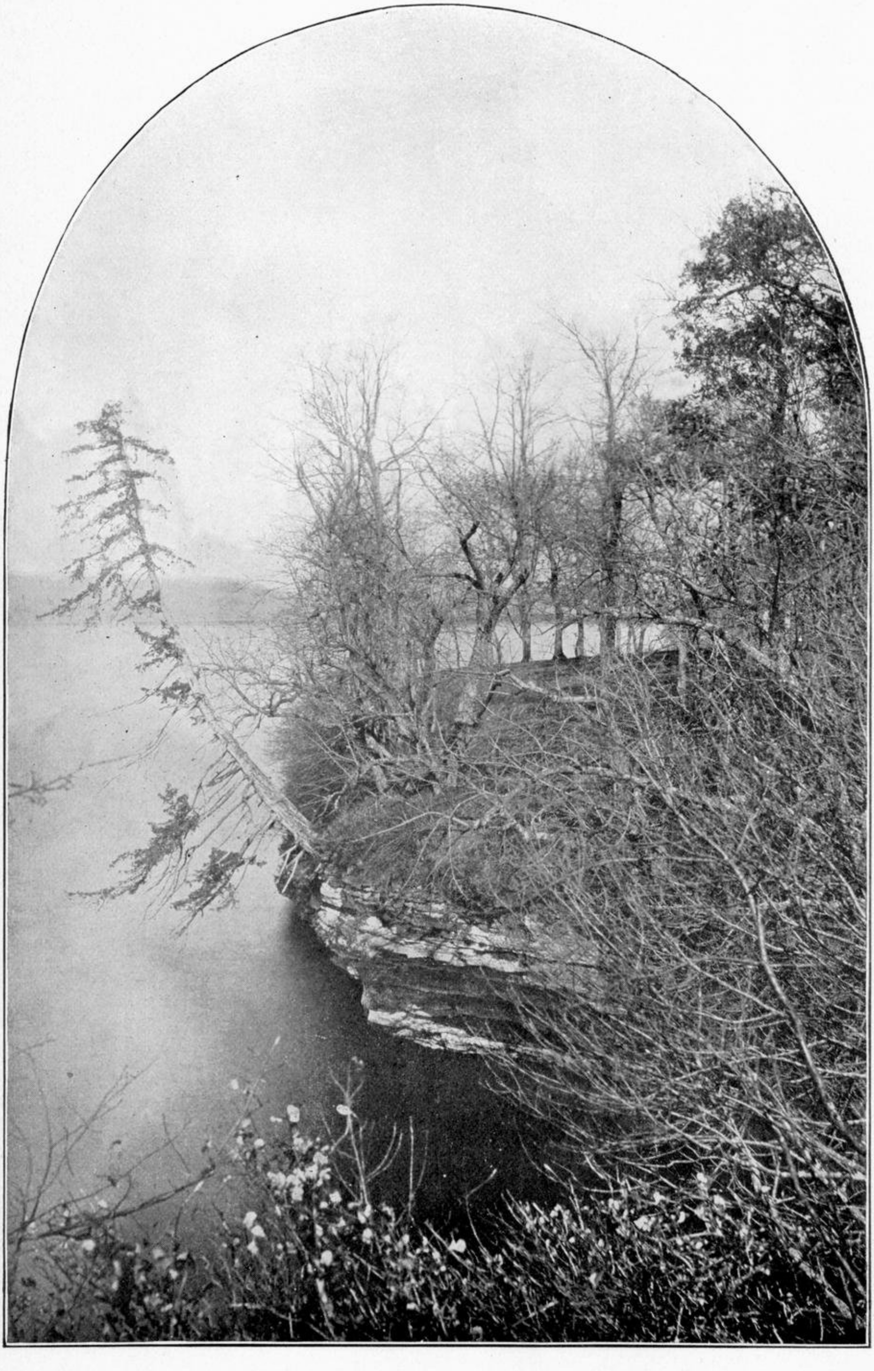
# On the lakes of southeastern Wisconsin. Bulletin No. VIII, 2d Edition, Educational Series No. 2 1910



Cedar Point, Lake Mendota, in 1880. A shore too young for the beach profile.

WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY

Edw. A. BIRGE, Director. Wm. O. HOTCHKISS, State Geologist.

BULLETIN NO. VIII, 2D EDITION. EDUCATIONAL SERIES NO. 2.

ON THE

# Lakes of Southeastern Wisconsin

BY

N. M. FENNEMAN, Ph. D.,

Professor of Geology, University of Cincinnati.

SECOND AND REVISED EDITION

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# Wisconsin Geological and Natural History Survey



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# NOTE.

This report on the physical geography of the lakes of Wisconsin is intended to assist students of physiography, and especially the teachers of the southeastern part of the State in using the natural features of the region as an aid to understanding the principles of physical geography and geology. In a former bulletin published by this Survey* the physical geography and geology of the region of Devil's Lake and the Dalles were discussed, with special reference to the forces which have produced the scenery of that district. In the present bulletin attention is directed to the origin and history of the small lakes which are so abundant in Southeastern Wisconsin, and the work done by them upon their shores is discussed in detail. It is expected that the report will be used as a guide for students and teachers who visit the lakes, either to study their physiography or to demonstrate to others the part which lakes play in the forces which modify the landscape. The discussion of general principles is somewhat less extensive than in the bulletin on Devil's Lake and much attention is given to the details of the work of the various lakes.

It will be noticed that little or no reference is made to the largest of Wisconsin's inland lakes, Lake Winnebago. The area of this lake is so great and its depth so small that the conditions are, in many respects, different from those of most of the smaller lakes.

Reference is made at various points in this bulletin to hydrographic maps. These are maps heretofore issued by this Survey on the separate lakes. They include most of the lakes whose physical geography is here discussed. Copies of the maps will be sent to any persons who rceive this bulletin and desire to obtain them.

E. A. Birge,
*Director.*

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* Bulletin No. V. Educational Series No. 1.—The Geography of the Region About Devil's Lake and the Dalles of the Wisconsin, with some notes on its surface geology. By Rollin D. Salisbury, A. M., Professor of Geographic Geology, University of Chicago, and Wallace W. Atwood, B. S., Assistant in Geology, University of Chicago, 1900. This bulletin is now out of print.

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The lakes of Wisconsin are of no small importance to the state. If all other considerations be set aside, their money value is many times that of an equal area of good farm land. The prices obtained for lots fronting some of these lakes are not exceeded except in the larger cities. The amount of money brought to the state annually by summer residents of the lake districts is such as to rank this source of income with the great industries.

The scientific aspect of the lakes is no less important. Basins capable of containing water are so numerous and so diverse in character as to form a constant allurement to the study of the geological history of the state, especially of that part of its history when most of the state was covered with ice.

The immediate purpose of this report is educational. It is in accordance with this purpose that the report is issued as the second in a series of educational bulletins. That lakes form a large part of the natural scenery of Wisconsin is sufficient reason why they should be utilized in the work of teaching. In addition to the opportunities they afford for the study of lakes as such, they show valuable analogies to the work of the ocean. The same forces and processes are at work here with the exception of those involved in tides. The same forms are produced and their relations are more clearly seen because their dimensions are smaller.

The lakes covered by this study are distributed over an area extending from Waupaca county on the north to the southern boundary of the state, and from Lake Michigan westward to the Driftless area. Only those lakes are here described which were included in the hydrographic survey made under the same authority. The hydrographic maps thus prepared were used in the field as the basis of work.

The field work on which this report is based was performed chiefly in the summer of 1900 and completed in September, 1901. In the case of each lake or lake district, the topography and surface geology of the vicinity were first examined in sufficient detail to warrant the statements made about the geological history of the basins. The shores of each lake were traversed on foot or followed by boat, and in case of the more important lakes both methods were used. The central purpose of these examinations was to note the effects of the forces and processes connected with shores, chiefly those of waves and currents. The work of these forces is revealed in changes now in progress but more especially in the topographic forms, which, in their manifold variations and combinations, make up the varied scenery of shores.

In close connection with the study of shore processes is the question of the power of the water on the bottom as revealed by the character of the sediments. In the examination of these sediments a considerable amount of dredging was done. In the case of Lake Mendota, Mr. Chancey Juday, under the direction of Dr. E. A. Birge, carried on the work of dredging systematically during the autumn of 1900 and the spring of 1901. The samples were taken with care and the depths from which they came were noted with exactness. The study of these samples is the chief basis of the discussion of bottom currents in Lake Mendota.

It has been found advisable to devote a chapter of the report to the work of waves and currents and to give a brief general treatment of the topographic features which are produced by their agency. The entire descriptive accounts of the shores of the several lakes may be considered as illustrative of the general principles in chapter II. A similar discussion (chapter I) is devoted to the geologic conditions of the area and the general principles of the origin and extinction of lake basins. The general geology of the area as given here is based upon the reports of the state issued under the directorship of Dr. T. C. Chamberlin. The geologic and topographic surroundings of each lake are discussed in the chapters devoted to the several districts.

The plates are in large part from photographs which were taken by the writer during the regular field work. Others are from photographs purchased for the purpose. Plate XX is from a cut furnished by the C., M. & St. P. Ry. Co., Plates VIII and IX are from pictures in the collection of the United States Geological Survey and were obtained through the kindness of Mr. Bailey Willis.

In the field work and in the preparation of this report, the assistance and counsel of the director of the survey, Dr. E. A. Birge, have been constantly sought and have been uniformly valuable. A special acknowledgment is here made of the assistance received from Professor T. C. Chamberlin, consulting geologist in Pleistocene geology. In some cases it has been possible to refer the suggestions received to his published works; the personal communications were in many cases equally valuable. From Professor C. R. Van Hise, consulting geologist, similar assitance was received.

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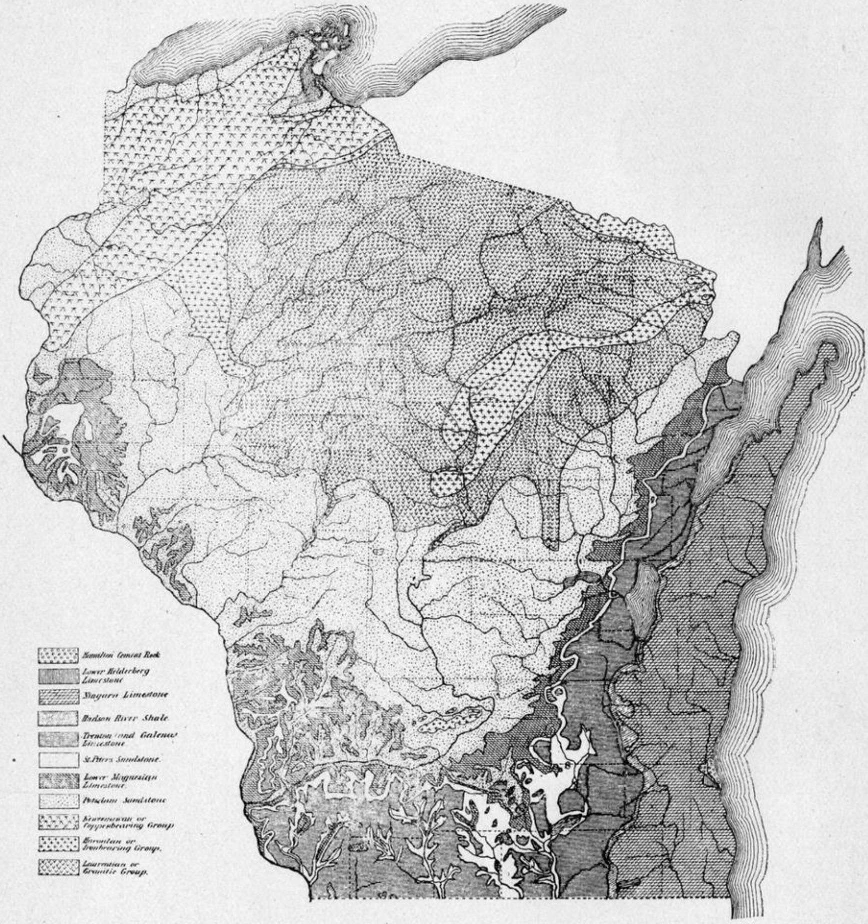
## NOTE ON SECOND EDITION.

Since the writing of this report, the state Geological and Natural History Survey has made hydrographic surveys of the Lakes Waubesa and Kegonsa, Dane county. Following that work, Mr. Fredrik T. Thwaites studied in great detail the geologic history of those lakes and the topography of their shores. In the course of his geological work, which extended over an area of about 60 square miles, he prepared the contour map of the surface of bed rock, reproduced in this report as Plate XXXVII. That part of Chapter III which relates to Lakes Waubesa and Kegonsa is adapted from his report. Some additional material from his investigations has been incorporated under other headings in Chapter III.




General Geological Map of Wisconsin, reproduced from Geology of Wisconsin, Vol. I.

# LAKES OF SOUTHEASTERN WISCONSIN

## CHAPTER I.

### LAKE BASINS AS RELATED TO THE GEOLOGY OF WISCONSIN.

#### GENERAL GEOLOGY OF THE AREA.

*Underlying rocks.*—In the northern part of Wisconsin a large area of pre-Cambrian crystalline rocks is exposed at the surface or covered only by the glacial drift. (See Plate I.) The strata of Paleozoic rocks dip away from this center and are exposed (supposing the drift to be removed) in bands, the older and lower ones outcropping nearer the Archaean center. For purposes of physiographic study the strata may be regarded as alternately strong and weak. The outcrop of each strong stratum constitutes a ridge whose eastward slope is long and gentle in general agreement with the dip of the stratum (Fig. 1); the

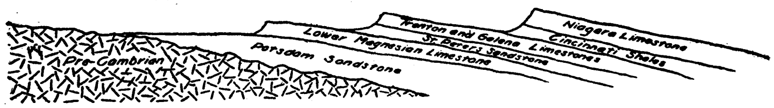


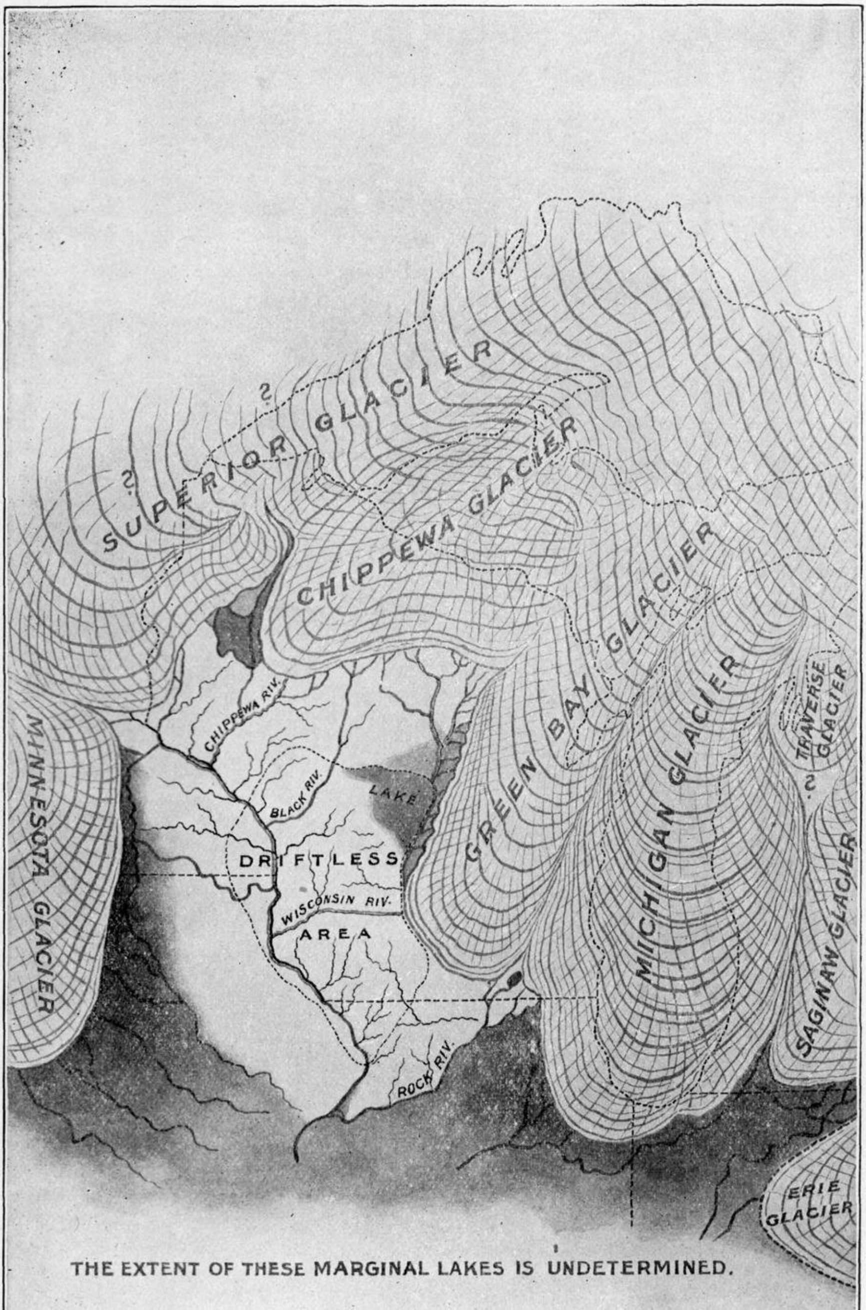

Fig. 1.—Diagrammatic cross section of formations in Eastern Wisconsin.

corresponding westward slopes or escarpments are in places precipitous and bare of vegetation, but in general they are much reduced by weathering and by the covering of glacial drift. At places these ridges have now a very zigzag course, due to valley cutting by side streams descending their scarp slopes to join the larger streams which occupy the valleys on the outcrops of the weaker strata.

The three strong limestone strata whose edges are prominent in the manner described are the Lower Magnesian, the Trenton (together with the Galena), and the Niagara. In the eastern part of the state the strike of these strata, and therefore the trend of the ridges is east of north. Here the Niagara escarpment is very prominent, despite the covering of drift. It is much less serrated than that of the Lower Magnesian limestone farther west. Among the pre-glacial stream valleys which indent the margin of the latter are those in which Green Lake and the lakes at Madison are now retained behind dams of glacial drift.

*The glacial drift.*—In very recent times, geologically speaking, most of the United States north of the Ohio and Missouri rivers was covered by an ice sheet which spread southward from several centers of accumulation in northern Canada. The glacial invasion was repeated at intervals, some of which were probably much longer than the time which has elapsed since the last disappearance of the ice. With few exceptions the lakes and other features of glacial origin referred to in this report are concerned only with the last advance of the ice.

This last or late Wisconsin ice sheet was divided for some distance back from its margin, into lobes (Plate II). One of these lobes occupied the valley of Lake Michigan and is known as the Lake Michigan glacier. Another, the Green Bay glacier, advanced through the vallely whose axis is now marked by Green Bay and Lake Winnebago. For a hundred and fifty miles the margins of these two lobes were in contact or separated only by the ever accumulating moraine. This line reaches from the place at which the lobes became distinct on the Green Bay peninsula to a point south of Whitewater. Notwithstanding the approximate or complete contact of their edges, each of the lobes had the features of a distinct glacier, in that the ice moved outward from the center toward the margin at all points. The transportation of material below the ice and in its basal portion was necessarily in the same direction. Hence along the common margin of the two lobes drift was accumulated from both sides.




Glacial Lobes of the Wisconsin Ice Epoch, reproduced from Geology of Wisconsin, Vol. I.

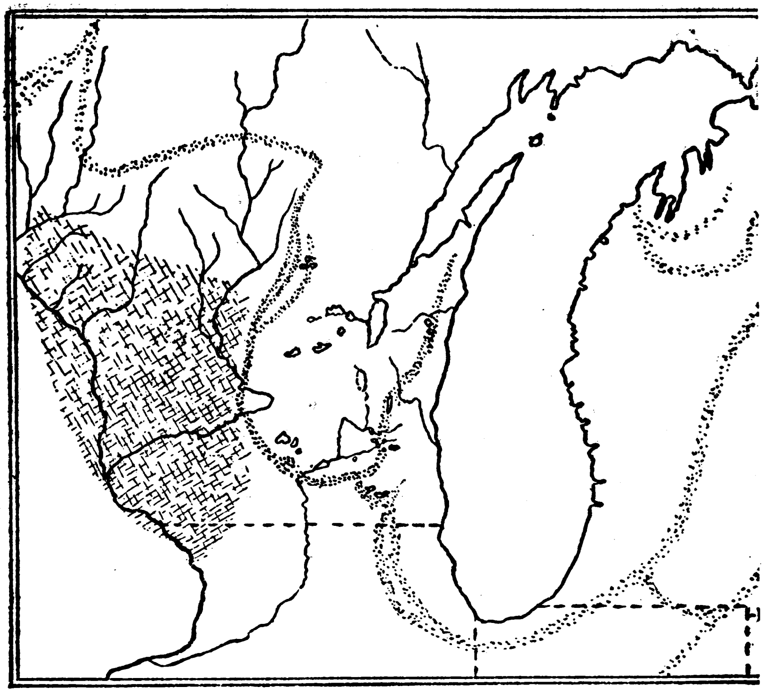


Fig. 2.—Terminal moraines left by the late Wisconsin ice sheet, adapted from Third Annual Report, U. S. G. S. (Chamberlin).

The result of accumulation of drift at the line of contact of two lobes is seen in the very tumultuous ridge known as the Kettle moraine. This is simply the combined terminal moraines of two glaciers. In its making it was necessarily subject to certain conditions which do not attend the making of terminal moraines by a single glacier. The most important of these conditions was a restricted drainage. The constant melting at the front of two vigorous glaciers yielded a great volume of water which could escape only by flowing between the glaciers along the zone of accumulating drift. A very large part of this drift has, therefore, been thoroughly worked over by water and laid down as kame gravels.

The accumulation of drift was not confined to the margins of the several glaciers. Deposits made beneath the ice are almost universal over that part of Wisconsin which was visited by the glacier, reaching a maximum thickness of three or four hundred feet. The surface slopes of this ground moraine are, in general, much less abrupt than those of the terminal moraines. Being less hummocky, it has also fewer undrained depressions, though some of its undulations do contain swamps and lakes. (Plate IV.)

## ORIGIN AND CLASSIFICATION OF LAKE BASINS.

The basins of all the lakes referred to in this discussion may be conveniently grouped in four classes, designated as follows: 1. Pits due to melting out of ice blocks. 2. Erosion valleys blocked by drift. 3. Valleys between terminal moraine ridges. 4. Undulations in ground moraines. Troughs of small glacial lobes are preserved in a few cases but none of the lakes here described owes its entire basin to such an origin.

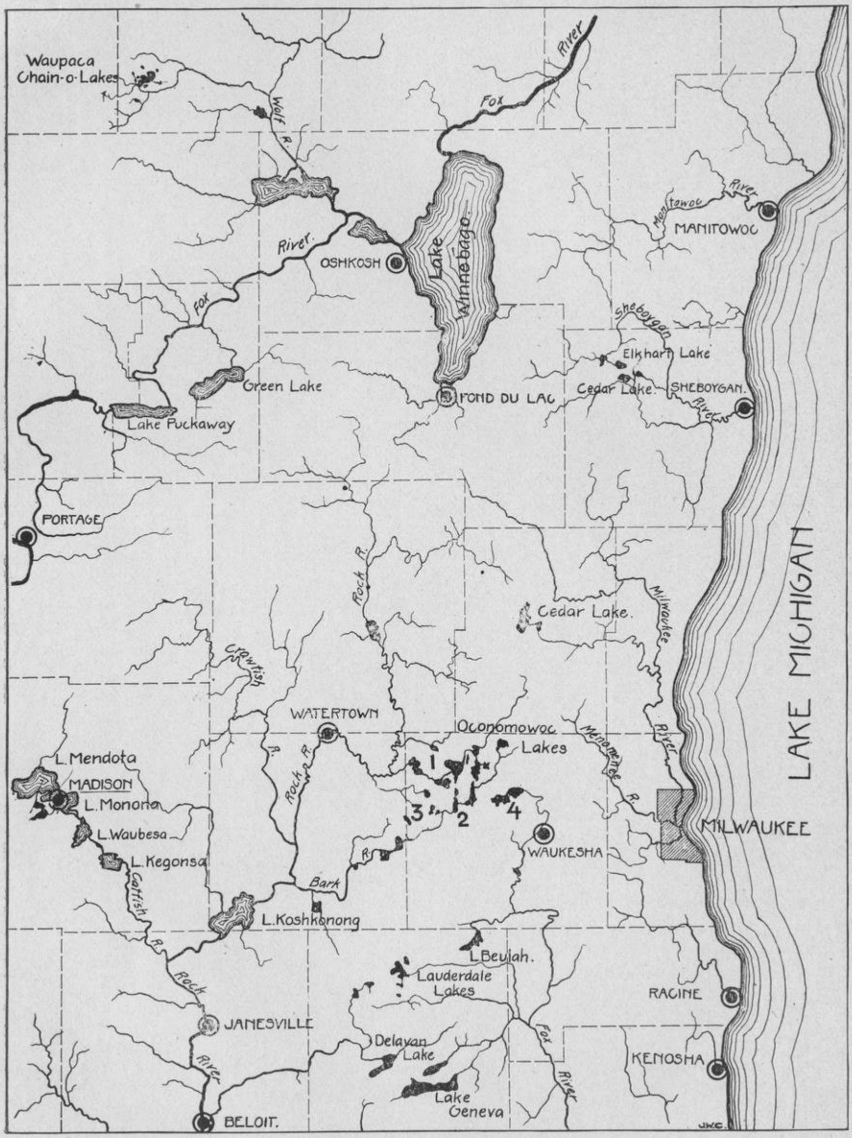
Lakes of each class may be distinguished in the field from those of other classes by certain criteria to be enumerated below. In the area considered, there is occasional gradation between classes, but in the large majority of cases the origin is due mainly to a single one of the causes implied in the above classification.

*Pits.*—The melting out of any mass of ice which has been incorporated into a deposit of drift, will cause a basin. Such masses may be so included in various ways:

(a) In that style of terminal moraine which has been called dump moraines,[1] ice blocks may and sometimes do form a part of the mass of the ridge. Their melting leaves pits or kettles in the unstratified bowlder clay. Such kettles are small; they lie normally on ridges, and rarely, if ever, hold water permanently.

(b) When a lake borders the ice front, icebergs may float out and ground, and these may become surrounded or covered

[1] The classification of drift deposits here referred to is that of Chamberlin.—A Genetic classification of Pleistocene Deposits. Compte-Rendu of the Fifth Session of the International Congress of Geologists. Washington, 1891, pp. 176–192.




Sketch map of Southeastern Wisconsin. In the Oconomowoc group of lakes, Lac la Belle lies west of 1, Okauchee lake east, and Oconomowoc lake almost south of 1. Nagawicka lake is northeast of 2, with Pine and North lakes continuing the chain to the north. The Nashotah-Nemahbin series lies northwest of 2. 3 is in the center of the group formed by Otis, Silver, Golden, etc. Pewaukee lake is marked 4.

as the lake is filled with sediment. Pits produced by the melting of these are also small.

(c) The origin of the large pits which may contain prominent lakes, and of the great majority of pitted plains in Wisconsin is connected with the habit of the ice during the retreat of its front by excessive melting. It has been well shown by the studies of Professor Chamberlin in Greenland* that the ice of continental glaciers is rather sharply divided horizontally into two zones. The lower zone carries the debris, which may compose a large part of its mass. The ice above this debris-laden portion is clear and free from load. When the front retreats the clear upper ice may disappear rapidly, but when the surface of the lower zone begins to melt, the stones, clay, etc., are left as a superficial coating and soon form a bed so thick that the ice below is protected from further melting. Thus it may hap-

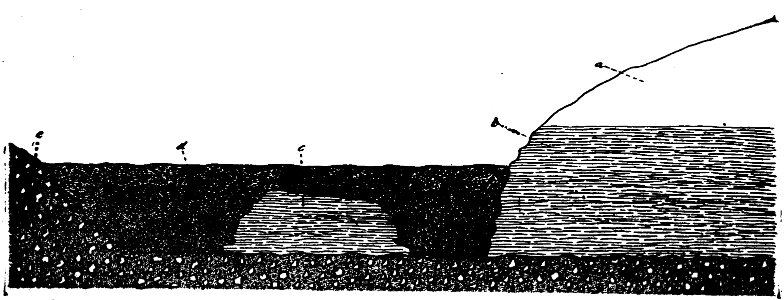


Fig. 3.—Burial of ice mass by gravels: a, Clear ice of upper part of glacier; b, Debris-laden ice of lower portion of glacier; c, Buried block of lower portion of glacier; d, Gravel laid down by streams issuing from the glacier; e, Any obstruction to free drainage away from the glacier.

pen that the front of the clear ice above may be melted back some miles while masses of the lower portion lie buried and stagnant (Fig. 3). It is plain that if the drainage away from the glacier is vigorous, the detrital covering of these remnants will be washed away and they will melt promptly, leaving no trace of their presence. A sluggish drainage, on the contrary, may not only preserve the covering, but thicken it by constant deposit. When the aggrading streams from the glacier have built

* Bulletin of The Geological Society of America, Vol. 6.

a plain over such ice masses, the subsequent melting of the latter may cause basins of truly lake-like proportions.† The conditions for such sluggish drainage were present to an unusual degree at places along the Kettle moraine, which is described in chapter VI, on the Oconomowoc Lake District.

The characteristics by which basins due to this cause are distinguished are as follows: (1) The surrounding material is waterlaid, hence more or less stratified, but usually quite imperfectly. It may all be called kame gravel. (2) The level below which the basins are sunk is a plain. This follows from the nature of the deposition and is a very noticeable feature. It may, of course, happen that pits are so closely crowded that their several rims are broken and in places do not rise to the level of deposition. (3) The steep slope. This may be called the pit slope or kame slope, and is frequently almost as steep as the material can lie. (See Plate XXIII.) Cliff cutting would only renew or freshen the same slope. In general the original kame slopes have suffered little reduction and are almost as steep as where kept fresh by cliff cutting. Where cutting has been in progress at their bases and given a greater steepness, a convex curve in vertical cross section is produced. This is often a marked feature. Where small bays have been cut off by bars and reduced to swamp, the kame slope may lie behind the swamp.

*Erosion valleys blocked by drift.*—Pre-glacial valleys may be wholly or partly obscured by the drift covering. Their chances to escape filling are about in proportion as their direction agrees with that of the ice movement. If that agreement is close the glacier may even deepen the valley by scouring, though it does not follow that this result is necessary. The same valley whether deepened or partly filled, may receive local deposits which constitute dams when the ice retires and water again flows into the valley. Some of the finest lakes of Wisconsin were formed in this way.

These lake basins may be recognized in the field by the following characteristic features: (1) There must be a valley

† This conception was received by personal communication from Professor T. C. Chamberlin.

in the subjacent formation itself and not merely in the drift. This valley may show itself in rock cliffs as on Green and Mendota lakes, or it may be known by exposures near the lake as at Pewaukee, or it may become known only in the drilling of wells. If the material in which the former valley was cut be of an unconsolidated nature as an older drift sheet, the determination is much more difficult though not necessarily impossible. (2) There must be a dam of glacial drift. This dam may be of either terminal or ground moraine. Lake Mendota is held by a dam of terminal moraine, while the divisions between the other lakes of the chain on the Yahara river are only swells in the ground moraine. (3) The surrounding slopes show in general a ground moraine topography or the veneering of an erosion topography. (See chapters on Green lake and the Madison lakes.) Thus they distinguish these lakes in general appearance from pit lakes. (4) There is frequently a line of lakes along the former valley as the Green–Puckaway line and the line along the Yahara river. This is not always present; Pewaukee lake, for example, is alone. Neither can it be said that the lakes are always elongated in the direction of the main valley; Monona, for example, is elongated in another direction and Lake Kegonsa is nearly circular. But whether by a series of lakes or the elongation of one, or the mere continuation of the valley above the water level, the course of the pre-glacial valley can be fairly ascertained in all such cases in the area studied. (5) When the depth of the valley has been increased by scour, the products of such excavation may appear in the drift to leeward. It may also appear in some such cases that the bottom of the lake lies deeper than the bed rock under any portion of its rim; in other words, that there would be a basin in the bed rock itself if the drift were removed, a condition which could not be brought about by the mere damming of an erosion valley.

*Valleys between terminal moraine ridges.*—That part of the Kettle moraine which was formed between the Michigan and Green Bay glaciers, has at places a number of nearly parallel ridges.* When basins are enclosed between such ridges, they

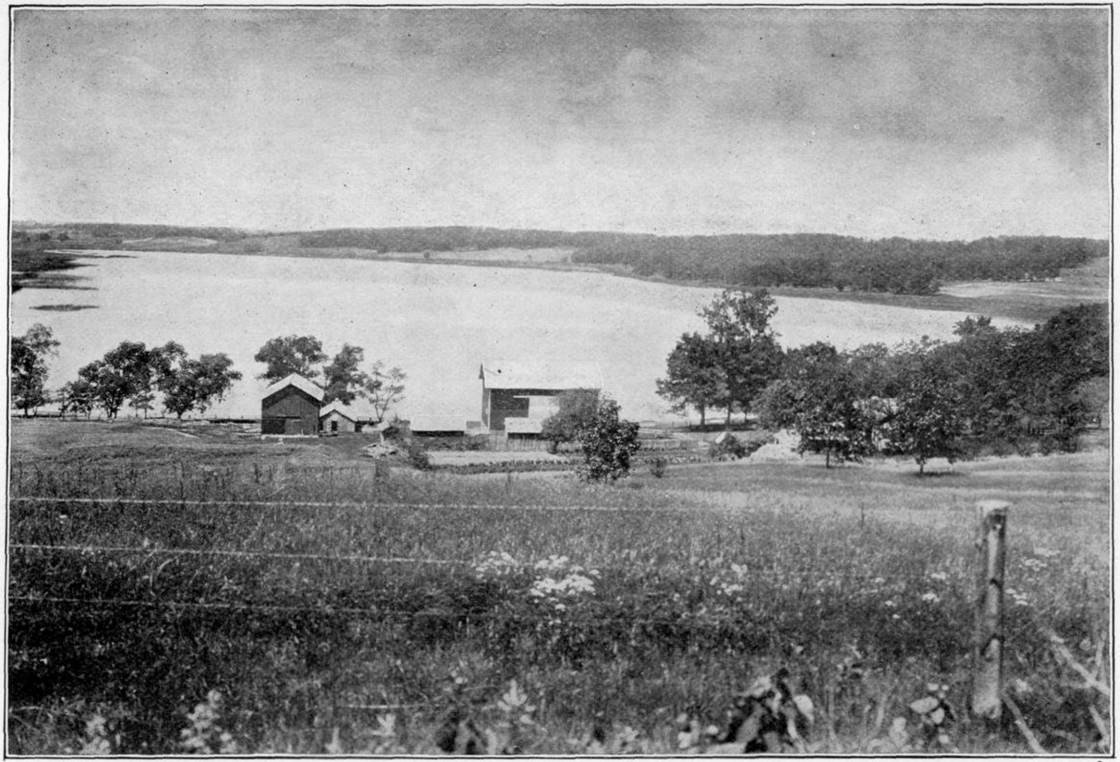
* For description and mode of formation see chapter VII.

may be distinguished from those of the other classes named by certain definite marks: (1) The ridges themselves must be recognized as terminal moraine. The topography of the slopes, therefore, has an expression which is distinctive. (2) Such basins have their length in the direction of the terminal moraine. (3) The depth of drift on their border must be such as to exclude them from class 2, (erosion valleys blocked by drift) though it may easily happen that lines of terminal moraine may, for some distance, be superposed on pre-glacial ridges or that a valley between parallel moraines may agree in position with a pre-glacial valley. This is probably true of the moraine around Big Cedar lake, which is one of the best examples of this class.

It should be observed that even in this example there was another factor concerned in the origin of the basin. While the major features are those of a trough between two ridges of terminal moraine, it is quite probable that but for the presence of ice blocks, the outwash from the glaciers would have entirely filled the trough with gravel as it partly filled it by a gravel plain on the west side.

*Inequalities in ground moraine.*—To this class must be referred a large number of basins whose conditions of formation cannot be more definitely given. They are (1) shallow, since the curves of ground moraine are gentle when no other conditions are prominent. (2) Agreeing with these gentle slopes under their waters, the slopes of their shores are likewise smooth. (See Plate IV.) This type grades into type 2 as the reason for inequality becomes more apparently due to erosion valleys in the pre-glacial surface.

*Troughs of small glacial lobes.*—The spreading of the glacier near its margin, together with its melting along lines where the ice is thin, tends to cause marginal lobes or scallops which may be so narrow as to have the form of fingers. Such a portion of the dying glacier occupied the valley of University Bay, an arm of Lake Mendota. The features which this bay shows should distinguish all basins and parts of basins due to this cause. (1) Its length is in the direction of the ice movement. (2) At its lee end is a terminal moraine which, in this case, is crescent-shaped and extends for some distance back along



Turtle Lake, Walworth county, a lake in the ground moraine. The slopes of the banks are characteristic of the ground moraine.

the sides. In general such valleys cannot be accounted for as simple stream valleys blocked by drift though it is to be expected that such lobes would be located on drainage lines rather than on divides.

## EXTINCTION OF LAKES.

Even the so-called permanent lakes are but fleeting features of the landscape and are soon obliterated by the surface agencies. The recognized processes in their extinction are three: (1) The corrasion or downcutting of the outlet, (2) filling by detritus eroded from the shores or brought in by streams, and (3) the accumulation of the remains of vegetable matter growing in the lake itself. To these may be added filling by animal remains, for some marl, at least, is of animal origin.

The proportions in which these three processes operate vary greatly. It is estimated by de Lapparent that of all the detritus handled by the ocean as shore drift, fifteen-sixteenths are brought down by streams from the land, leaving but one-sixteenth to be supplied by waves through the wearing back of cliffs. Probably the reverse proportion would be more nearly correct for small lakes of the drift covered area. It is probable, for example, that Lake Mendota receives fifteen times as much detritus from the wasting of its cliffs (see Ch. II, page 24) as is brought in by the Catfish river and other small streams. Lakes having other topographic surroundings may differ widely in these proportions. The smallness of stream detritus in the extinction of these lakes in the drift is due directly to the peculiar topography and the small dissection of the land by streams, that is, to the newness of the surface. As the surface becomes older and more dissected the factor will become larger, provided any lakes then survive to receive the sediment.

Several factors, however, tend to make the wasting of the cliffs of these small lakes more rapid than that of the cliffs of the ocean. The glacial drift is a very loose material; again, the very absence of stream detritus enables the lake waters to expend their energies in obtaining load from their shores. At the present time also, the youth of the shore line is such that a very large proportion of the shores is cutting. (See page 32.)

Lake Mendota is at least two-thirds surrounded by cliffs. Lake Geneva has even a larger ratio of cutting to building coasts. This process might at first appear to be a balanced one so far as the extinction of the lake is concerned. It might be pointed out that while the sediments thus won go to fill up the lake, the basin is being at the same time broadened. But the increase of capacity by local broadening of the basin is always less than the decrease due to filling, especially when the shores are high. Indirectly also, this process by supplying the materials of shore drift aids the cutting off of bays by bars (see Ch. II) and thus hastens their extinction by excluding currents and waves and favoring vegetable accumulation. Eventually also, the broadening of the marginal shelf, which is the necessary correlative of cliff cutting, must favor vegetation. Estimates of the actual amount of filling by detritus received from the shores may be based on the known recession of cliffs in historic time, or on the width of the subaqueous terraces. Such estimates make it safe to affirm that if all such detritus ever received from the land by one of the larger lakes of this area were spread evenly over its bottom, the filling thus effected would be expressed in inches or a very small number of feet.

Downcutting of the outlet by corrasion is, under present conditions, a factor of greater importance. Many of these lakes are fed so largely by springs that the outlet is a stream of considerable power in proportion to the feeble inflowing streams. In the area covered by this survey, the outlets, without exception, flow over bowlder clay or kame gravels, in which valleys are easily cut. It should be noted that the pure water issuing from the lakes is able to do more cutting in this loose material than the same water could do if supplied with some sediment. The opposite statement, frequently made, is true for outlets cut in solid rock, such as the Niagara river. Here a certain amount of load becomes tools with which to cut down the bed of the stream, but for the same stream flowing over uncompacted materials, the so-called tools are unnecessary and become merely so much load which hinders the work of corrasion.

The level of Lake Geneva was lowered by the corrasion of its outlet at least seven feet before the construction of the dam. One-eleventh of its capacity was thus destroyed. In the same way

Lake Mendota lost probably one-seventh of its water, and other lakes lost similar amounts. These fractions are much larger than those which would express the amounts of water displaced by detritus. It should be observed, however, that the corrasion of outlets becomes smaller as stream grading proceeds, while the load of sediment delivered by streams becomes progressively larger as the topography advances toward maturity. This distinction must be one of importance in case of such a lake as Green, whose bottom lies two hundred and thirty feet below its outlet (ignoring the dam). The lake will doubtless be extinguished long before the stream has cut its valley to that depth. These outlets would be cut down faster were it not for the regulative influence of the lake on floods. So long as dams are maintained at a constant height, the variation in the level of these streams is very small. For most of the lakes of eastern Wisconsin it is measured in inches rather than in feet. The same amount of water discharged in occasional torrents would do much more work.

Vegetable accumulation is more in evidence than either of the processes considered above. The bottoms of many lakes are covered with chara, eelgrass and pondweed. The surface at the same time supports algae whose dead remains are added to the deepening mire on the bottom. Simultaneously bogs of grass and sedge are pushing outward from the shores. Fields of these heavy mats are loosened by the wind and become floating bogs, whose debris is dropped upon any part of the lake bottom. Even the "cleanest" lakes give abundant evidence of the importance of organic accumulation as a geologic factor. At the west end of Lake Geneva, the superb gravel beach separates the lake from a broad area which was once lake, but is now filled with vegetable material. The large fields of peat north of Williams bay and east of Buttons bay are about four feet thick over areas which were once lake.

In the old age of a small lake vegetable accumulation is greatly accelerated, so that the customary appearance of the "dead lake" is that of a grassy flat where peat has taken the place of water. (Plate XXI, Fig. 1.) This peat is often many feet deep and the ratio of vegetable matter to mineral impurities indicates the rate of vegetable accumulation as compared with that of detrital filling. Below this peat is usually clay or marl. This emphasizes the fact that the peat represents, for any one spot, the closing stages of the lake's life. The clay expresses the preponderance of sedimentation at an earlier stage while the lake was deeper. At this earlier time, vegetation was doing its more active work in other and shallower parts of the lake. In judging of the former extent of such a lake, it is to be remembered that the surface of the flat is lower and therefore narrower than that of the water was before, because it was only in the old age of the lake that this process was able entirely to displace the water. The final extinction may be by either of the other processes, sedimentation or drainage, by the former particularly in arid regions and by the latter where the catchment area is large and the stream which runs out of the lake is correspondingly strong.

# CHAPTER II.

## THE WORK OF LAKES UPON THEIR SHORES.

Like all topographic features, shorelines have a life history. They have their infancy and their systematic development to maturity and old age. Each stage has its own characteristic set of features. A study of these features as seen on any shore supplies the necessary data to determine the age of the shore. As in all geographic forms this age is measured, not by years, but by the progress which has been made toward the completion of a certain work. What this work is in the case of shorelines may be stated to better advantage at the close of the chapter. The progressive change from the time when the water first assumes its level and rests against the new shore to the time when it has brought its boundaries into such harmony with its movements that no more work can be done, is termed a cycle.*

### WAVES AND CURRENTS.

The immediate agents of work are waves and currents. Both are caused by the wind, which may co-operate with them, or may cease while their work goes on. The waves which concern us here are of two kinds: those of oscillation and those of translation. These two kinds involve different principles of movement, but it is probably quite generally true that on shallow marginal bottoms both tendencies unite to produce waves of a hybrid kind.

*Waves of oscillation.*—In waves of oscillation, which are the common waves on deep water, no transfer of water takes place. Except where there are wind-driven currents, the particles in such a wave move in circular orbits, each one revolving about the

* Compare cycle of stream work; Salisbury and Atwood, Bulletin V, this series; also page 32, at close of this chapter.

point which it occupies when the water is at rest. It will be seen later that in shallow water these circular orbits become elliptical by the shortening of the vertical diameter and the lengthening of the horizontal. If the water is drifting before the wind, the path of each particle becomes a spiral.

In the accompanying illustrations (Fig. 4 to 10) each circle represents the orbit of a particle of water. The paths of adjacent particles cannot, of course, be represented. The particles chosen for this purpose are spaced sufficiently far apart so that their orbits are easily distinguishable. The several particles may be thought of as rotating in the direction of the hands of a watch while the wave advances from left to right. Each one is more advanced in its orbit (or has a more advanced *phase*) than the one in front of it. By connecting the several points a curve is produced which has the form of the water wave. The particle at the crest of each wave is moving forward in the direction in which the wave is traveling, while the lowest particle in the trough is moving backward at the same rate. Particles in front of the crests are rising in their orbits while those in the rear are descending.

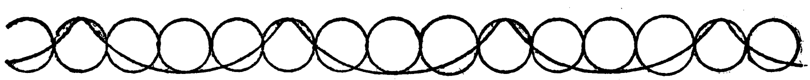


Fig. 4.—Series of particles in their orbits. The circles represent the orbits of the particles. When the latter have positions represented by the small squares, the wave surface is represented by the solid line. When each particle has advanced through one-fourth of its orbit to the position represented by the small cross the waves have advanced to the position represented by the dotted line.

It follows that a particle starting at the crest and making one complete revolution occupies successively all positions from crest to trough and back to crest again, hence the wave form moves forward a distance equal to its length while each particle is making one revolution. It has been found that for waves of a given length, the time occupied in one revolution is the same, whatever be the size of the orbit and the consequent height of the wave* This is equivalent to saying that the rate at which waves travel depends upon their length alone.

* G. G. Stokes—"On the Theory of Oscillatory Waves." Cambridge Trans., Vol. VIII, p. 449.

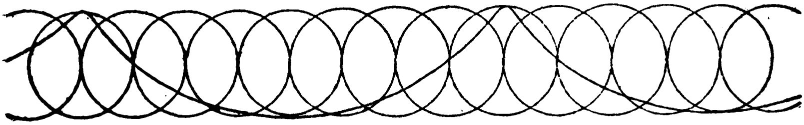


Fig. 5.—Series of particles in their orbits, assuming that at any given moment each particle is advanced in its orbit ninety degrees more than its neighbor to the right.

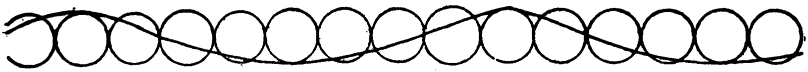


Fig. 6.—The same with orbits doubled in size; absolute amount of differential movement the same as in figure 4, hence the phasal difference is but half as much or forty-five degrees.

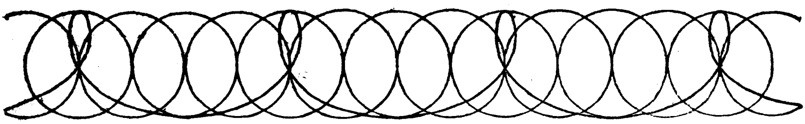


Fig. 7.—The same as fig. 5, with phasal difference reduced to forty-five degrees.

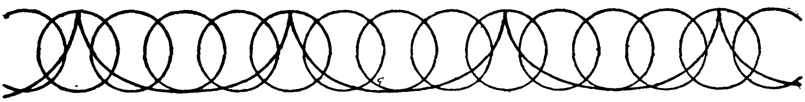


Fig. 8.—The same as fig. 6, with phasal difference increased to ninety degrees. A condition for breakers.

Fig. 9.—The same as fig. 8, with orbits sufficiently reduced in size to prevent breaking; represents the steepest possible form of waves without breaking.

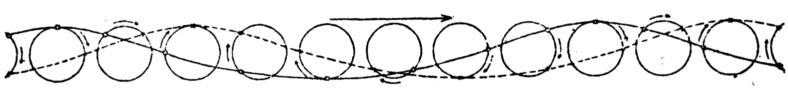


Fig. 10.—The same as figs. 5, 8 and 9 with orbits still further reduced.

If each one of a series of particles is describing its own orbit and the phases of successive particles differ (as shown in Figs. 5 to 10), it follows that each particle is subject to a gliding between its neighbors. The amount of this gliding will be spoken of here as the differential movement of particles. It would, of course, be impossible to represent in a diagram the differential movement between two particles which touch each other, hence for this purpose particles are chosen which are removed from each other by at least a considerable fraction of the diameter of the orbits. The difference in position of any two successive particles in a diagram may then become a considerable fraction of the entire orbit. This difference of position in the orbit is referred to as the phasal difference.

If a series of particles be assumed to be moving in orbits in the general manner above described, the details of the motion may be so varied as to produce an infinite variety of forms, differing as to length, height, shape and rate of travel. As will be seen by a study of figures 5 to 10, all these changes are brought about by merely varying the size of the orbit and the differential movement between adjacent particles, the latter being apparent in the phasal difference between two successive particles in the diagram.

It may be seen by comparing figures 5 and 7 that when the differential movement between adjacent particles is great, the length of the wave is correspondingly small. A comparison of figures 5 and 6 shows that when the differential movement between adjacent particles remains the same, the height and length of the wave vary in the same proportion, (as the diameter of the orbit) hence the form of the wave remains unchanged. Figure 9 shows a striking contrast between the forms of crests and trough. A comparison of this with figures 5 and 10, or a comparison of figures 6 and 7 shows that as the wave becomes higher in proportion to its length this contrast of sharp crest and round trough becomes increasingly apparent.*

The limit of possible steepness of waves is the curve known as the common cycloid. In this condition the crests are sharp angles or cusps. Fig. 9 shows a series of particles in waves of this shape. In figure 8 the differential movement of particles has been increased beyond the amount which results in cusped waves. If the several particles of this series be connected the resulting curve is seen to be looped instead of cusped. The

* All these curves are the *trochoid.* This curve is generated by a point within a circle rolling on a horizontal line. If the point be taken on the circumference the common cycloid is generated. Lines of water particles which are horizontal when at rest, whether at or below the surface, assume the trochoid shape during wave motion.

water surface can not assume this form, hence the wave "breaks." A sudden wind may so augment the orbits of particles that the height of the waves increases more rapidly than their length; the differential movement of particles then becomes excessive. Whitecaps are breakers resulting from this cause. Later in the storm, the waves have lengthened and whitecaps are less frequent. True breakers, as the word is used, result from the interference of a shallow bottom, to be discussed later. (See Plate XXXIV.)

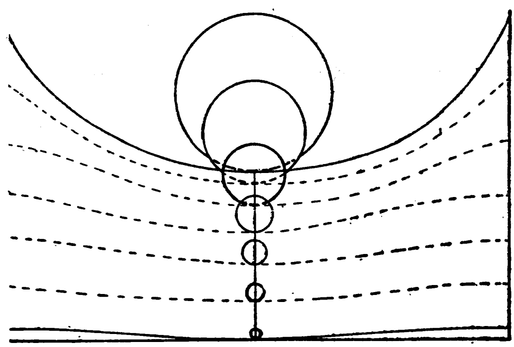


Fig. 11.—Decrease of orbits with depth.

The diminution of orbital movement below the surface is in geometrical ratio and very rapid. (Fig. 11.) A rough approximation may be made by dividing the orbits by two, for each increase of depth equal to one-ninth the length of the wave.* Even this very conservative statement involves practically still water at a depth equal to one-half the wave length, but no such simple formulas are more than roughly approximate, and that only for certain conditions which are assumed to be common.

* Prof. C. S. Lyman—"A New Form of Wave Apparatus." Journal of Franklin Institute, Vol. 86, p. 192. Formula

$$r' = re^{-\frac{k}{R}}$$

where $r$ = radius of surface orbit; $r'$ = radius of orbit at depth equal to $k$; $R$ = radius of rolling circle (producing the trochoid), and $e$ = base of Napierian logarithms.

The solid curved lines in Figure 12 are drawn through particles which, for the instant of time assumed, occupy the same positions in their respective orbits, that is, have the same phase. For example all the particles along the line A B are at the uppermost points of their respective orbits and moving to the right; those on the line E F are at the lowermost points and moving to the left; those on the line C D are at the extreme left of their respective orbits and rising; those on the line G H are at the extreme right and sinking. The same particles would be ranged in straight vertical lines if the water were at rest.

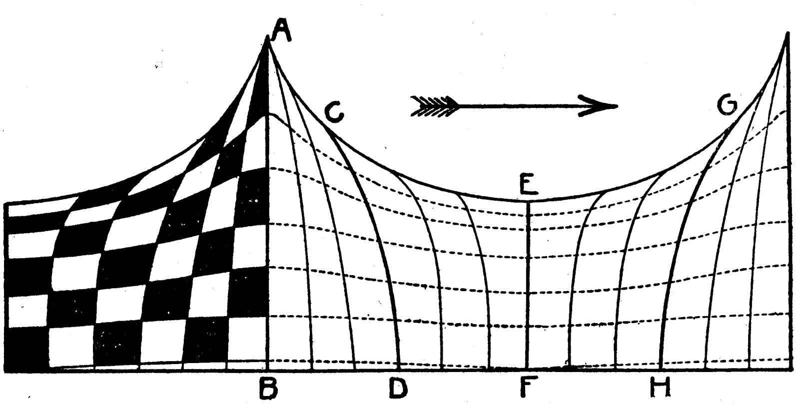



Fig. 12.—Trochoid curves and lines of like phase.

In like manner all particles on one of the trochoid curves (dotted lines in the figure) would come to rest on a straight horizontal line. Near the surface, the rectangles formed by these lines when the water is at rest are greatly distorted and rapidly changed in form during wave movement; at a moderate depth their shapes are subject to little change.

When the depth of the water is so small that wave agitation reaches the bottom, the orbits described by the particles, even at the surface, are no longer circles but ovals resembling ellipses. The bottom particles can, of course, have no vertical movement, but retain their horizontal movement in straight lines to and fro. The ovals approach nearer and nearer to circular form as the surface is approached.

*Breakers.*—When waves advance on a bottom which becomes progressively shallower, the effects may be seen at the surface in four changes of form: (1) The wave becomes higher, the orbits of the particles becoming larger, because the motion is continually being transmitted from a larger to a smaller quantity of water. (2) The wave length is continuously diminished, because friction on the bottom is shared by all the particles above, giving rise to increased differential movement between particles. (3) The crests become steeper and shorter in comparison with the troughs, the necessary accompaniment of shortening waves. (4) The form becomes asymmetrical, the front becoming steeper than the back. This results from the more rapid movement of the crest than of the trough, which in turn is due to the fact that motion in the upper portions of orbits is less interfered with by friction on the bottom than in the lower portions.

The breaking of waves on a shelving shore results in part from their shortening and steepening as noted above; in part, also, from the more rapid progress of crest than of trough. On most shores the breaking of waves (disregarding white-caps) occurs close to the water's edge. Here the wave makes a plunge. Between the shore and the line where this plunging occurs, there is no true wave motion, merely an alternating inrush and outrush of water. If the offshore slope be very small, the incoming waves may break far out from shore. The conflict of orbits in the breaking wave so reduces its size, that it may recover its true wave form and advance a long distance over the shallowing bottom without further breaking. It then breaks again near the water's edge as in the ordinary case. If the slope of the bottom be suitable, waves may break at some distance from shore and advance inward with continuously foaming crests. Even in this case there is commonly a final plunge near the water's edge where the volume of rising water in front of the crest is too small to continue the advancing form.

From what precedes, it is apparent that there are two entirely different processes, either of which may end in the breaking of a wave. The one essential condition is that the wave form should be steepened beyond a certain limit. This steepening as seen above (p. 16) is due to an increase of differential movement between adjacent particles. This may be caused by the urging of a strong wind on the back of the wave, that is, by the *acceleration* of the upper particles. Or the same end may be reached in exactly the opposite way by the *retardation* of the lower particles on a shallow bottom. In each case the gain of differential movement is distributed through a vertical column of water. The former agency produces the so-called whitecaps, generally at a distance from shore. The final breaking in this case is caused by the blowing over of the wave's crest before the greatest theoretical steepness has been reached (Fig. 9, p. 15). Likewise when true breakers are caused by friction at the bottom, the more rapid motion of the crest contributes to premature breaking. Typical breakers due to friction on the bottom must, of course, be looked for on a windward shore, since on a lee shore the effects of acceleration due to wind is united with that of retardation on the bottom. Such breakers have, therefore, in part the nature of whitecaps.

The crests of advancing surf on a shelving bottom are usually in lines nearly parallel to the contours of its shore. Even when the direction of the crests in the deeper water offshore is nearly at right angles to the shoreline, they are refracted on the shallow marginal bottom into a position approximately parallel to the water's edge. This is a necessary result of the retardation of that end of the wave which first enters shallow water. Its progress is delayed as if waiting for the more remote end to swing round for a simultaneous advance toward the shore.

*Waves of translation.*—These, as the name implies, involve an actual transfer of water instead of an oscillatory movement. They are contrasted with waves of oscillation in many ways. One wave of translation is quite independent of its companions. It is true that the conditions which produce such waves on lake shores generally give rise to a series of similar waves of translation, but the propagation of any one wave is a process complete in itself and the waves may be any distance apart.

A water particle concerned in such a wave is simply lifted and carried forward in a semi-ellipse and does not return to its former position. Moreover all water particles from surface to bottom move forward the same distance. Each one starts from rest as the wave approaches, rises, moves forward and down again in an elliptical curve, and comes to rest again in its advanced position when the wave has passed.* (Figs. 13 and 14.)

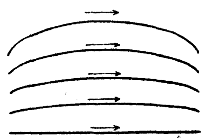


Fig. 13.—Paths of individual particles during the passage of a wave of translation, the horizontal movement being the same at all depths, the vertical movement decreasing with depth to zero.

Such a wave can be produced only by the sudden addition of a new volume of water to the lake or to some part of it. The wave travels onward as described, to the shore, where it delivers the extra volume of water. When the slope of the marginal bottom is so gentle as to cause an offshore breaker line, such waves may sometimes be seen advancing shoreward from that line, their crests rising above the general level of the water, the interspaces being quite flat and much broader than the crests. The sudden supply of an additional volume of water

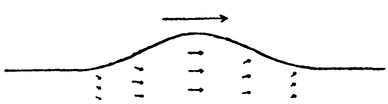


Fig. 14.—Direction of movement of particles within a wave of translation rising as the crest approaches, descending when it has passed.

necessary to produce such waves comes from the plunging crests at the offshore breaker line. Such waves break onshore just as waves of oscillation do. They are not to be confused with ordinary waves which are wind-driven or confounded with current. They are best distinguished in appearance by the flatness of the water surface between their crests. Under favorable conditions, this phenomenon is well shown on the shore of Lake Michigan at Jackson Park, Chicago.

*Undertow.*—It is a matter of common observation that the coming in of breakers on a beach is accompanied by an outward

* See J. Scott Russell—"The Wave of Translation." London, 1885.

moving of water at the bottom. The necessity of this is frequently due to the fact that the incoming breakers are wind-driven and therefore accompanied by an onshore current at the surface which must be compensated by a reverse movement below. When there is no current due to wind, there may be, on a gently shelving bottom, almost pure translatory waves between the line at which the waves break and the shore. Even where the waves do not assume this character, common oscillatory waves on a shallow bottom carry more water forward under their crests than backward under their troughs for the reason that the motion of crests is less interfered with by friction on the bottom. From whatever cause the water may come shoreward at the surface, the compensating outward movement below is known as undertow.

The volume of water moving out as a undertow is greater at some distance from shore than near the water's edge, because some of the water turns back before reaching the extreme limit. Its power, on the other hand, diminishes rapidly as the depth increases; increasing depth and cross section involve decreasing rates of travel; power to move objects varies as the square of this velocity. Again, the competency of a current to move stones of a certain size depends, not on its steady progress of so many miles per hour, but on its maximum rate even though kept up for but a fraction of a second; hence a given amount of water passing out at a given rate as undertow will have greater efficiency if its motion, instead of being uniform, be broken up into quick jerks, between which there may be intervals of quiet or even of slower movement in the opposite direction. This is what occurs near shore where the same water which is moving out as undertow is also subject to the oscillatory movement of waves. This advantage, also, is rapidly lost as the water deepens and the influence of wave oscillation is less felt.

This same principle of concentrating motion into sudden impulses may sometimes favor the incoming instead of the outgoing water. The water may be carried shoreward on a gently sloping bottom, entirely by waves of translation, which are separated by three or four times the length of one wave. In such a case the shoreward motion will be performed in much less time than that used by the returning water. It will, therefore, be more efficient as will be seen by its effect in pushing sand shoreward. The shoreward urging of bottom materials may also be favored by onshore currents provided there is a lateral escape for the water. If it must return by undertow sediments cannot be carried shoreward by wind drift.

In general it may be said that the slope of a marginal bottom is rendered more gentle by the carrying of sediments outward from the shore toward the deeper water and that the slope is made steeper by the pushing of sediments shoreward, thereby adding to the land and shifting the water's edge lakeward. These two tendencies are in conflict. If the offshore slope is very steep, the undertow is favored and the steepness is being reduced; if the slope is excessively gentle, pure waves of translation are favored, which carry sediments shoreward and co-operate with currents, mentioned below, in building the land lakeward and steepening the slope. Between the two extremes there is a slope which provides an equilibrium between the in-bringing and th out-taking forces. This form is called the profile of equilibrium.

*Shore currents.*—Currents as considered in the modification of lake shores, have their beginnings in the general drift of the surface water before the wind. When this drift impinges on a shore it tends to follow the direction of that line with a degree of detail dependent upon the strength of the current; the feebler the current the smaller the sinuosities of the shoreline to which it can conform. The return of the water may be by vertical or by horizontal circulation. In the former case the return currents are beneath. This is especially necessary where both sides of the lake are equally exposed to the force of the wind and all the water of the surface is thus driven in the same general direction. If one side of the lake be relatively protected from the wind, the return of the water may be by a surface current running contrary to the wind on the protected side. For example, a northwest wind blowing on a small lake with high banks, may drive a strong current south along the east side while the water returns to the north under the protection of the high west coast. This is sometimes observed but vertical circulation is more common.

## SHORE FORMS DUE TO WATER WORK.

*Forms due chiefly to cutting.*—When the basin is first filled, the water rests against a surface which is in no way adapted to its movements. Usually the coast line is far too much broken by headlands and reentrants to be followed by shore currents. The slopes of the marginal bottom have likewise no adjustment to the processes which determine profile. The topography in which basins occur is such that generally, though not necessarily, salient points and curves have steep slopes both above and below the water line, while reentrants are marked by gentler slopes.

When the offshore slope is steep, incoming waves suffer little loss of power until the shore is reached. If the basin be limited by vertical or very steep walls extending some distance below the surface, the waves are reflected and do not break. Such a wall may endure a long time showing little evidence of the power of the waves. This principle is well known to engineers and is applied in the construction of breakwaters. A talus may accumulate by sub-aerial weathering which will offer the conditions for breaking waves.

When the slope is such that waves break, the mass of water in the crests delivers a powerful blow as it plunges forward against the coast. This blow may be very effective if the material of the cliff be uncompacted, or if it be rock which is broken into blocks by joining cracks. (Plate XXV, Fig. 1.) But if the cliff be of homogeneous, unfractured rock the most powerful blow of water has little effect.* If, however, some fragments be allowed to lie at the foot of the cliff and to receive the force of the water's fall, these fragments will be hurled against the solid rock with telling effect. Such "tools" are early supplied by cliffs themselves when composed of jointed blocks, but the first ones are easily carried away to deep water by the outrush which follows the breaking of the surf, if the slope of the constructional shore be steep. After this process has gone on for some time a notch will have been cut in the steep slope, affording a resting place for fragments which the surf may hurl

* See Gilbert, Lake Bonneville, page 31.

FIG. 1.
Beach on Lake Nagawicka, looking west. Currents from the south were unable to round the point suddenly and have therefore built a temporary spit off shore.

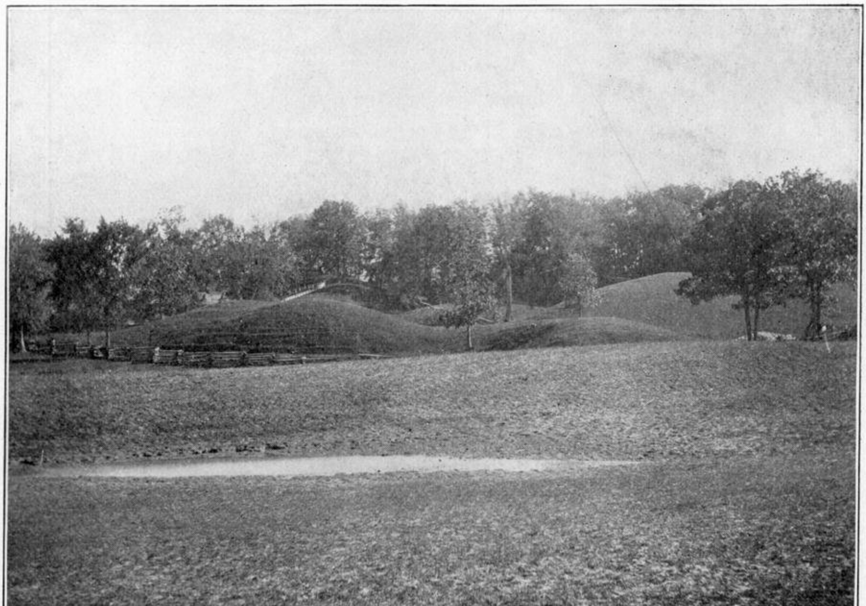


FIG. 2.
Kame area near Oconomowoc.

against the cliff. (See Fig. 15, also Plates XXXI and XXXII, Fig. 2.) From this time forth, the work of cliff cutting will be more rapid. The erosion is limited to undercutting in a narrow belt which reaches little, if any, higher than the crests of the waves. The cliff proper, or steep face above, is due to the falling of material whose support has been cut away. (See Plates VIII, IX, X, and frontispiece.) If undercutting stops, the steepness of the cliff is soon reduced by weathering. (Plate XXV, Fig. 2.) If the cliff be high a small amount of undercutting will cause the fall of a large amount of débris which will require a proportionately long time for its removal by waves and currents. The lower the cliff, therefore, the more rapid its recession.

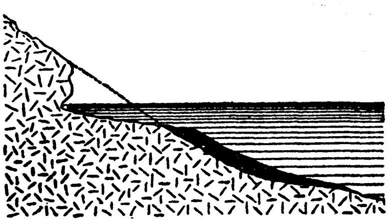


**Fig. 15.—Ideal section of a cut-and-built terrace (Gilbert).**

The rate of cliff recession varies with the strength of its material, the power of the waves, the capacity of the currents which must remove the waste, and the height of the cliff. The shores of Lake Geneva have at several points receded fully a rod since the original government survey, made in 1835.* This rapid cutting is very local and often very temporary. For reasons depending on the recent raising of the lake level, the rate is much too great to be taken as an average for the entire history of the lake. The average total recession of all the cutting coasts of this lake, since its formation, may be estimated at a small number of rods.

The distance through which the cliff has retreated landward is the width of a cut terrace, which has remained as the stump of the bank which has been cut away. This shelf is usually

* Information furnished by Mr. Beckwith of Lake Geneva

widened by the accumulation on its front of some of the waste which the cliff has yielded. The feature is then called a cut-and-built terrace. (See Fig. 15.) So long as the terrace is narrow and steep, heavy stones may thus be added to its front. As its width increases and its slope becomes more gentle, this growth by building becomes slower and slower and may cease entirely. At all events it is progressively limited to constantly finer material. The terrace is constantly being cut down by the waves and currents which wash its surface. The result of this cutting is, in turn, to conserve the power of future waves to be expended at the foot of the cliff. When the edge of the shelf is distinctly marked, its depth may be taken as that at which wave action ceases to stir the sediments. (Compare Lake Mendota, p. 56, also Green lake, p. 155.) This depth is here spoken of as wave-base.*

*Forms due to transportation and deposition.*—While the cut or cut-and-built terrace is narrow and steep the resultant of all the water's action on its surface has a strong offshore component, which succeeds in dragging the products of erosion to its outer edge and dropping them there in deep water. As the shelf widens this becomes impossible and the pebbles on the bottom are then repeatedly borne to and fro within the breaker line.

The direction in which waves approach the shore is rarely quite perpendicular. When the final plunge is made the water is seen to run up on shore at an angle and to fall back again in such a manner as to transport pebbles in a zigzag line. This is one of two important processes in transportation. It is peculiar to the beach, a form which is adapted to the transportation of shore drift in the manner here described. The beach has some analogy with the wave in that its form is relatively permanent while the materials which compose it are constantly changing. Its development at the foot of a cliff is begun when stones first find a resting-place at the water's edge. These stones accumulate first in reentrant angles or small bays, forming bay-head beaches. (See description under Lake Mendota, p. ..; also Plate VI, Fig. 2.) It will be seen later how the beach also develops on slopes which are too low for the profile of equilibrium.

* Following the suggestion of Dr. F. P. Gulliver—Proceedings of the American Academy of Arts and Sciences, Vol. XXXIV, No. 8, page 177.

When the beach is developed at the foot of an actively cutting cliff the structure has but a single slope, but is steeper above than below the level of the water in repose. This may be best explained by the fact that the water in rushing upward from this line is losing power and depositing load, while in falling back it is gaining power and taking up load. Below this line of the water's edge these conditions are reversed. The entire shoreward movement is being constantly communicated to a decreasing amount of water, hence the power on the bottom is increased, while in falling back the opposite condition involves loss of power and deposition.

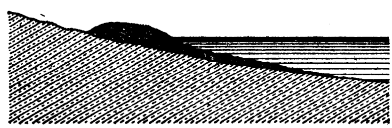


Fig. 16.—Ideal section of a beach (Gilbert).

For the same reason the materials of the beach become progressively finer from the water's edge upward and also downward from the line where the surf makes its final plunge. Hence the largest stones transported are between these two lines, under the edge of the water. This is the strip which is continued in the subaqueous embankment (see below). It is therefore common to see the latter made of gravel when the beach above the water line is very sandy. (See Green lake, page 161.)

Where the beach fronts a low slope, a ridge is built whose back or landward slope is steeper than its lakeward slope in front. (See Fig. 16.) This profile of the beach ridge is common to such structures whether built at the water's edge or as bars and barriers, originally constructed at a distance from shore.

The other process of transportation whose action is more widespread than that above described does not require that the materials to be transported (the *shore drift*) shall be caught between the plunging surf and the shore. It is the work of currents rather than of waves. Currents alongshore are more or less efficient over a considerable zone. Of themselves they are relatively weak in stirring the materials on the bottom, but where waves are active the currents need only take advantage of the moments when sand grains are in commotion and pebbles are tilted up on edge. At such times a very feeble current may impart the decisive impulse which determines that motion shall be in one direction rather than another. This mode of transportation is common to all bottoms which are shallow enough to be reached by wave agitation. Fragments of considerable size may be carried alongshore in this manner where there is no water sufficiently shallow to admit of breakers. This is true at Cedar Cliff, Lake Mendota. (See frontispiece.)

Where a current fails to conform to the curves of a shoreline, its most common mode of deviation is to leap from headland to headland, cutting across bays, running tangent to the shore at one or both sides. In this case the shore drift, which travels with the current, is likewise carried away from the shore and dropped in the path of the current. It is built into a subaqueous embankment whose surface will be just near enough to that of the water to bring the sand or gravel, of which it is composed, within the competency of the current assisted by wave agitation; therefore the larger the individual stones, the nearer will the top of the embankment be to the surface of the water. The growth of this embankment is at the distal end, where the stones which have traveled its length are dropped into deeper water after the manner of the building of a railroad embankment. Some material fails to make the entire journey and is dropped on the sides, adding to the width of the structure. Waves begin to break over the ridge and the dashing water piles some of the stones into a higher ridge. Vegetation soon takes hold and the structure is firmly held above water. The subaqueous embankment has become a spit which has assumed all the functions of a beach. (See Plate XXII.)

Wind drift may follow an irregular shore more or less closely but may lack the definiteness of course necessary to enable it to hold its unity and continuity in crossing a bay. Such drift does not build bars, partly because the material carried is being used to fill the minor indentations of the shore, and partly because the current is dissipated in crossing the bay. The resulting

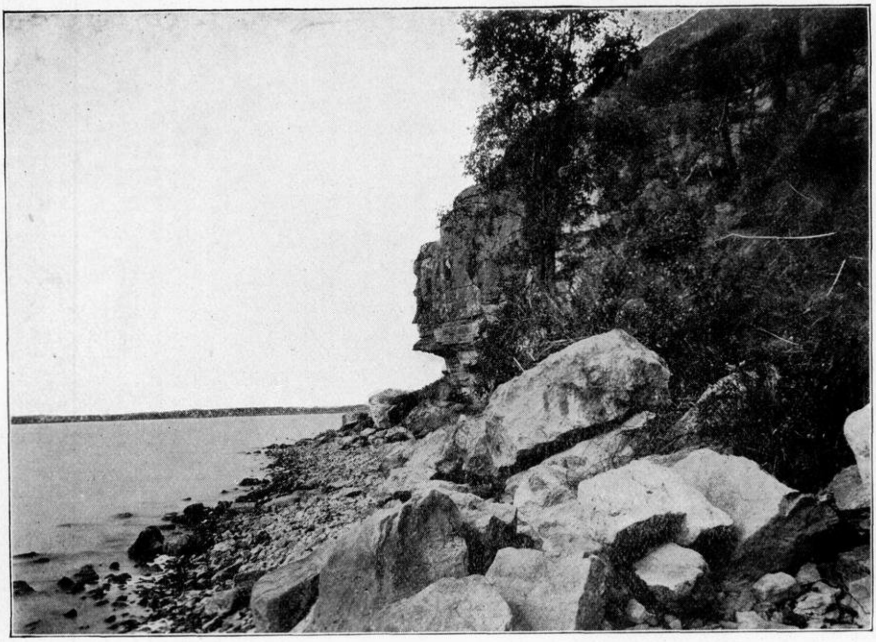


FIG. 1.
Farwell's Point, Lake Mendota. The waste of the cliff lies at its foot and is hurled by the surf against the base of the cliff.

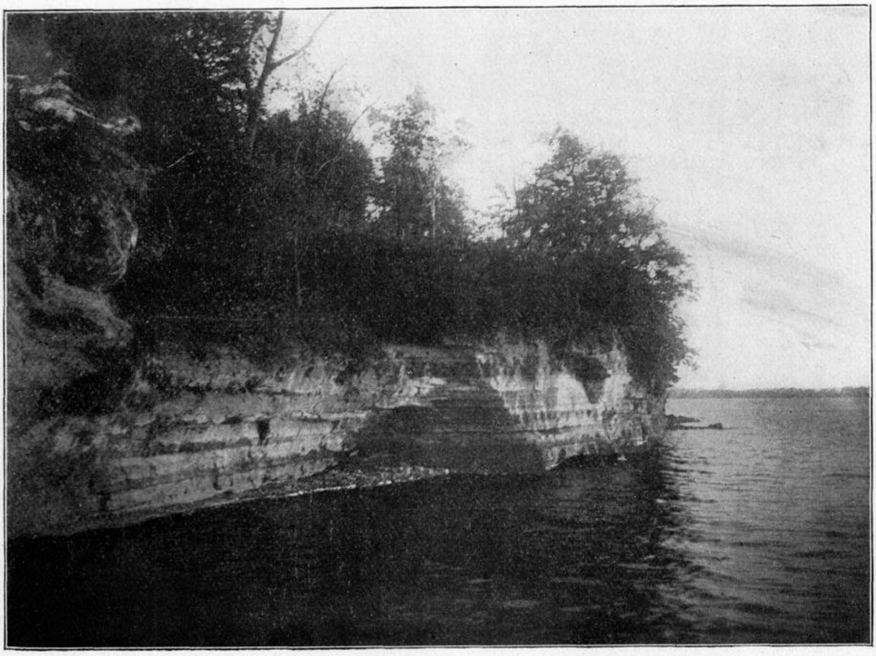


FIG. 2.
A part of Maple Bluff, Lake Mendota. A small bay-head beach shows the beginning of beach development.

deposit forms an indefinite shoal instead of a definite bar. (See Turtle bay, Elkhart lake, page 142.)

The subaqueous ridge may entirely span the bay, in which case it is commonly called a bar, though the word bar is also frequently applied to spits having one free end and also to structures which have been raised above water and have become beaches. The bar still further excludes currents and large waves from the bay and thus favors the growth of vegetation. If sediment is being washed in by streams that also is held in the bay which, through these agencies, becomes first a swamp and then meadow or forest. The bar, instead of connecting two parts of the shoreline, may connect islands, or an island with the mainland. For this variety the Italian term tombolo has been suggested.* (See Plate XXVIII, Fig. 1.)

It happens, not infrequently, that while one set of winds and currents has succeeded in building a spit in its own direction another set of winds and currents may dominate for a sufficient time to turn the point and form a hook. (See Plate XXII, Fig. 2. This happens most frequently in bays where the main shore current by building a spit part way across the bay, constricts the course of currents which intermittently set into the bay. When for various reasons the current setting into the bay has become weakened the spit may grow again in its initial direction and be repeatedly turned forming a series of prongs directed shoreward from a trunk. (See Figs. 20 and 24.) Spits may also be built by the turning off of currents from headlands where there is no bay; they may then be turned landward again, forming looped bars by a combination of currents which it is not always possible to account for by the configuration of the shres. (Plates XVII and XVIII. See Gilbert, Lake Bonneville, p. 55.)

For various reasons the position of a beach once built may be shifted farther and farther lakeward, its successive positions being marked by a series of beach ridges forming a wave-built terrace. (Fig. 17.) This is very frequent in narrow bays so situated that the currents on both sides set toward the head of the bay

* F. P. Gulliver—Proceedings of the American Academy of Arts and Sciences, January, 1899.

at the same time. The water escapes by undertow which cannot dispose of all the shore drift carried in by the currents This is then added to the widening beach at the head of the bay. (See Elkhart lake, p. 143.) Again, a current which is able at one time to conform to the outline of a bay, passing in at one side and out at the other, becomes stronger and may not be able to

Fig. 17.—Ideal section of a wave-built terrace, built of shore drift.

describe so sharp a curve after its course has been more smoothed by the natural development of the shoreline. The cutting away of small headlands and the filling of small bays and the similar smoothing of inequalities of the bottom help to make for the shore current a path along which it may travel with the minimum waste of energy. When this has been accomplished the current with its greater power, will sweep less close to shore in the larger bays and their beaches will tend to move lakeward. (See Lake Mendota, Plate XI, Fig. 2.)

Fig. 18.—Ideal section of a barrier (Gilbert), showing how the offshore slope is steepened by this feature.

The various forms of beaches, spits and bars may be, in the main, regarded as attempts to bring the shoreline into harmony with the horizontal circulation of the water. The barrier is a feature of deposition whose function it is to correct the profile, increasing the offshore slope where that is too low, by moving the shoreline lakeward. (Fig. 18.) It is, in a general way, parallel to the shore, an offshore ridge which is built above the water level in a manner described above, under bars, and which develops a beach and substitutes itself for the shoreline. In the main the material seems to be brought alongshore because of the greater transporting power of currents along this line. The ridge begins to grow along the line at which heavy storm waves break. It is only when the offshore slope is deficient, that there is an offshore breaker line. It is in this case only that the line of maximum agitation, and therefore of greatest transportation, lies offshore instead of at the water's edge. In its beginnings the barrier is to be regarded as a train of sediment moving along the line of greatest agitation, and not as a depositional form laid down as a permanent deposit. When the ridge has been raised above water and become a beach, it is equally dependent upon a supply of material, without which it must steadily be eroded back. (See Gilbert, Lake Bonneville, p. 40; also the writer in The Journal of Geology, Vol. X, p. 29.)

The typical bar and the typical offshore barrier have much in common and the processes tending to form the one and the other frequently unite their efforts on a single structure. A part of the process is the same in both cases. Nevertheless, the conditions for the two are so distinct that it is very desirable that the two types be clearly contrasted. (1) Both follow the line of maximum transporting power. In case of the bar, this maximum is due to a littoral current which locally leaves the shoreline because it is unable to follow its shorter curves. In case of the barrier, there need be no current except a broad and unlocalized drift which follows the general direction of the shore. The maximum of transporting power along an offshore line results not from a localized current but from excessive agitation on the bottom by waves (p. 27). This is due to an offshore breaker line which occurs only when the offshore slope is deficient. Of course, as soon as the barrier has been raised above water and becomes the beach, it will have its own littoral currents. (2) The material of the bar is derived from the waste of the cliff from which it springs. That of the barrier is gathered from the bottom to which it has been brought chiefly by rivers. It is not necessary that the barrier should anywhere touch the coast.

It may readily be seen that barriers are not to be expected in most of Wisconsin's lakes. The conditions of their origin have generally given them steep offshore slopes. Where the opposite is the case, wave agitation is so small that swamp conditions soon prevail. Most of the shore drift is derived from cliffs rather than from streams.. Where the undertow is sufficient to spread this out on the bottom, the slope may generally be deemed sufficient so that barriers will not be needed.

On the shores of many of the Wisconsin lakes, there is, superposed on the cut-and-built terrace which extends outward to the contour of wave-base, a narrow subaqueous shelf of marked characteristics. It may be from 5 to 20 feet wide, but whatever its width, its edge is always at the depth at which the storm waves break. This universal association has suggested the name of *breaker terrace*. These features, when of characteristic form, are always composed of cobblestones and are therefore most frequently found along shores composed of kame gravels.

The breaker terrace is found most frequently in those lakes whose levels were raised by dams some 50 or 60 years ago. This would suggest that it is, in the main, a feature of renewed cutting of a steep shore at a higher level. Such renewed cutting must inevitably result in a partial burial of the former terrace, the newly deposited detritus being thickest near the waters edge. In the early stages of the marginal terrace in kame gravels abounding in cobbles, it is quite probable that the features here noted would persist for a considerable time, that is, until the shelf had grown to such a width that the fall from the water's edge to the depth at which breakers occur should fail to offer sufficient slope for the continued dragging out of cobblestones. The characteristic distinctness of form and outline might then be lost and in place of a distinct breaker terrace would appear a more or less indefinite band of coarse materials.

While this feature has been most frequently observed on lakes whose level has been recently raised, it is not improbable that with materials in which cobblestones are abundant this additional step in the descent from the water's edge to wave-base may be a normal feature for a considerable part of the shoreline's history. The sudden change of power on the bottom at the breaker line, which is true of both incoming and outgoing waters, might be expected to show itself in some such change of slope, just as the similar change of power is shown at the depth beyond which waves fail entirely to agitate material on the bottom. The effect of this sudden change in the power of the outgoing water, is to drop the coarser materials with some degree of suddenness causing the terrace thus built to present an abrupt

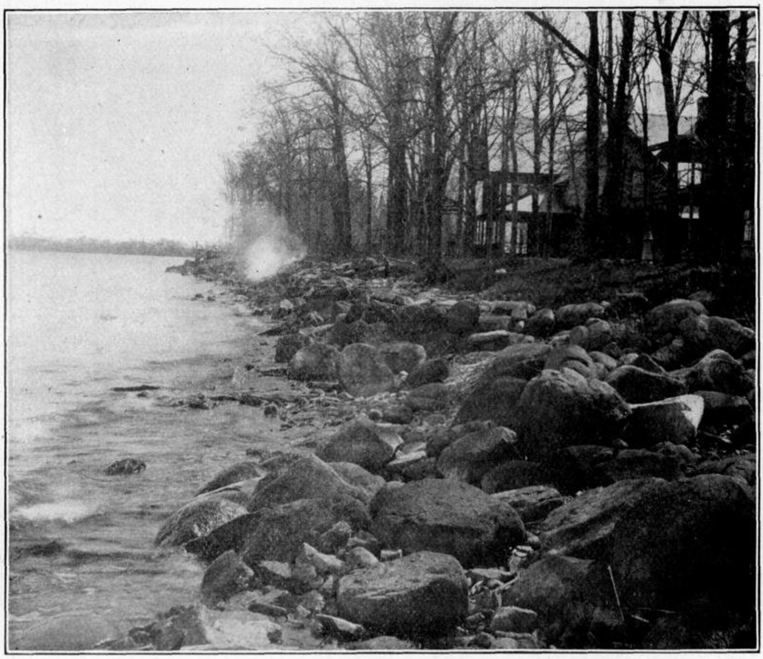


FIG. 1.
Lake Winnebago. Boulders dropped from the low cliff at Oshkosh. The ice keeps them crowded close to shore, which tends to protect it against the waves.

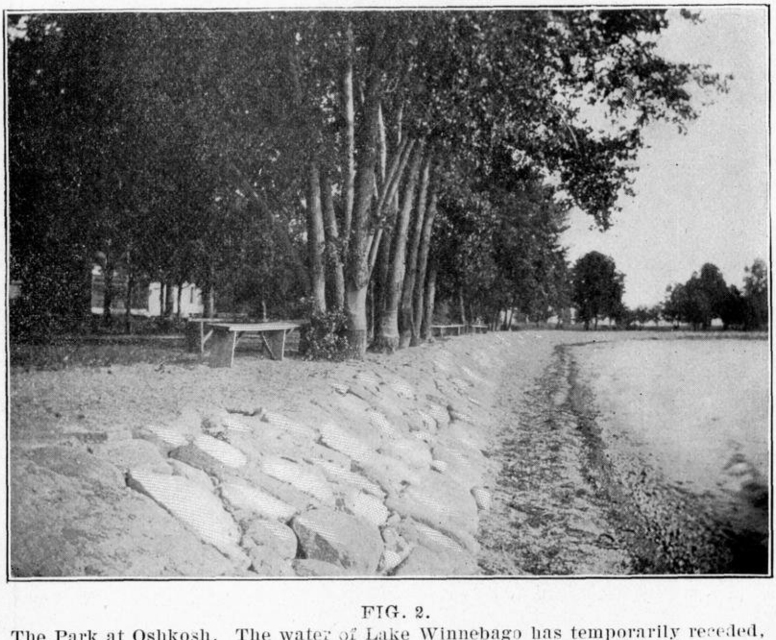


FIG. 2.
The Park at Oshkosh. The water of Lake Winnebago has temporarily receded, showing a new terrace of gravel begun since the wall was built.

front. Considered with reference to the stones of which the terrace is built, the undertow beyond the breaker line is entirely without power, hence the abruptness of the terrace front may be regarded as normal. It is probable, however, that the degree of abruptness now observed in so many of the Wisconsin lakes could not be maintained without occasional changes of level.

### SHORE FORMS DUE TO ICE.*

When a thick sheet of ice, covering a small lake, expands under the influence of rapidly warming weather, the consequent pushing may result in the overriding of low shores for many feet by the edges of the ice. (See Plate XII, Fig. 1.) If the shores be such as to offer great resistance, the ice itself may be upheaved in long ridges. If the shore against which the ice is braced yields before the enormous stress, its materials are pushed up into an irregular ridge called the rampart. (See Plate XIII.) In most cases ridges of this origin are readily distinguished from beach ridges by their irregularity, both of plan and crest, and by their composition, which is of the materials of the shore. The majority of old ramparts found are of glacial drift which is rich in bowlders, for the simple reason that ridges of such material are very durable. (See Elkhart lake, p. 143.) Many ridges are of composite origin, their positions being determined and their materials largely furnished by beach action, their forms and altitude being imparted by ice work.

Ridges are frequently met with, which in position and horizontal form would be called spits, but whose composition is of bowlders and thoroughly unassorted material. Such ridges may generally be accounted for by the agency of ice, pushing up the materials of a shoal bottom which a subsidence of the water level has brought within reach of the ice. This occurrence is well illustrated in the ridge of "Willow walk," Lake Mendota, and in the similar ridge which extends northward from the east side of Governor's island. (Compare Fig. 31.)

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* See paper by Dr. E. R. Buckley in the Transactions of the Wisconsin Academy of Sciences, Arts and Letters, Vol. XIII.

Many lakes in the kame gravels have a characteristic shelf or walk at the foot of their steep banks. This feature may have any width up to three or four yards and is usually about two feet above the water level. It is formed by successive additions of gravel on its front. The gravel being incoherent and having no great bowlders is pushed up from the beach to a somewhat uniform height. Repeated contributions in the same manner produce the terrace or walk. For this feature the name ice-push terrace is suggested. (Fig. 19, also Plate XXIV.) The usual associations of this form are those of a slowly falling lake level, a factor which aids greatly in bringing the beach gravels within the grasp of the ice.

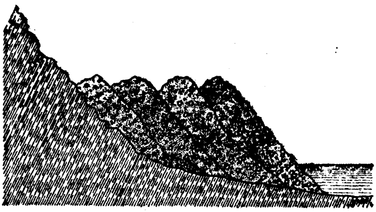

Fig. 19.—Ideal section of an ice-push terrace. built of shore materials either assorted or unassorted. Contrast the wave-built terrace Fig. 17, p. 30.

Perhaps the most wide-spread evidence of the agency of ice is found in the lines of bowlders just above the water's edge. These are rarely absent from shores where the waves are cutting into bowlder clay. Such heavy bowlders are less easily dragged off-shore by the outrush following breakers; again, even at the same distance from shore, their size causes them to be incorporated into the ice sooner than the smaller stones on the bottom. A selection is therefore constantly going on, the smaller stones being more easily carried off-shore in summer and the larger bowlders being more readily pushed on-shore in winter. Wind driven ice is also often very effective in this process. (Plate VII, Fig. 1.)

CYCLES OF SHORE LINES.

In summing up the effects which the waters of a lake have on its shores, a certain systematic development appears, by which the features which indicate youth gradually give place to those which denote age. Infancy is generally characterized by irregularity and by lack of adjustment to the movements of the water. This is seen when the water first enters the basin or in case of a rise of level. Generally speaking its curves are short and its bays and headlands many. Similarly the depth of the marginal bottom lacks uniformity. Shore currents at this stage lack continuity; they are subject to eddies and whirls and they penetrate even the minor bays. The erosion of the shore is almost universal, its waste products being used to fill up minor depressions and to pave the beach which is to be the roadway for future transportation alongshore. This done, the currents take on more majesty of flow, passing by the smaller re-entrants which they span with bars built of the material of the wasting headlands. This simplifying of the shore-line by destruction and by reconstruction is the business of youth. Each step in eliminating the smaller curves makes larger changes possible by giving to shore currents broader sweeps and more continuity of motion.

There comes a time when no more cut-offs can be made. The beach then in use will not be abandoned for another as the shore of a bay is supplanted by the bar in front. The beach at any given place will change its position gradually, shifting landward or lakeward, according as the balance of transportation of shore drift is toward or from that place. The work of this mature stage* uses beaches which were being made ready in youth. The methods of work involve steady progress, in contrast with the sudden changes resorted to in younger stages.

For a long time, parts of the shore continue to erode while others are building, but, with increasing adjustment, this too must disappear. If little or no material is brought in by streams the entire shore must eventually recede. The rate of erosion must be slow, for the only disposition of the products of wasting is by carrying out in suspension to the deep water. The amount thus disposed of is limited by the comparatively slow process of reduction to mud by extreme attrition on the

* The significance of the word *maturity* as applied to shores has not yet become uniform among good authorities. It is sometimes used to denote a somewhat later stage than that described here.

beach. If abundant sediment is brought by streams the balance of beach action may be in favor of building the entire shore lakeward. Few shorelines reach a stage beyond maturity. Lakes are such transitory features that they are usually extinguished long before maturity is passed. In the case of the ocean the rising or sinking of coasts brings about new shore lines often at short intervals.

When a new shore line is assumed by a falling of the water's level the banks are necessarily low and the outline consists of broad curves. The principles applying to its development are the same as those which control the case of a shore produced by the original filling of a basin, but the variety of scenery is wanting. Barriers are frequently built along shores determined by a sinking of the water level. As seen above, they indicate a deficient off-shore slope. The normal profile of an adjusted marginal bottom is found to be steeper near the water's edge than farther out.* A fall of the water within certain limits, therefore, carries its edge down the steeper slope to a new position from which the off-shore slope is deficient.

A new shoreline indicated by a rise of level is of the same nature as that which is assumed when the basin was first filled. This case is exemplified in many of the lakes included in this report, whose levels have been raised by dams.

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* The writer, Journal of Geology, Vol. X, page 27.

Profile Rock at Farwell's Point, Lake Mendota. Note the effect of undercutting in producing the chin and neck.

# CHAPTER III.

## THE LAKES ON THE YAHARA.

### GEOGRAPHY OF THE DISTRICT.

*Names of the Lakes.* The four lakes on Yahara River are now known as Mendota, Monona, Waubesa and Kegonsa, the order given being in the direction of the stream's flow. These Indian names were not used by the aborigines themselves, having been applied in about the year 1858 by the late Dr. Lyman C. Draper, founder of the Wisconsin State Historical Society. Dr. Draper was requested by Governor Farwell to give Indian names to the lakes for use in a pamphlet designed to advertise the city of Madison. The names were selected purely on account of their euphony; hence their meanings have no significance as applied to these lakes. They are taken from the language of the Chippewas who never dwelt in this vicinity, their habitat being in northern Wisconsin. The name Wingra, meaning *dead* in the language of the resident Winnebagoes, is an exception, having been actually applied to that sheet of water. The formerly common name "Dead Lake" is therefore a translation. That tribe called the entire region "Taychoperah" or "Four Lakes" but do not appear to have used separate names for the individual lakes of the Yahara Valley. Contrary to the popular impression, such Indian names were not intended by the Indians themselves to have poetical significance, but were descriptive or related to some trivial incident and were used merely for identification. The common names, "First," "Second," "Third" and "Fourth" were applied to the lakes by the United States land surveyors, denoting the order in which they found the lakes in ascending the river.

*Drainage.* The name Yahara river is applied to the outlet of Lake Mendota, which traverses the three other lakes of the group, flowing southeastward to join Rock River about 25 miles from Madison. The upper course of the Yahara flowing into Lake Mendota from the north, is known as Catfish Creek. The four lakes are but local enlargements of the Yahara valley. A fifth lake, Wingra, adjoining the city on the southwest, discharges its water into Lake Monona through a small stream known as Murphy's Creek (now canalized).

A drainage basin of perhaps two hundred and fifty square miles discharges its water into Lake Mendota. A part of this water enters as surface drainage, mainly by the Catfish river and Six Mile creek. Another part derived from the rainfall over the same catchment basin, enters the soil and reaches the lake as springs. These springs may also bring water from beyond the limits of the drainage basin, while ground water from a part of that basin may feed springs which issue beyond its limits. The lower lakes of the chain receive all this drainage which overflows from Lake Mendota, and before Lake Kegonsa is reached the catchment area has been almost doubled.

## GEOLOGY OF THE DISTRICT.

The rocks exposed in this vicinity are: (1) The Potsdam sandstone proper. This underlies Lakes Monona and Mendota, and some tributary valleys on the north side for at least six or eight miles from their mouths. It may be seen now at the foot of the cliffs at Maple bluff, Eagle heights, and the other rock cliffs of Lake Mendota. It is the bed rock over considerable areas around the lakes, but it rarely appears in outcrops on account of its friability and the drift covering.

(2) The Mendota limestone. (Compare Green lake, p. 151.) This calcerous horizon in the upper Potsdam receives its name from Lake Mendota, on whose shores its type is seen. It is best exhibited at Maple bluff, where it forms the capping of the upland, sixty feet above the lake. Its base is perhaps thirty feet above the water. It shows here one or more of the fine green bands so characteristic of the Mendota. Another characteristic appearance, the chocolate colored mottling, is also well displayed. The same rock, with the same appearance, lies at the top of the cliffs at Farwell's point and Eagle bluff. It has a

faint dip to the south and appears at the water's edge on the south side of Lake Monona at Ethelwyn park.

(3) The Madison sandstone is not conspicuous in cliffs. It is softer and less resistant than the Mendota or the Lower Magnesian limestone above, hence its area of outcrop is usually a gentle slope between the more obtrusive outcrops of the limestones.

(4) The edge of the Lower Magnesian limestone (Ordovician) often gives steep slopes to the higher hills several miles from the lakes. Beyond this border are large patches of St. Peter's sandstone covered here and there with smaller remnants of Trenton limestone. For more than ten miles from Madison all strata higher than the Trenton have been eroded away.

The Trenton limestone once lay in an unbroken nearly horizontal sheet over this whole area, as it still covers the eastern part of the state and almost covers the southwestern. (See Geology of Wisconsin, Vol. I, p. 260.) The Trenton itself was probably covered by one or more of the higher formations which now cover it in eastern Wisconsin and at Blue Mounds.

The streams which existed just before the ice age began cutting their valleys in rocks not lower than the Trenton, and probably not higher than the Niagara. This means that the bottoms of the earliest valleys in this vicinity may have been any where from six to twelve hundred feet higher than the city of Madison is today. The valleys were carved lower and lower until the beds of the streams were deep in the Potsdam sandstone and the streams themselves were running at a level perhaps two hundred feet or more below that of the present lakes or Yahara river.

## PHYSIOGRAPHIC HISTORY OF THE DISTRICT.

*Pre-glacial topography.*—The origin of these lake basins must be explained by the late geologic or physiographic history of the region. It is only since the surface of northeastern United States has been known to have been glaciated, that its various features, such as lakes, rivers and hills, have been consistently interpreted. The effect of the glacier was to obliterate many small valleys and to change the larger both in form and in the nature of their drainage. It likewise left on this part of Wisconsin a thick cover of drift of irregular thickness so that the delineation of the pre-glacial topography involves serious study.

Three classes of evidence have been relied upon in determining the lines of the pre-glacial valleys of the Yahara and its tributaries. One class of these records is visible to the eye of the traveler; it is found in the long, continuous though winding valley partly occupied by the Yahara river with its chain of lakes. This valley is carved in rock, which may sometimes be seen outcropping on the hillsides and stream channels, or it may be known only by well borings. To the eye of the topographer, however, the hills themselves reveal their rock cores by their forms even where completely covered by a mantle of drift. The foundations of some of these hills are made known by the flatness of their tops and the steepness of their upper slopes where the former rock escarpment is otherwise obscured. Another class of evidence of pre-glacial stream erosion is seen on the geological map. From this it appears that along a strip reaching southeast from Lake Mendota, the drift lies on older and lower rocks than on either side of this strip. A third class of evidence more striking in its nature is that derived from wells. It is ascertained in this way that along the line of the Yahara valley, the thickness of the drift is from 200 to 300 feet, the surface of the bed rock being about 600 feet above the level of the sea, while on both sides of the line at distances of one mile or less, the rock surface beneath the drift rises 900 feet or more above sea level. By evidence such as this the course of the preglacial Yahara river is fairly well known. Its course and that of its immediate tributaries between Madison and Lake Kegonsa are shown on Plate XXXVII (map in pocket). Its upper course, above that part of its valley now occupied by Lake Mendota has not been so fully determined. It is known, however, that it embraced the valley now occupied by the Catfish river which enters Lake Mendota from the north.

Westward from Lake Mendota there is a continuous valley past the villages of Middleton and Cross Plains to Wisconsin river, that portion between Middleton and Lake Mendota being marked only by a sag in the drift which all but fills the preglacial trough. This valley was in part eroded by a tributary which flowed eastward to join the pre-glacial Yahara at Madison. The western and longer part of the valley was eroded by a northwestward flowing tributary of the Wisconsin. The headwaters of these two tributary streams flowing in opposite directions were separated by a low divide some 4 miles west of Middleton. The divide at that place was doubtless affected by a decided notch or col.

*Changes due to Glaciation.*—When the last or Wisconsin glacial epoch came on, the drainage was changed. The ice lay upon Wisconsin, except its southwest corner. It covered the Wisconsin river valley as far west as Prairie du Sac. It covered likewise the Yahara and extended for a time to the low divide west of Middleton. Both before and after this maximum extension, while the valley of the Middleton Tributary was blocked by the ice in its lower part, the water escaped from it by reversing its direction, spilling over the low col in the divide to the west and joining the Cross Plains tributary to the Wisconsin. While these conditions continued, the notch was cut so low that the very existence of a former divide at that place is now known only by other evidence. At the same time the valley near Middleton was to such an extent filled by moraine that after the departure of the ice the water continued to flow westward from about a mile west of Middleton. At the same time the Yahara valley was left partially filled with a rolling ground moraine, the swells of which subdivided it into the present basins.

*Suggestion of ice erosion.*—The possibility must always be admitted that the basin of Lake Mendota has been deepened by the erosive action of the glacier, so that its bottom may be lower than that of the pre-glacial stream valley. This process would be favored by the fact that the length of the basin lies in the direction of the ice movement; also by the fact that the basin is in the friable Potsdam sandstone. The very sandy mass of moraine of terminal aspect, at the west end of the lake is in harmony with this suggestion. Lake Monona has its length in the same direction and has at its southwest end a similar sandy moraine deposit. Lakes Waubesa and Kegonsa, on the other hand, lie in that part of the valley whose direction is in the main transverse to that of the ice movement. They are shallow as compared with Lakes Monona and Mendota. Lake Waubesa has in its lee no such morainic deposit, and it is not probably that the moraine south of Kegonsa owes its material to the lake basin.

In so far as the basins of Lakes Mendota and Monona were deepened by erosion, such erosion was probably limited to the slopes of the original valley and did not affect the channel. The latter was probably filled to a depth of at least one hundred feet. This is inferred from the data of wells. A few miles to the southeast the pre-glacial surface was found to be nearly two hundred feet below the surface of the lakes.* Similar depths of bed rock are noted near the southern shore of the lake on a line followed by a tributary to the pre-glacial Yahara.

The deepest part of Lake Mendota is an abrupt pit, eighty-four feet in depth, southwest of Governor's island. The depression has its length in a direction transverse to that of the ice movement, which was in a general way west by south. Its width from the rocky rim on its northeast side, seventy feet above its bottom, to the rim on its southwest side thirty feet above its bottom, is less than two hundred yards. Such a hole is not to be thought of as excavated by ice moving in a southwesterly direction. If its depth is due to this agency, there must have been local or temporary movement of the ice transverse to its general direction. Such variations of movement do occur. following the lines of well marked valleys. It is possible, however, that this depression represents the unfilled or partially filled valley of a pre-glacial stream, having on its east side a rock bluff, and that this portion of the trough was preserved, as transverse valleys sometimes are, by its temporary filling with fragments of ice. On this supposition the beds of pre-glacial streams lay lower than the bottom of the present lake, and however much ice erosion may have increased the capacity of the present basins, it did not increase their depth.

*Lake levels.*—As the early settlers found these lakes, the surface level of Lake Mendota was very little above that of Lake Monona, but later a dam was built which holds the water of the former lake five feet higher than that of the latter. The build-

* Thwaites, Fredrik T.

ing of this dam has had important effects on the shore features, as will be seen later. When water first filled these basins, the level of Lake Mendota, at least, if not of the others, doubtless stood at least as high as, or a little higher than the level of the present Mendota when dammed to its full height. The evidences by which such a fact may be known may consist of forms which have been either cut or built at levels higher than that at which the waves can now work; or the evidences may lie in materials appropriate to beach action and found higher than the present beach. As to the forms, some faint cliffs occur at the foot of the hills, both north and south of Six Mile creek, half a mile or more from the present lake shore. That these are indeed cliffs cut by the lake is made plain by bowlders which are strewn at their feet, as bowlder lines are now found at the foot of any active cliff in bowlder clay (see p. 33). The soil and vegetation on opposite sides of this line also show a contrast. The higher ground in which the cliff was cut carries oak forests, while the lower bowlder strewn ground bears only grass. A similar bowlder line is seen at the foot of the hill in the swamp behind University bay. None of these evidences indicate a former level more than two or three feet above that at which the present dam is capable of holding the lake. Other cliffs are found in abundance behind swamp lands, some of them so distinct as to be scarcely distinguishable from cliffs now cutting, but most of these do not lie above the present lake level.

### SHORES OF LAKE MENDOTA.

*Cliffs.*—While the lake has been losing in capacity by the falling of its level, and by retiring from its bays, it has on the other hand been extending its limits, along most of its shore line. It is to this wearing away of banks by waves and currents that the lake owes its fine cliffs. Probably two-thirds of the shore is thus wearing back at the present time.

At any well exposed headland on this lake where the waves are cutting back the shore, they are capable of cutting down the shelf which remains where the cliff once stood, to a depth of about twenty feet, that is to say, the wave-base for this lake is about twenty feet below the surface. (Ch. II, p. 26.) An examination of the hydrographic map of the lake will show that at the foot of most of the cliffs, the off-shore slope is comparatively gentle until the twenty foot contour line is reached, when it falls off suddenly to deep water. The outer edge of this shelf is the extreme limit at which the shore may have stood when the waves first began to cut the cliff. Probably most of the cliffs never occupied positions at the edges of their respective shelves. Many of these shelves have been broadened by deposit on their lakeward sides as well as by the cutting back of the land. Others may be altered from marginal shoals which existed when the basin was first filled.

Shelves or terraces formed by cutting alone may frequently be recognized by the nature of the material which covers their surfaces. If the cliff is cut in bowlder clay, the shelf will consist of the same material. In this case its down-cutting must be accomplished by the carrying away of such materials as the waves and currents are able to handle. The bowlders and cobble stones will be left in place but dropped to continually lower levels as the clay and sand in which they are embedded is eroded away. A dredge of the kind used in this survey, when dragged over such a bottom, rattles over the larger stones and only occasionally brings up gravel. The distinct shelves west of Picnic point and Second point are found to have such bottoms.

Not all the cut terraces of Mendota show their origin so distinctly by such a layer of heavy residual material free from finer stuff which might be handled by wave-and-current action. Down-cutting shelves may be temporarily covered with a sheet of sand, which is in process of transportation. The shelf may be swept clean and eroded only during heavy storms, or by storms from a certain direction, or it may never be free from such a sheet of moving sand. A considerable amount of vegetation may still further mask the significent features and obscure the real process. Where a cliff is seen to be actively cutting back, the shelf at its foot may safely be assumed to be cutting down despite temporary coverings of sediment, but the process of down-cutting is always more or less intermittent.

Cliff cutting in bowlder clay characterizes many miles of the coast. That on the northwest side of Picnic point is particularly active. The cliff is nearly bare of vegetation. Trees at the top have been undercut many feet. Large roots still projecting lakeward, show that when the trees were young, they stood a considerable distance back from the brow of the cliff. Eventually this process must destroy the point, possibly reducing it first to an island by eroding away its narrowest and lowest part known as the portage. The shelf which remains at the foot of this cliff has been mentioned as covered with heavy residual stones which reveal its origin as a cut terrace. In passing around to the southeast side, the character of the shelf changes. It is here covered with sand and mud supporting a rank vegetation. The outline of the shelf is in exact harmony with its origin, as indicated by its materials. The point has been cut back from twenty to forty rods on its northwest side where the heaviest storms beat; on the southeast side the cutting is less active. Before the currents can be turned to follow the shore, their momentum has carried them with their load far in an easterly direction where their energy is dissipated and the load must be dropped. The terrace on this side is therefore of the cut-and-built type (Fig. 15, p. 25). It is quite significant also that the outer edge of this eastward extension is a few feet lower than the edge of the cut terrace on the west side. It illustrates that the process of planning down a shelf to wave-base is necessarily slow, while the edge of a platform, which is being built of fine mmaterials, is constantly at wave-base.

The lake front of the city of Madison from Willow walk (near the outlet) to University bay is a cliff. The numerous piers now obstruct the shore currents and cutting is doubtless less rapid than formerly. The fine cliff at the University campus is now much protected by its dense covering of trees and undergrowth. Even without the protection due to vegetation, the cutting of such a cliff of glacial drift becomes more and more slow because of the bowlders which are dropped from its face and accumulate at its foot. (Compare Green lake, p. 156.)

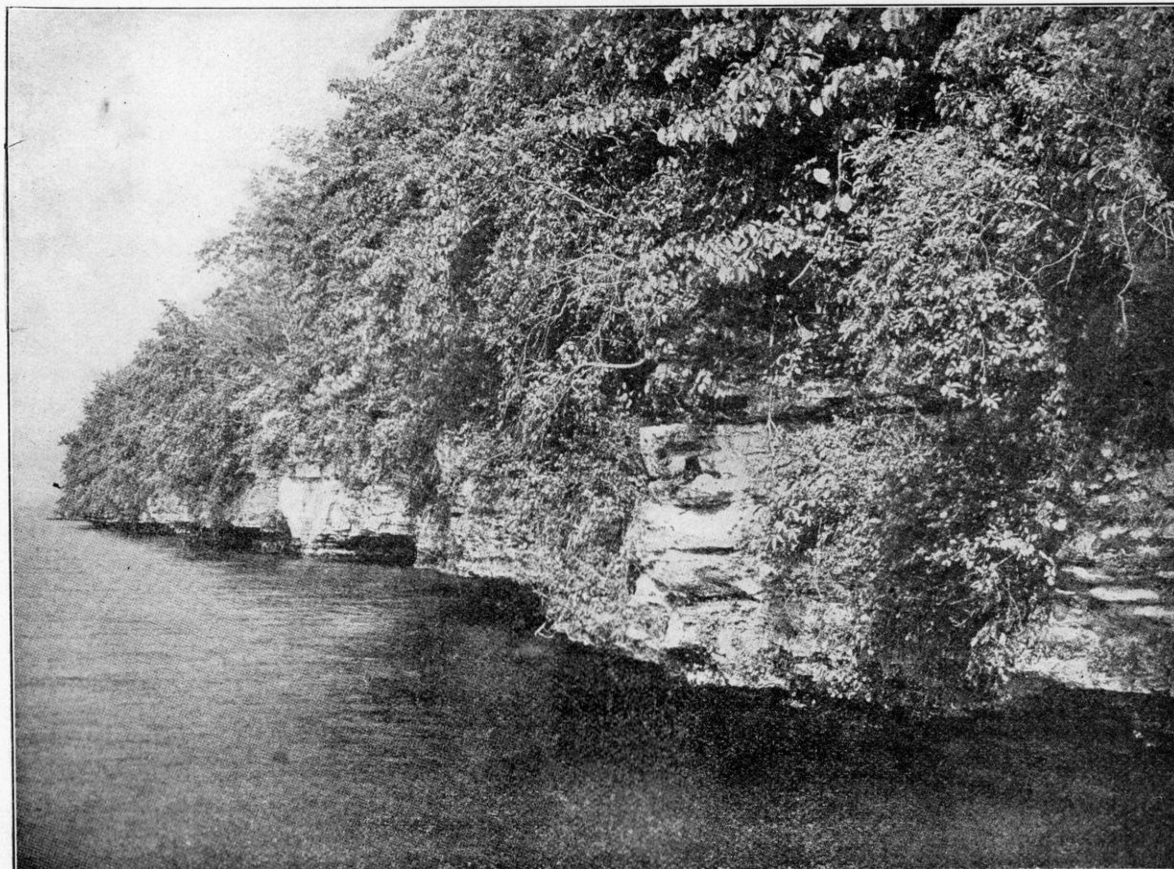
The effectiveness of this protection, both by vegetation and by bowlders, is said to have increased greatly in the last forty years. Previous to that period the wasting of the cliff had been the cause of some anxiety. This rapid recession was a temporary effect of the raising of the level. The horizon of wave action had been suddenly lifted beyond the beach whose form had become adapted to resist attack.

A fourth of a mile east of Second point, the style of bowlder clay cliff is varied by deep gullying; the same is seen north of Mendota beach. This gullying is favored in each case by a long back slope yielding a large run-off during rains and by an absence of forest. Both these conditions are fulfilled at all places on Lake Mendota where the cliffs are conspicuously gullied.

A very long and beautiful cliff cut in bowlder clay reaches from west of Fox's bluff to the flat which borders Six Mile creek. The distinct terrace at its base, which at a depth of fifteen feet gives way to a sudden slope into deep water, is of the cut-and-built type and probably in large part built rather than cut. When examined by dredging, it was covered with vegetation growing in sand. The glacial drift in and near Fox's bluff is very sandy and the material thus yielded has made a very shapely beach. Toward the north the terrace becomes more and more of the built type and broadens into the extensive shallow in and in front of Catfish bay. The edge of the terrace just north of Fox's bluff is at fifteen instead of twenty feet. This means that wave-base is higher here because of the protection from the strong west winds.

If the material in which the cliff and beach are being cut is rock, the bottom is not infrequently found to be covered with large fragments. Despite the apparent solidity of such a bottom, the shelf must suffer continual downward erosion to the wave-base. This is accomplished both by the abrasion of the fragments and the slow undermining of their foundations by wearing away the rock below.

Such beds of fragments cover the broad shelf which lies west and south of Governor's island. This shelf is nearly one-fourth of a mile wide. At its inner edge is a vertical cliff twenty feet high. It is impossible to affirm that all this was once a land area belonging to Governor's island. Probably the cliff never stood at the extreme edge of the shelf, but the whole bench has been cut downward by the process described above. No part of it is built terrace, at least in the vicinity of its steep front to the southwest. The whole has the same form and features which it would have if the cliff had been driven backward



Cliff at Eagle Heights, Lake Mendota. A youthful shore.

over its entire width. On the other hand, so great an amount of erosion would imply a perfection of beach development which does not now exist and does not appear to have existed before the raising of the lake level.

The phenomena off Maple bluff (Plate X and frontispiece) are identical with those off Governor's island, but the former, sixty feet high, cannot be cut backward so rapidly as the latter, twenty feet high; hence the shelf below is narrower. Its edge is also less sharply marked by a sudden change of slope, for the reason that the slope of the original bottom was but little more than that of the top of the cut terrace.

The fine rock cliff which stretches from Eagle heights to Merrill park (Plate IX) is seen to have at its base a comparatively narrow shelf, indicating that the recession of the cliff has not been great. Three factors enter here: (1) The greater resistance of the rock, as compared with the till cliffs at Picnic and Second points. But the rock is the same as that at Governor's island and Maple bluff where recession has been greater. (2) The height of the cliff. There is a contrast here with Governor's island but still not with Maple bluff. (3) The smaller fetch of the waves raised by the heavier storms from the west. On this point the conditions of cliff cutting at Eagle heights are clearly in contrast with those at Maple bluff.

Other rock cliffs appear at Livesey springs, West point and Farwell's point. At Livesey springs the weathering along jointing planes gives scallops of unusual beauty; at Farwell's point the falling of talus blocks has left the striking outline called "profile rock." (Plates VIII and VI, Fig. 1.) The freshness of this breaking suggests the rapidity with which cliff cutting is going on.

Governor's island is an approximately circular landmass about twenty feet high and fifty rods in diameter. On its lakeward or southern side it is composed of rock. The whole is covered with till and the northern half of the island reveals nothing else. It is now joined to the mainland on the north by an artificial roadway. The question at once suggests itself whether this island has been severed from the mainland by wave action or whether it was united by a bar which was subsequently followed by the roadway (see hydrographic map). It cannot be known with certainty that the channel behind the island is made entirely by waves and currents, but it has been enlarged by their action and the island may once have been joined to the mainland by a natural isthmus. The currents of the lake (at least at its present level) do not favor a bar in this position. That a large amount of cutting has taken place is evident from (1) the rapidity of cutting at present; (2) the rock shelf of almost one-fourth of a mile south and west of the island; (3) the small island called Rocky roost which, with the line of bowlders connecting it to Governor's island, has the appearance of a remnant of a larger mass whose finer constituent materials were eroded away leaving this pile of bowlders; (4) cutting of the mainland is now in progress on the west side to within two hundred feet of the roadway. The island is likewise being cut on its north or landward side. Similar accumulations of bowlders on the east side strengthen the inference. If the roadway followed the line of a natural bar there would be on one side a beach, on which shore drift would be in process of transportation by the same current which made the bar. If the roadway were removed today, currents would again sweep through the passage and widen it, instead of turning off from mainland to island (or the reverse), as is done by currents which build bars. (Compare Plate XXVIII, Fig. 1, Big Cedar lake.)

*Beach structures.*—The structures which Lake Mendota has built are no less significant than the cliffs which have been cut. The latter show the quarries from which much material has been taken, but this material has not been discarded in a disorderly way. Every foot of beach is a busy workshop where the stones dug or quarried from the cliffs are being broken up, assorted and even polished, ready to be used in building. The structures thus made are often of peculiar beauty. The exquisite curve of the beach west of Picnic point is not surpassed in grace by any line in architecture. (Plate XI.)

Much of the material cut from the cliffs has been used in building the subaqueous terraces already mentioned. Though hidden from view its function in its present place is very important. It has all been so disposed of as to make the paths of currents smooth and regular. It is only by the gradual perfection of this roadway that the lake is able to build those more impressive features which appear above the water. The clay from the cliffs has in large measure been carried beyond this terrace. Being easily held in suspension there is no definite limit to its distribution.

Of the third class of deposits, the distinctively beach structures, this lake has many and various forms. All stages may be seen from the bay-head beaches (Chapter II, p. 26) just beginning on an infant coast line, to old bars which are now being eroded away along with the cliffs from which they sprang.

The most infantile bit of coast on the lake is on the west side of Maple bluff, probably at the steamer landing below Cedar cliff. (See Frontispiece.) Even this coast had reached a more advanced stage of youth before the dam was built at the outlet. Its infancy has been renewed by the change of level. The water rose three or four feet against the vertical cliff so that large waves from the west no longer break but are reflected from the vertical or overhanging wall and lose their force and form in a choppy sea. Here there is not only no beach, but at places no shelf sufficiently near the water surface to provoke breakers and support stones within their grasp to be hurled against the cliff. The line of this cliff is serrated by more rapid erosion in jointing cracks. (See Plate VI, Fig. 2, and compare Green lake, Plate XXXI.) In these triangular recesses are seen the earliest forms of beach accumulation. They have been called bay-head beaches. The accumulations of detritus at this stage is slow. Temporarily they even favor greater erosion within the bay heads than upon the headlands, for their stones are used by storm waves to pound against the cliff. With the development of the coast, these short strands will be extended laterally and the gradually forming shelf at the foot of the headlands will come to retain stones within the grasp of large waves which will then form breakers and dash the stones against the cliff. With the exception of Devil's lake there is no other stretch of shore line so young in its cycle, on any of the lakes in eastern Wisconsin.

Slightly more advanced stages of the same features may be seen at some places on the south side of the bluff (Plate X), also at Livesey springs, and at places from Eagle heights to Merrill park. (Plate IX.) Along most of this fine cliff the development has gone still farther, so that a distinct shelf holds stones which are moved by breakers, while gravels are sometimes carried along shore between the heavier fragments. The same is true of the other rock cliffs, as West point, Farwell's point, Governor's island, and most of the south side of Maple bluff.

A type of structure representing a more advanced shore development is seen in the bars which have not yet been raised above water. One of these, more than a mile in length, stretches across Catfish bay.* The area of the bay behind the line of this bar was once larger than at present by one or two square miles. There was then considerable activity of waves and currents. They cut distinct cliffs at the base of the wooded hills which bound the present grassy swamps. These cliffs still remain, some of them a foot or more above the lake level at high-water and having bowlder lines at their bases. From the fading cliffs which lie above the present water level, the lake has long since receded. From other cliffs the lake has receded so recently that the roots of trees still stand out just as they were exposed by undercutting. This may be seen east of the Catfish river, where the widening swamp is now crowding the lake still farther from its former shore. That these cliffs whose cutting must have ceased within the lifetime of comparatively young trees, should now be separated from the lake by hundreds of feet or even yards of swamp is among the impressive things which emphasize the rate of vegetable accumulations when conditions have once become favorable. The swamp area is in part a delta formation of the Catfish river, but the upper layers are largely of vegetable origin. This accumulation is still rapid, making the swamp land less swampy and extending its area lakeward. Even since the building of the bar some currents of less strength continue to follow the shores within the bay. These and the pushing of the ice have built some poor ridges of sand, especially on the west side. On the east side for some distance north of the bar the waves are still actively cutting a cliff in very sandy drift.

The stronger currents, however, no longer enter the bay but cross it along the line of the bar. Their habitual course has

* This statement assumes that the lake is held at the full height of the dam.

Maple Bluff, Lake Mendota, in 1880. The beginning of beach development is seen in the accumulation of rubble at the right.

shifted even since the bar has been forming. This has resulted in building repeated ridges or shallows near the west side instead of a single linear embankment. The materials for this building have come in large measure from the long cliff stretching away to the southwest beyond Fox's bluff. As seen on the map the curve of the bar is a continuation of this line. The cliff at the east end, capable of yielding detritus for the bar, is now limited by the bay west of Governor's island. Its contributions, however, have the advantage of being more easily identified. The waste from the highly colored green layer of friable sandstone in Farwell's point is easily traced westward. Its disintegrated products recognized by their green color have been dredged from the bar west of its middle point.

In the main it must be supposed that the position of the deep channel which divides the bar into two parts, indicates greater vigor of bar-building from the west than from the east. That this channel is at times filled to a sufficient degree to allow the crossing of shore drift along the bar is proved by the presence of green sand from Farwell's point west of the channel. Such filling is only temporary, the lakeward current from the bay being sufficient to reopen the channel. The depth of the passage may be expected to vary with the dominant current. At times it has been found to be as deep as fourteen feet.

Over most of this embankment the water when at full height is still from one to two feet deep, but its building is probably rapid and, geologically speaking, the time is close at hand when this bar will be a beach and the bay behind will become first swamp and later solid ground. The crest of this bar is of irregular height; both horizontally and vertically it lacks the beautiful curves which characterize structures which are purely of beach origin. These irregularities suggest that when the level of the lake was low and much of Catfish bay was swamp, the pushing of ice against its grassy front added to the height of the beach. The ridge, where broad and indefinite, may owe much of its volume to the wrinkling exemplified in Plate XIII, Fig. 2.

Another bar, in every way similar, now spans University bay. The water over this line is generally less than six inches. The cliffs at both its ends are actively contributing to its building and it will probably assume the functions of the beach even earlier than the one in front of Catfish bay. The interest in this bay lies in the fact that the present bar building is the second attempt to simplify the shoreline in this quarter. When the shore currents were following shorter curves and penetrating farther into bays, they built a bar along the line of the present lake shore drive. This older bar was raised above water and had become the beach probably before the present bar began building. It is possible that when Picnic point has been entirely cut away, and the bay in front of the present bar has been still further shallowed, a new system of currents may build another bar still farther out.

The future appearance of the bars which now lie below the surface in Catfish and University bays may be seen in the fine beach west of Picnic point. This beach lies upon a bar which has been raised fully two feet above high water. It is thirty feet broad between the lake in front and the swamp behind. Its form in vertical cross section is true to the ideal diagram* and the curve of its shoreline is symmetrical and beautiful. (Plate XI, Fig. 1.) At its east end may be seen, side by side, the old cliff which was cut when the currents entered the bay, and the new beach which marks the simplified shoreline. (Plate XI, Fig. 2.) The common future of beach structures, if the cycle be not interrupted, is readily foreseen in this instance. Picnic point will disappear in a few centuries and leave the bar exposed to the waves. The shoreline will then not only be pushed back to its original position behind the present swamp, but will continue to recede while the cycle continues.

A similar beach ridge of long and graceful curve borders the head of the bay north of Maple bluff. Here, as in the case of the older bar in University bay, a part of the ridge has been altered for a roadway, but its original character is evident. At the southeast end, the old cliffs of the lake in its former extent are quite apparent.

Again at the west end of the lake a ridge nearly a mile in length runs south from Pheasant Branch. The constituent material of this ridge is more sandy, in contrast with the gravelly character of the others mentioned. This results from the sandy

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* See Fig. 18.

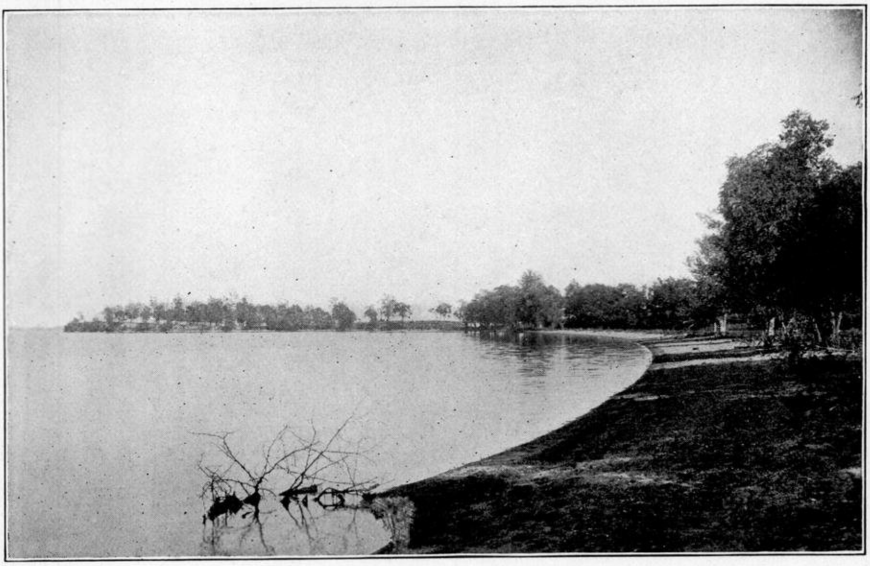

FIG. 1.

Beach west of Picnic Point, Lake Mendota, showing smooth curve. The fact of transportation along shore is emphasized by the accumulation of sand beneath the brush.

FIG. 2.

The same. The beach at the left is a new shore line in front of the old bay. At the right is an old cliff, cut when the currents were active in the bay.

character of the cliff to the south from which much of its material has been derived. The ridge is fully one hundred feet wide at its south end where its flat surface is covered with forest of oak and hickory and is occupied by cottages. The bay which was cut off by this former bar has advanced beyond the condition of swamp. It is a meadow or rather savanna having occasional trees overlooking broad fields of grass. The beach between Mendota beach and Merrill springs is of the same kind.

While the long beach ridge south of Pheasant Branch was built largely of the waste of the sandy cliff to the south, this process is now about at an end. The hydrographic map shows that the offshore slope is about the same in front of cliff and bar. The state of equilibrium has about been reached. Both are now about equally exposed to the waves. The cliff, while remaining steep from its recent cutting, is now receding slowly, if at all, so that a dense thicket is supported on its front. The beach ridge must be widening slowly, if at all. It sometimes receives large additions of sand on its front by the pushing of the ice, but these may be entirely removed before the next addition is made. In a comparatively short time, the shores of both highland and savanna will be experiencing the same degree of cutting or the same degree of filling.

Probably the shoreline most advanced in its cycle is at the east side of the lake, south of Maple bluff. For half a mile south of the steamboat landing at the golf grounds, is a low cliff, cutting rapidly in a narrow ridge of nearly pure sand. A spit has been built southward from this cliff in front of a small bay one-half mile north of the outlet (Fig. 20). This work was done by currents from the north and the growing spit might have been expected to span the bay as a bar; but the exposure to the west winds is such that the point of the spit was turned sharply into the bay, making a hook of acute angle. As is frequently the case with such hooks, the turn has been made at several successive stages of growth, thus making two or three hooks on the same trunk. A similar spit growing northward from the cliff south of the bay has been turned shoreward in a curve and united again with the mainland, forming a loop, enclosing a swamp. The advancement in the cycle is marked by the cutting away of the fronts of these beach structures. When the cliffs from which they grew held their positions farther to the west, the spits were built in continuation of the same line. With the recession of the cliffs comes the recession of the beach structures.

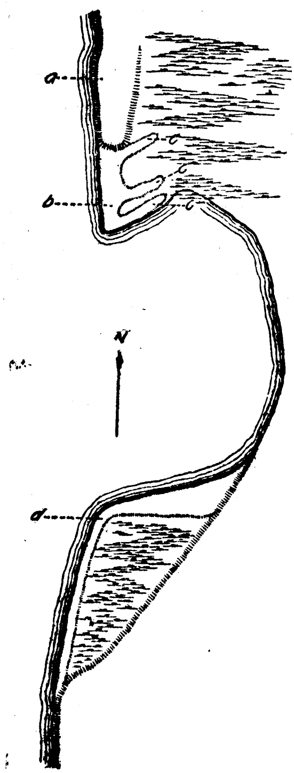


Fig. 20.—East Bay, Lake Mendota: a, Low and rapidly receding cliff in sandy material; b, Spit which is being cut back as the cliff recedes; c, Hooks formed by currents setting into the bay; d, Looped bar which has grown from the cliff on the south. Scale 6 inches = 1 mile.

This is especially marked in the one from the north, which springs from a cliff of sand; trees which have grown upon the spit are now undercut and falling into the water. When the line of cliffs and beach ridges has been pushed back a little farther there will be no bay and no necessity for spits and bars. The transient character of beach structures is well illustrated here.

Ice ramparts are seen in typical form on this lake. Many

FIG. 1.
Ice push, Lake Mendota, February, 1899, showing ice overriding the shore.

FIG. 2.
The same, showing ice pushed into the cliff of bowlder clay. The undercutting of trees shows recession of the cliff.

of them were renewed and enlarged by the powerful pushing of the ice in the spring of 1899.* (Plates XII and XIII.) Those on the east side of Picnic point rise at places ten feet above the lake. The trees upheaved in their making, which continue to stand with roots exposed, or to lie in disordered positions are calculated to excite the attention of the most indifferent. Equally picturesque results were produced west of the pier at the state hospital for the insane. Older forms of the same type are seen north of Morris park, and at various places for short distances.

An illustration of a different sort is found at Willow walk. This is a ridge extending a fourth of a mile south from the outlet to a low cliff, cutting in the till. For a part of this distance the ridge lies between the lake and a swamp below the lake level.† The adjacent lake bottom is strewn with bowlders and cobble stones. The ridge is composed of similar heavy stones and is primarily an ice rampart, though a portion of its north end is artificial and the entire ridge has been increased artificially to serve as a dam. In this case the bowlders have been gathered by the ice from the bottom of the shallow margin. It will be observed that this rampart lying between lake and the former swamp and united at one end to a cliff, has the exact relations of a spit. This is by no means uncommon; a similar one projects northward on the east side of Governor's island, and another heads westward across the mouth of Pheasant Branch creek. (Compare Sheboygan swamp, page 145.) Its origin has nothing in common with that of spits except that each indicates the path of shore currents. The lake in its early high stage doubtless covered the present line of Willow walk, as well as the flats to the east; but the same low ridge of ground moraine which is now parallel with the shore, farther south, extended as a shoal to the outlet. This shoal was cut down by the erosion of its transportable materials leaving its surface covered with large stones. As the level of the lake sank with the cutting down of the out-

* E. R. Buckley—Ice Ramparts. Transactions of the Wisconsin Academy of Sciences, Arts and Letters, Vol. XIII.

† In the improvement of Tenney Park, this swamp has been connected into a lagoon.

let, these stones came within the grasp of the ice which pushed them shoreward into a ridge. The cliffs to the north and south continue to retreat and the shoal in front of the rampart continues to cut down. Willow walk has the same tendency to shift its position to the east, which is seen in the beach ridges adjacent to East bay.

*Transportation beyond wave-base.*—Along a considerable portion of the shore of Lake Mendota there is a distinct marginal shelf or terrace. This belt slopes outward gently to a depth varying from fifteen to twenty feet. Its width varies from a few rods to nearly half a mile. At its edge begins a steeper, sometimes very steep, descent to the depths of the lake, This marginal shelf is in part cut terrace and in part cut-and-built. Where it results from cutting alone its surface is strewn with the heavier stones which could not be removed by the currents but have been let directly down by the erosion of the sand, sandstone or bowlder clay on which they rest. This is well illustrated on the north side of Picnic point where the cliff and shelf are cut in the drift; also on the southwest side of Governor's island where the cutting is in the Potsdam sandstone. Where the shelf is of the cut-and-built kind it is covered either at its edge or over its entire width with finer materials, brought by the currents and undertow. Examples of this kind are seen east of Picnic and Second points and off the coast of Morris park.

The existence of the well marked edge of the shelf shows that the processes concerned in its making come to a definite stop at a depth of fifteen or twenty feet. The cause of this stop is interpreted to be the inability of the waves to agitate the fine particles at greater depth. Beyond this line the processes associated with the shore do not operate. So far as they are concerned (shore currents, wave action and undertow) the deeper bottom beyond twenty feet would be mantled with a continually thickening sheet of mud.

Dredgings show that such a uniform sheet of mud does not exist at depths beyond wave-base.* The change from sand to

* Most of the dredgings on which this discussion is based were made by Mr. Chancey Juday, for the Wisconsin Geological and Natural History Survey.

mud occurs at some places at depths from forty or fifty feet. On certain spots large gravel stones or even bowlders are found at like depths.

At a few points the front of the terrace is so steep that stones may be supposed to have descended under the influence of gravity with little help from the movements of the water. Such a slope is found off Picnic point where the steepest gradient is one foot in six or eight feet (see hydrographic map). Here gravel stones one-half inch in diameter were brought up from a depth of fifty-five feet, but the action of gravity on a steep slope cannot be invoked because the gravel is found at least ten rods beyond the foot of the steep slope. The shoal off Second point has on its east side a very steep descent where sands and gravel are found more than fifty feet deep. On the west side of the same shoal these materials which show the power of water are found from twenty to forty rods beyond the foot of the steep slope and resting on a comparatively level bottom. The shoal west of this one shows similar phenomena, bowlders at a depth of twenty-three feet, cobble stones at forty-five feet and coarse gravel at more than fifty feet on a slope so faint that rolling under the influence of gravity alone cannot be supposed. The shoal west of the outlet shows similar stones at nearly fifty feet on a nearly level bottom. Perhaps the steepest slope in the lake is at the front of the terrace southwest of Governor's island. It descends to a hole eighty-four feet deep, the deepest point in the lake. Not only does the sand cover the front of this steep slope to its bottom, but it is found on the ascent beyond the hole up to a depth of seventy-eight feet, beyond which mud prevails on a shallower bottom.

The gentle slopes of the bottoms from which many of these coarser sediments were dredged excludes the supposition that they were brought here through quiet water. Nor is it supposable that these materials represent the undisturbed original bottom of the basin. The constantly accumulating sheet of mud must, under all ordinary conditions, have been far thicker than necessary to hide all the gravels of the original bottom. There remain two possible explanations of their presence: (1) That they were carried to their present position by deep currents. (2) That they are residual material out of which the finer constituents have been washed by deep currents. The first supposition is favored by a suggestion of gradation in the size of the stones as the water becomes deeper. Bowlders were not definitely located at a greater depth than twenty-three feet (on the shoal between Eagle heights and Fox's bluff), and sands were generally found beyond the limits of gravel. The determination of this gradation was not very decisive as the presence of the larger stones could be known only by the behavior of the dredge which could not lift them.

The supposition that the stones found are residual material from which the finer constituents have been eroded, requires less vigor of circulation than the above supposition, because currents of less power would suffice to carry away the finer constituents. It is probable that this is the dominant process though it would be impossible for either process to go on without the other. If the heavy stones found near some of the well formed marginal terraces are habitually transported by currents it is difficult to see how the neighboring shelves themselves can preserve their forms. It is safe to say that the activity of the deep currents of Lake Mendota is *at least* great enough to erode the finer constituents from the gravel. It is highly probable that in this process the heavy gravels themselves suffer some movement.

These deep currents are the necessary correlative of the wind drift at the surface. The corresponding return currents may at some time and in some lakes be at the surface but this horizontal circulation is relatively rare. When the return is by vertical circulation the lower member may be a uniform sheet moving in a direction opposite to that of the surface member; or the irregularities of the shore and bottom may make the movement of the sheet very unequal and may give to it locally almost any direction or any intensity.

The investigations on temperature conducted by Dr. Birge point to the conclusion that when the lake has a strongly marked direct thermal stratification, as in summer, when the temperature of the water varies inversely with the depth, there is little or no circulation of water at the bottom due to wind currents or any other cause. The lower member of the circulation does not reach the bottom and the form of the current would not be influenced by bottom topography. It is when the lake is homothermous that the currents may reach the bottom. Their power at such times would probably still be very small if not concentrated along certain lines by the influence of an irregular bottom topography and shore contours. That such concentration does take place is shown by the local nature of the stony deposits on the deeper bottoms and the prevalence of fine mud even at smaller depths. Such concentrations might well be expected at the foot of shoals, and this is where the stony sediments have been most noticeable. The end of Picnic point would be expected to show similar evidences of erosive power, which it does. The front of the shelf southwest of Governor's island is also favorably located.

SHORES OF LAKE MONONA.

The shores of Lake Monona have much the same aspect as those of Lake Mendota. The only differences which appear are those which would be expected from its smaller size. Wave action is less vigorous, hence cliff cutting is less rapid and the faces of cliffs are more densely overgrown with trees and underbrush. An additional reason for less vigorous cliff cutting lies in the fact that the level of Lake Monona has not been raised by a dam. (Compare Lake Mendota, page 45.)

The hydrographic map shows that the descent to deep water, where this is at all abrupt, begins at a higher level than it does in the larger lake. This indicates that wave agitation becomes ineffective at a less depth. If the shelf at the inlet of Lake Monona be compared with the shelf off Morris park, a part of Lake Mendota equally protected from the strongest winds, it will be seen that the former ceases at a depth of ten feet, the latter at fifteen feet. It is probable that such small and shallow bays as those on the south side of Lake Monona would long ago have been spanned by a bar, had they occurred in the larger lake. Such conclusions, however, are always venturesome, because of the difficulty of predicting the exact form of a current after a series of rebounds.

Along almost the entire frontage of the city of Madison from the crossing of the railroad tracks almost to the inlet, the lake lies against a high shore of glacial drift. Though classed as a cutting coast, it cannot be said to be actively retreating now, for much of it is protected by artificial structures which are renewed as fast as they are worn away by water and ice. This lake front is more used than that of Mendota and the numerous piers obstruct the movements of shore drift, causing local accumulations. These structures themselves, of course, receive the destructive wear which would otherwise be performed upon the shore; if not repaired from time to time they would finally disappear and the shoreline would resume its retreat.

The marginal shelf for a width of forty to eighty rods may be classed as cut terrace. Out to a depth of ten feet its surface carries stones too heavy to be transported by currents. As in all such cases this indicates merely that the shelf has been cut down; it does not follow that the whole area was once land. This shelf at its northeast end is continuous with the distinctly built terrace in front of the inlet. (Compare map of Mendota from Morris park to the inlet.)

The highland at Elmside has suffered much wasting by the waves and this process still continues active, but the bench at the foot of the cliff is nowhere covered with heavy residual stones. Some of these must lie embedded under the marginal sands. They have no doubt been at times uncovered, but they are now concealed beneath a sheet of sand. As the offshore depth is diminished by this sheet, the cliff must retreat with ever increasing slowness.

When the lake was new, the Yahara river entered a considerable bay, which covered the area of the present flats on both sides of the inlet. This bay was no doubt shallow from the first. The currents which ran across its front were scattered and irregular drift rather than concentrated currents, and built no well defined bars. The load which they carried was spread out in the finely marked marginal shelf, extending outward to a depth of ten feet. In the filling of some bays, the bar is the initial factor, causing stagnation of the lagoon behind, which in turn favors its filling by vegetation. This bay was sufficiently shallow so that vegetation flourished without the protection of a bar, and the ridges which now appear near the shore of the marsh came into existence only after the rising surface of the marsh and the falling level of the lake made ice push possible. They are ice

FIG. 1.
Newly made ice rampart, Lake Mendota, February, 1899.

FIG. 2.
Effect of ice push on marsh deposits.

ridges built of such fine bottom deposits as the currents could transport among the rushes and other vegetation. Near the highlands which limit the swamp both east and south, these irregular ridges unite into single well defined ice ramparts containing many bowlders, showing that the bottom within reach of the ice has at one time been bowlder strewn. (Compare Willow walk, Lake Mendota, p. 55.)

Beyond Elmside, the shore turns to the southeast and is low and sandy for nearly a mile. Starkweather's creek enters here through a swampy flat, similar to that which borders the Yahara river. Here again the swamp is fronted by a ridge. For purposes of study it is to be regretted that the making of the wagon road has for some distance obscured the original features of this ridge, but the larger part remains unaltered and clearly distinguishes the ridge in form and origin from those west of Elmside. In this case bar building was the initial step in converting the bay into a land surface. Beach action is here well developed, partly, no doubt, because of better exposure to the prevailing winds. A strong bar was built southeastward and another came to meet it from the opposite direction. The growth of the embankment from the northwest was so vigorous that the mouth of Starkweather's creek was crowded farther and farther southeastward. The creek now turns at a right angle and flows for one hundred and twenty rods parallel to the shore before it succeeds in entering the lake. (See hydrographic map.)

Going south beyond the stream for more than half a mile, the shore again comes to be against a cliff cut in drift; but before the shoreline meets the hills, a former cliff may be seen to the east beyond a strip of flat ground. The old cliff is best seen south of the ice houses which stand on the flat between it and the present shore. This flat consists partly of a very broad beach ridge of sand and gravel five or six feet above the water, and partly of a narrow strip of meadow between the ridge and the old cliff. The base of the cliff is now at least five feet above the lake. It is not safe, however, to conclude that the lake was five feet higher for the meadow itself has been raised by the accumulation of muck.

Beyond the highland mentioned above, and the small bay whose shore is marked by an ice rampart in front of a low valley, is the cliff at Allis's. This is one of the few places where the waves of this lake are cutting in rock. The adjacent marginal bottom shows the features of a cut terrace, that is, a rocky bed out to a depth of six feet. Doubtless the same feature would be seen continuing further out to deeper water if not covered by the work of terrace building. The rock disappears before Keyes' spring is reached.

Southwest of this spring is another area of lowland, in front of which a massive tree-covered beach ridge extends for some distance southwestward from the cliff spoken of above. At its widest point it reaches one hundred feet but it narrows to a single ice rampart of bowlders which continues for sixty rods to the next cliff. This part of the shore has had a different history. The presence of these bowlders pushed up from the adjacent bottoms where others still remain shows that the shore at this place is at least not receiving permanent deposits. It is possible that these bowlders lay on the original surface of a shoal, but it is more probable that the shoal has been suffering downcutting, leaving a larger proportion of heavier stones than was found on the original surface.

From this point to Winnequah the shore is one long cliff cut in till and continuing to cut, though not rapidly. Slowly wasting till cliffs are nowhere better illustrated. This one is almost all forested and its deeper parts are covered with dense undergrowth. At its foot is the characteristic bowlder line. The adjacent bottom which has been cut down to allow the waves to attack the shore is strewn with bowlders and cobbles, which could not be carried away.

South of Winnequah a peninsula of swampland extends into the outlet bay. Its position suggests that it is a wasting and not a growing form. It is fronted by a ridge reaching from Winnequah far around into the bay; but this ridge is not a curving bar behind which an area once lake is being converted into dry land; it is a rampart, containing heavy stones, which were left on the marginal bottom in the process of downward erosion and subsequently pushed onshore by the ice.

At intervals all around the outlet bay are feeble ridges fronting the swamp land. They are for the most part pushed up by ice and are composed largely of muck. On the south side, however, is an old spit, now a good beach ridge, which supports an elm tree two feet in diameter, showing that the ridge must have maintained its position for a long time.

West of this in the slight reentrant opposite the peninsula on the north side, is another evidence of a former higher level. This consists of a bowlder-strewn area similar to those described on Lake Mendota. (See page 43.) Without doubt it indicates a former shore, but not more than two feet above the present level. (Compare Turville point and the Monona Assembly grounds.)

West of this the till is resumed and soon attains the same character which it has at Winnequah. The terrace at the foot of Raywood Heights, for a considerable distance from shore, is strewn with heavy residual stones.

At Ethelwyn park, the Mendota limestone comes down to the water and makes a rock cliff. It is thin bedded and easily broken up; it is being actively eroded by the waves and the shelf at its foot is covered with fragments. The existence of a rock hill in the pre-glacial topography doubtless determines this salient curve. The reentrant just east of this headland similarly corresponds to an old erosion valley; a well at this place was sunk forty feet without reaching rock.

The head of Turville bay west of Ethelwyn park (see Plate XIV, Fig. 1) is approaching the stage where vegetable filling will proceed at an accelerated rate. Rushes and pond lillies now prevail, but cat-tails are coming in at the edges, and sedges and grasses will soon follow. (See Plate XXVI, Fig. 1.) At the middle of the west side is a highland of steep slope, which comes down to the water at one place in a cliff. This same steep slope when followed north or south has the form of an old cliff behind a flat terrace five feet above the lake. No bowlders are found at the foot of the steep slope and in their absence the form cannot be definitely regarded as cut by waves.

Farther north on the east side of Turville point, the old level two feet above the present has left its familiar marks in faint cliff and bowlder line. The massive ice rampart which stands on the northeast side of this point is among the finest seen on any lake. The name "rampart" seems peculiarly appropriate when the form is viewed here in its typical development. The point is of low ground and the ridge rises abruptly on its inner side, five feet or more. The height from the outer side is, of course, greater. Age has smoothed out the crags and ruggedness which characterize the recently upheaved forms on the shores of Lake Mendota.

The ridge of which the Monona Assembly Ground occupies the northwest end has a hummocky topography. It presents a moderately steep slope toward the lake and its base is for the most part cutting. Where the rise from the water is gentle, the push of the ice has been effective in raising ramparts.

Beyond Murphy's creek is another hill with a shore of similar character. When the lake stood at the higher level indicated at Turville point and west of the outlet, it entered a bay between these two hills. The base of the hill in the Assembly Ground was then vigorously cut. Standing on the west end of this hill, the result of this cutting appears in the contrast between the north and south slopes. A similar cliff was cut at the east end of the hill beyond Murphy's creek. In a curved line between these two cliffs, was built the broad low ridge, now seen just east of the wagon road. The present beach ridge connects the present cliffs with an almost straight line.

The bay at the west end of the lake is necessarily cut off from active circulation. On this account and by reason of its small depth its life must in any case be short as compared with that of the lake as a whole.* This tendency to early death is greatly increased by the construction of the railroad tracks which complete the isolation of the bay from the circulation of the lake. The width of the flats along its border measures the amount of shrinkage which the water surface has already suffered. An old cliff which was once cut with vigor, lies south of the road, just west of the South Madison station. Another is seen west of the street going south from Greenbush. The present shore line has ridges similar to those mentioned around the outlet bay. They owe their origin chiefly to ice.

* Since the making of this survey the shores of this bay have been much improved artificially by dredging and the filling of swamps, thus counteracting the natural processes tending toward extinction.

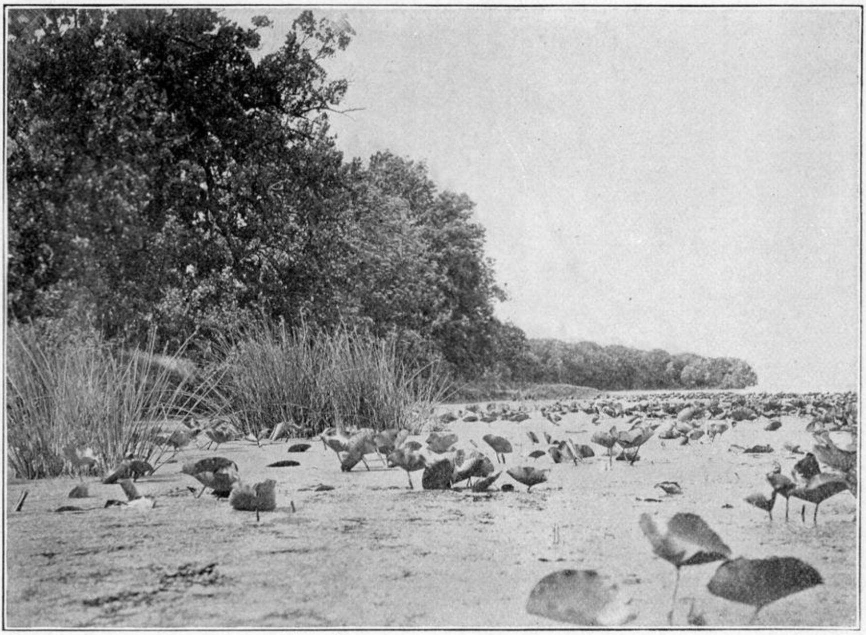

FIG. 1.
Shore of Turville Bay, Lake Monona.

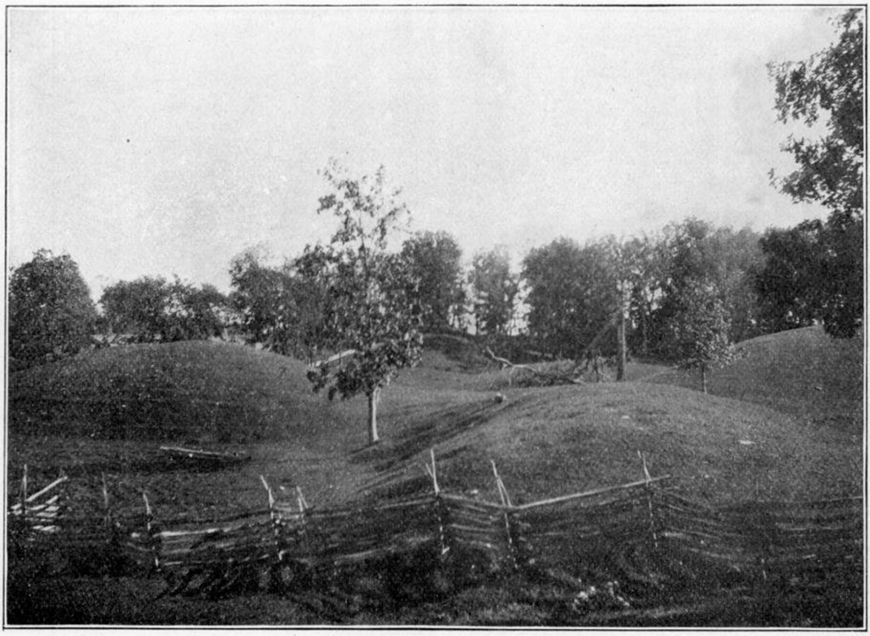

**FIG. 2.**
**Kames** west of Lac La Belle.

## ORIGIN OF LAKES WAUBESA AND KEGONSA.*

*Origin of the lake basins.*—The map of the bed rock surface (Plate XXXVII, p. 178) in the vicinity of these lakes may be considered as fairly representing the topography of the area previous to the glacial period. Erosion of the rock by the ice itself doubtless made minor changes of form. To the extent of these, the map here shown is inaccurate as an expression of pre-glacial topography, but the appearance of the rock itself does not indicate that it was profoundly eroded by the ice. A greater discrepancy lies in the pre-glacial cover of soil and rock waaste. This was probably thin on the hills, while in the valleys it may locally have been several scores of feet. It may fairly be compared to the soil cover in the driftless area of southwestern Wisconsin.

The valley of the former Yahara is seen to follow in a rough way its present course. On its northeast side were isolated hills, one of which rose to 987 feet, while on the southwest it was flanked by a considerable upland, much of which rose above 900 feet. Well borings show that the valley bottom was at least as low as 630 feet near Lake Waubesa.. It is probable that this represents almost the maximum depth of the valley.

The ice overrode this area from the northeast, deploying as it advanced so that near Madison the movement was more west than south, while over the basin of Lake Kegonsa the movement was almost due south. In the main the Yahara valley was crossed approximately at right angles and was therefore filled with drift. This condition prevented the deepening of tributary valleys from the northeast, although the movement of the ice was essentially in the direction of their axes. In reascending the slope on the southwest side of the Yahara, the best conditions for ice erosion within the area were found in the tributary valleys up which the glacier advanced. A moderate amount of erosion may have been thus accomplished.

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* This entire account to the close of Chapter III is an abbreviation of a report by Mr. Fredrik T. Thwaites. "Geology of the vicinity of Lakes Waubesa and Kegonsa, Dane County, Wisconsin." Manuscript, University of Wisconsin Library. Plate XXXVII (p. 178) is also the work of Mr. Thwaites.

North of the upland which lay south of the Yahara valley and including the site of Lake Waubesa, the ground moraine is marked by many drumlins and swamps. On the bold northward edge of the upland the deposit of drift is relatively thin and the dominant features of the topography have survived since the pre-glacial time. The belt thus characterized includes Lake Kegonsa. While the ice in its extreme advance went some miles to the south and west, for a considerable time its front stood just south of Lake Kegonsa, practically on the summit of the ridge or overlooking its south slope. Here it built the Milton terminal moraine.

Lake Waubesa occupies a portion of the old Yahara valley where the trend was most nearly south and where, therefore, the liability to drift filling was least. (See map, Pl. XXXVII.) The maintenance of a deep valley if not actual ice erosion was further favored here by the entrance of a considerable tributary from the southwest (Pre-glacial Waubesa Creek). East of the junction of these streams the Yahara valley was narrow and its course transverse to the ice movement. It therefore received a deeper filling of drift, which now constitutes the dam making the shallow (36 ft.) basin of Lake Waubesa.

The exact conditions attending the making of the Kegonsa basin are less satisfactorily known because the pre-glacial topography on its east side has not been determined in the same detail. It is, however, like Waubesa, a mere local enlargement of the old Yahara valley which was exceptionally broad at this place on account of two tributaries from the west. The basin is but 31 feet deep below its dam of drift, its bottom being therefore, hundreds of feet above the old Yahara channel.

## SHORES OF LAKE WAUBESA.

This lake has an area of 3.2 square miles and a maximum depth of 36 feet. Its shores are characterized by an alternation of drumlins and swamps, the former nipped by cliffs, the latter usually fronted by low beach ridges. The lake's work on its shores is practically done and but little cliff cutting or building of beach structures remains for the future unless the water level be artificially raised. This cessation of work is due in part to a fair degree of harmony between existing contours and the lake's movements, brought about by the work of waves and currents in eroding headlands and building new beaches. In addition, the natural aggression of vegetation, aided by a gradual and probably small fall of level is further impeding and weakening both waves and currents. Most of the cliffs are losing their steepness, and most of the beach structures are known by trees growing on them to be at least one or two centuries old.

Following the shore from right to left, beginning at the outlet, an ice rampart fronts the low island between the natural outlet and an artificial channel to the north. This rampart continues northward to the drumlin against which the lake continues slowly to cut its cliff and which is already in large part removed by the waves.

North of this cutting cliff the work of ice is again shown, in a natural cordon of bowlders (see p. 33) protecting the shore from further cutting. This merges into an old rampart, which separates the lake from a peat swamp three or four feet above the lake level.

At Edwards Park is the only rock cliff on the lake. Here the waves continue a slow cutting in the Madison sandstone. At the north end of the park a four-foot cliff is cut in till at the top of which is the remnant of an old rampart now being undermined by the waves.

North of the railroad is a great extent of marsh, whose level is near to that of the lake. All this was once a part of the lake, a diminishing remnant of which still exists as the "Lower Widespread" and the "Upper Widespread." Before the railroad was built, shore currents from the southeast made repeated attempts to cut off this northward extension by bars. A number of the resulting unfinished structures of sand lie roughly parallel to the railroad and it appears that the track itself took advantage of the largest. (Compare the north end of Lake Kegonsa where no railroad has been built.) These structures doubtless owe much of their height to ice-push.

On the west shore, fronting both the island south of the railroad and the swamp on the north, the ice has raised a series of similar low ridges of sand. These must antedate those parallel to the track, for they are the result of an almost east-west push, in exerting which the ice must have been braced against the higher ground east of the Lower Widespread. A still older chapter in the lake's history is recorded by the bowlder line which at places lies behind these ridges on the west side.

A massive ridge, the combined effect of beach and ice work spans the bay in front of the swamp south of this island. Beyond this is a high cliff of till, covered with trees and underbrush, which at the same time preserve the cliff from wasting and indicate that cutting at its base has practically ceased.

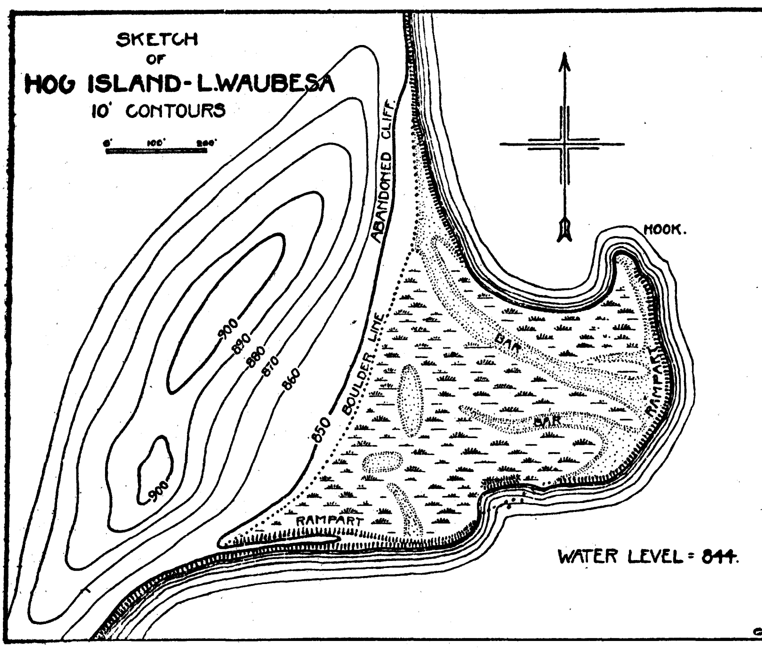



Fig. 21.—Hog Island, Lake Waubesa.

The history of the so-called Hog Island (a peninsula) is an epitome of the history of the lake. The oldest record is that of cliff cutting against the drumlin (see Fig. 21) which lies just west of the peninsula. At that time the water stood slightly higher than at present, currents followed the base of the hill, and the extremity of the present peninsula was marked by a shoal. (Compare Colladay's Point, Lake Kegonsa, p. 74.) The falling level brought the stones of the shoal within the grasp of the ice which crowded them up into a rampart which being above water formed the beginning of an island. The south bound currents no longer able to follow the old shore, took a new course toward the new island, building an imperfect bar. The same process was begun by east bound currents on the south side. In both cases the bars were deformed by ice-push and the original rampart or "island" on the shoal continued to grow by the same agency. Lastly swamp took possession of the area enclosed by these features.

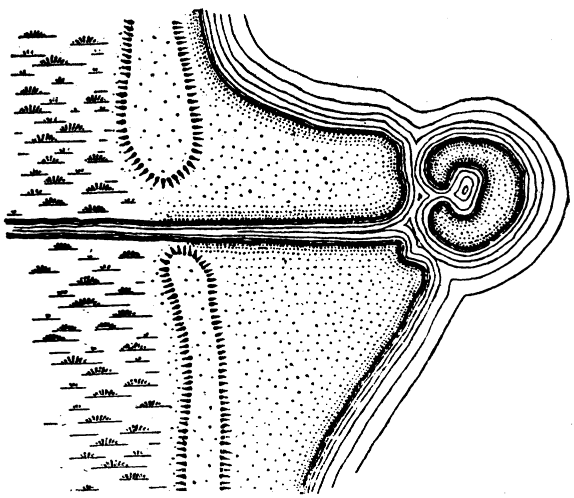


Fig. 22.—Delta in Lake Waubesa.

The broad reentrant curve south of Hog Island shows the usual ice-made ridge fronting a swamp. At one point the rampart is breached by a small stream which drains the cultivated fields to the west. So much sediment is carried by this minute stream that it has built a delta about 100 feet into the lake. This delta has the characteristic triangular shape (Fig. 22) of such deposits, formed on a previously straight shore in water not affected by currents. The apex of the triangle in such cases points lakeward and the stream enters the delta at the middle of the base. The opposite position, represented by the Nile delta and commonly thought of as typical, requires an original indentation of the shore and currents alongshore which smooth the delta front and limit its protrusion.

Passing the cliff in the sandy till of the next drumlin, another low shore is reached which repeats the features of the one just passed. The accumulation of soil from the cultivated lands to the west and south has raised the level of this marsh almost a foot. While this process is aiding the reclamation of the swamp, it illustrates the rapidity with which the soil of certain kinds of drift may wash away when conditions are favorable.

On the steep shore south of Brams Point, (an old cliff now protected by the shallowness of the water and the presence of rushes,) is a terrace some 5 feet above the lake, probably illustrating the principle of the ice-push terrace (p. 34). A similar feature is found against the island near the railroad. Brams Bay, south of this highland, had formerly a considerable extension inland. At that time cliffs were cut both in the drift on the north and the sandstone hill on the south. These latter cliffs now overlook land abandoned by the lake. The ridge in front is largely the work of ice.

South of this point rushes become more and more abundant and the structures begun near the old shore have been transferred to positions successively farther lakeward, the directions of ridge-building also changing with the changing habits of the currents. The feeble currents are not now able to prevent the accumulation of muck offshore.

The lake once covered the whole area of the marsh to the southwest extending to the township line, where the peat surface is at places from 10 to 15 feet higher than the lake level, thus covering the ancient shorelines. Rock cliffs formed a part of this old shore, but they are now covered by their own waste and that from the hillsides. Some very large springs, issuing from the Madison sandstone, are found on the banks of this marsh. The site of this marsh represents the pre-glacial "Waubesa Creek," a tributary of the old Yahara.

East of this marsh at "Watercress Park" the shore for some distance is occupied by cottages standing on an old and broad sandy rampart, behind which is the former cliff. The headland at Sherlock's springs (in part at least of drumloidal origin) and the marshes south and north of it, repeat the features already described in similar topographic relations. The marsh on the north side shows the not uncommon phenomenon of a belt of open water separating swamp from higher ground. It has been variously explained, sometimes as due to fires which could advance only so far as the peat was dried, and again attributed to the death of swamp plants in dry seasons.

Bordering the outlet on the south is a drumlin against which cliff cutting still continues. One-half mile farther southwest a drumlin indenting the water's edge forms the most exposed headland on the lake. Bowlder lines around its base show that it was once an island. The ridge stretching eastward from the north end of the drumlin, while in general an ice rampart, involves an unusual condition by reason of which the bowlders of the drumlin were carried eastward after the manner of the growth of a spit. This condition seems to be found in the eastward pushing of the ice, tangent to the north end of the hill. Agreeing with this explanation are the indefinite form of the ridge and the fact that where the rampart turns north its composition at once comes to be of finer materials, such as might have been pushed up from the shallow bottom.

The swiftness of the Yahara river at the outlet is in marked contrast with the torpor which is beginning to affect the lake. Despite the many bowlders in its channel which are able to retard its cutting down, it is probable that this process has been effective to the extent of a foot or more since the lake's origin. Some two miles below the outlet, the stream has cut down to bed rock. An examination of the geological map shows that it here crosses a remnant of younger formations reaching as high as the Lower Maagnesian, on both sides of which the underlying rock is Potsdam. Through one of these side passages the pre-glacial Yahara flowed. Before Lake Waubesa can be drained by natural processes, therefore, it is necessary that the Yahara should corrade its channel downward into this pre-glacial hill as deep as the bottom of the lake.

It is not improbable that the mill dam once maintained about 2 miles down the stream maintained the lake's level at an elevation slightly above that at present. The reconstruction of a simple and inexpensive dam raising the lake's level by one or two feet would in large measure restore the youth of the shores and greatly retard the progress of encroaching vegetation.

SHORES OF LAKE KEGONSA.

This lake is somewhat larger than Waubesa, having an area of 5.3 square miles with a maximum depth of but 31 feet. It is nearly circular, thus having less occasion to simplify its shoreline by the cutting back of headlands and the building of bars. While the higher lands bordering Lake Waubesa are generally drumlins, those on the shores of Kegonsa are of preglacial origin but veneered by drift. An exception to this is the terminal moraine on its south side. It has fewer swamps than its northern neighbor, and, having fewer bays and freer currents, it is less affected by weeds.

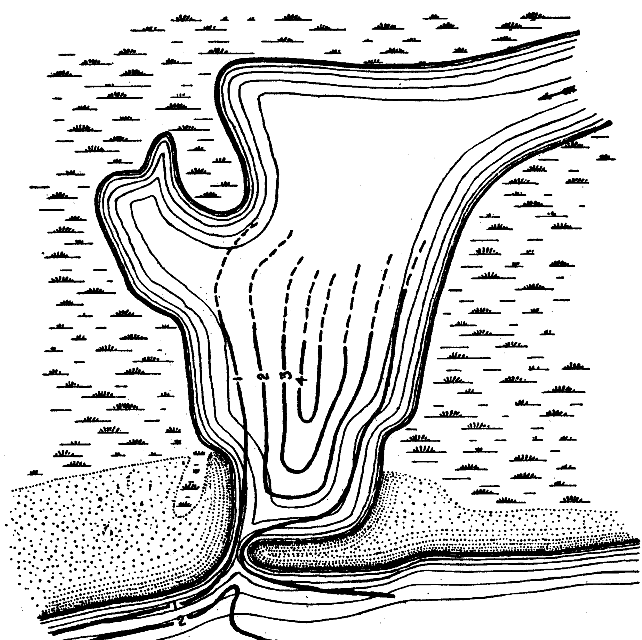


Fig. 23.—Mouth of Door Creek, Lake Kegonsa.

Beginning at the inlet, the mouth of the Yahara river is seen to be shifted far to the east by the prevailing currents which shift the sand and gravel in that direction, yet less than a quarter of a mile to the east, the mouth of Door Creek has been similarly crowded westward. (Fig. 23.) The latter shows in a characteristic way the continuation of the bar beneath the stream forming a kind of shallow sill over which the stream escapes, while preserving a much greater depth behind it.

For nearly a mile in front of the wide Door Marsh the waves have built a fine sandy beach ridge from 2 to 3 feet above the lake level. A subordinate ridge on its front shows that it is still receiving additions. The minimum age of the main structure is indicated by a basswood tree 3 feet in diameter, which grows upon it. This ridge which now constitutes the shore was not the first attempt made by the waves to cut off the former northward extension. Two previous attempts are now represented by long spurs parallel to the coast and lying in the marsh behind. Both are massive and the inner one heavily wooded.

Just east of Door Creek and extending outward from the beach, is a small peninsula which originated as a shoal, but which with the gradual falling of the lake level came within the grasp of the ice. It was then pushed up into a ridge above water. The change of shore currents so as to go around this ridge instead of behind it resulted in swamp filling which now unites the ridge with the shore. (Compare Hog Island, Lake Waubesa, p. 68.)

On the eastern side of Door swamp, the old cliff, cut in rock when the lake covered that area, is well preserved. The relations between old cliff and new shore line at this place are the same as those illustrated in Plate XI, Fig. 2. South of this is a low till cliff, now being cut but faintly, fronting one of the most beautiful parts of the entire shore. The materials of the beach at its foot are largely derived from the low limestone cliff at its south end. The peninsula at this cliff owes its existence to this outcrop of thin-bedded Lower Magnesian limestone.

Turning eastward at this point, the shore is marked by ice ramparts where the slope is sufficiently low to admit of yielding before the expanding ice, but shows an actively cutting cliff against the higher ground. The materials of this cliff are carried eastward in a bar which has deflected the mouth of the small stream some distance to the east. South of the outlet, where the railroad skirts the shore, the gravelly beach is in the main artificial but as the Lake Kegonsa station is approached, old ramparts now being cut by the waves are again encountered.

A short distance west of the station begins a long cliff which comprises almost the entire south shore. It is cut, for the most part in bowlder clay, but in part also, in the stratified drift which is found somewhat plentifully in association with the terminal moraine which rises south of the lake. The low peninsula near its west end is due to the form of the underlying rock. The cliff is normally cutting slowly if at all, being protected by a natural bowlder line. At a few places, these bowlders have been removed in the "improvement" of grounds, with the result that cutting began anew. The unusually high water of 1905 likewise had a general tendency also to renew shore erosion. As usual where the lakeward slope is sufficiently gentle, the pushing of the ice has thrown up ridge. Almost the whole south shore is occupied by summer cottages.

A creek from the west enters the lake through a small marsh at the southwest corner. The road along the shore at this place seems to follow a natural ridge made by waves and ice. Barbers Point to the north, a rock hill containing a quarry, and the low ground lying south and west of Colladay's Point show only such features as are common to such topographic relations.

Colladay's Point, the most striking features of the west shore, lies on a ridge of Mendota limestone which extends about 1 mile in a direction east by south and includes the outer shoal shown on the hydrographic map. This point may represent an original exposure of the rock above water or it may have been a shoal close to the surface. In either case it owes its present height and shape to the work of ice. The ridge now surrounds a lagoon. The coarse angular limestone fragments on the beach may all be derived from the structure itself, or may in part have been brought from the limestone cliff to the northwest.

A fine gravel beach fronts the lowland north of this limestone cliff. This type of shore gradually passes into a high till cliff heavily overgrown with trees and brushes, one of the few spots on this lake not altered by man. A lower cliff to the northeast gives way to the spit of coarse gravels whose eastward growth has shifted the Yahara inlet to the east.

A gently cutting shore, Lake Geneva.

# CHAPTER IV.

## LAKES GENEVA AND DELAVAN.

Lake Geneva has a character which is peculiarly its own. It has an almost complete rim of high wooded slopes with a notable absence of swamps on its borders. Its waters are deep, clear, and cold. It is large enough to allow of vigorous waves which show Nature's power as well as her beauty. This opportunity for wave action has given rise to a variety of shore features which have much scientific interest as well as scenic charm.

Lake Geneva is probably the most widely known summer resort in Wisconsin, the natural result of its rare beauty and its accessibility to large city populations, especially to that of Chicago. Its banks are already largely appropriated to the purposes of summer residents. Each year a temporary population of some thousands is to be found in the cottages, hotels, villas, and veritable palaces, which occupy its shores. Steamers, public and private, may be numbered in dozens, and row boats in hundreds. This development as a resort has been followed by the establishment of annual conventions whose popularity has enhanced the fame of the lake. The Yerkes observatory belonging to the University of Chicago, is located west of Williams Bay. This point affords not only the present natural advantages of a clear atmosphere, but also the reasonable hope that the atmosphere will not in the future be clouded with smoke.

### GEOLOGICAL RELATIONS.

The Niagara limestone underlies the eastern part of the lake basin and the country on the north, south, and east of the lake. It is so deeply buried, however, by the drift that it is rarely reached even by deep wells. Near the Narrows it is found at a little more than one hundred feet below the lake level. Between this point and the city of Lake Geneva it is reached by a very few wells about fifty feet deeper.

At various places the drift is firmly consolidated into sandstone or conglomerate. This is reported from a few wells as sandstone. It is also seen as coarse conglomerate in the cliff at Camp Collie and in the gravel pits at Fontana. West of the Narrows on the south side it appears at the water's edge as a ledge of hard gritstone.

West of the lake lies a narrow north and south belt of Hudson river shales, likewise deeply buried by the drift. The basin of Lake Delavan lies wholly within this belt, which is here less than three miles wide. This narrow band of shales sends an extension to the east to meet the western end of Lake Geneva. This strip extending eastward indicates that the overlying Niagara limestone was eroded away along the line of the lake valley by a stream which probably flowed westward.

From the erosion of the Niagara limestone along the line of the lake valley, it might seem to be a fair inference from the geological map alone that the present lake valley is a pre-glacial river valley, blocked by the drift. The history of the lake basin is, however, somewhat complex, involving the work of two distinct epochs of glaciation known as the earlier and later Wisconsin glacial invasions. The ice of the earlier Wisconsin epoch moved in a westerly direction through the pre-glacial Geneva valley, building a ridge of terminal moraine at the west end of the present lake. In the later Wisconsin epoch a small glacial lobe some 35 miles in width occupied the angle between the Green Bay and Michigan glaciers. (Plate II.) This smaller glacier is known as the Delavan Lobe.* In the vicinity of Lake Geneva the ice of the Delavan Lobe moved almost south. It built the high terminal moraine which borders the lake on its south side and curves around to a northerly direction at both ends of the lake. At the west end this terminal moraine is superimposed upon the older ridge mentioned above. After building

* Alden, Wm. C., The Delavan Lobe of the Lake Michigan Glacier, Professional Paper, U. S. Geol. Survey, No. 34. The history given here of Geneva and Delavan Lakes is in the main based upon Dr. Alden's account.

this ridge (the Darien moraine) the ice front retreated from four to six miles northward, and halting again, built the Elkhorn terminal moraine. Between these two ridges the basin of Lake Geneva remained unfilled. The fact that it was not filled by outwash when the front of the glacier stood at the inner ridge may indicate that the drainage from the ice went in other directions or that a remnant of ice occupied the basin. Except for the gravel terrace on which the village of Lake Geneva stands, the shores of the lake do not have the topography characteristic of basins preserved by icy blocks. (See p. 4.)

Lake Como, two miles north of Lake Geneva, occupies a shallow basin in a longitudinal trough in the Elkhorn moraine. Delavan lake lies in a valley similar to that of Lake Geneva, but having its length in a northeast-southwest direction. In this vicinity (four miles northwest of the west end of Lake Geneva) the two moraines of the Delavan Lobe have a northwest-southeast trend, crossing the old Delavan valley almost at right angles. They, therefore, form two dams about four miles apart, between which is an unfilled remnant of the old valley, the Delavan lake basin. The filling of this basin by outwash from the glacier was probably prevented, at least in part, by the presence of an ice block, for at places both the material and the topography of the shores agree with those of basins formed in this way. For the most part this basin is bounded by the strip of ground moraine which intervenes between the outer and inner terminal moraines of the Delavan glacial lobe. This strip reaches to Lake Geneva and embraces a part of its north shore.

### SOURCES AND OUTLETS OF LAKE GENEVA.

The water of Lake Geneva is derived partly from springs, which discharge immediately into the lake, and partly from numerous small streams which deliver the water of other springs a short distance away. The village of Fontana is well named for its abounding springs. One small group issuing within a radius of a few feet furnishes fifteen horse power to a mill a few rods distant. These and the many other springs at Fontana unite their waters into the clear cold stream which enters the lake at its western end.

At certain places lines of springs issue from the base of a bluff at a considerable elevation above the lake. On the north side of the lowland at Fontana and the west side of the lowland north of Williams Bay, such lines of springs or seepage lie from thirty to forty feet above the lake. In each case the result has been an accumulation of peat on a slope below the seepage line. This peat now forms a terrace ten to twenty feet high of varying width up to some hundreds of feet. The one which lies west of the road for a distance of three-fourths of a mile north of Williams Bay is especially perfect, having a gently sloping top, a steep front, and a perfectly definite upper boundary at the foot of a steep wooded bluff. This bluff is so steep, even close to its foot, as to suggest some recent or continuous agency cutting at its base. Such an agent could be none other than the spring water issuing from the sands or gravels at that line. This combination of cliff-like slope and terrace bears a striking resemblance, except in materials, to wave-wrought features.

The outlet of Lake Geneva is to the northeast through the White river, a stream of considerable size and eroding power. If allowed to do its work uncurbed this stream would steadily cut down its channel and reduce the level of the lake. Up to the year 1836 the stream had succeeded in cutting down to a level six or seven feet below the present surface. At that time a dam was put in, which has since held the water at its present level. Seasonal variations have an extreme range of a little more than two feet.

The lake has left no distinct record of a level higher than that of the present high water mark, hence the amount of cutting which the outlet accomplished previous to 1836 cannot be definitely known to be greater than the six or seven feet which the dam has replaced. Here, as in other cases, it was found convenient merely to refill the notch which the stream had cut, thus causing the waves to renew their attack upon the shore at the horizon where the earliest cliffs were cut and the first small beaches built. As viewed from the railroad bridge east of the dam, the narrow valley cut by the outlet is very clear. The stream here meanders between bluffs about one hundred and twenty yards apart.

SHORES OF LAKE GENEVA.

The shore processes of Lake Geneva are being carried on vigorously; probably more so than would have been the case had the water always stood at its present level. Before the outlet had cut its notch in the rim, cliffs were being cut at nearly the same places where cutting is now at work. The farther these cliffs were cut back, the broader became the terraces intervening between the cliffs and deep water. The broadening of these terraces meant increasing hindrance to incoming waves. The continuation of this development at the same horizon leads inevitably to a weakening in the cutting of cliffs. The energy thus taken from cliff cutting was expended in cutting down the shelf. When the level of the water fell waves were obliged to spend all their energies upon the platform which they had built, cutting down its level and carrying its materials out to deeper water. When the level was restored the water at the foot of the old cliff had therefore a greater depth than it would have had without the intervention of the lower stage. The renewed attack was therefore made with greater energy. It is before the vigor of this second advance that cliffs are now retreating, for sixty-five years have not been sufficient to exhaust the advantage whch was being stored up while the waves were at work on the cutting down of the terrace.

The cutting shores of Lake Geneva largely predominate over the building shores, though cutting is not so nearly universal as it once was. The cliffs vary in freshness from those whose fronts are as bare and steep as the side of a new railroad cut,* to gentle grassy and wooded slopes at whose base there is almost an equilibrium between erosion and deposit.

The south face of Camp Collie was until recently one of the first class. This point is well exposed to all winds not northerly.

* Mr. Beckwith of Lake Geneva, a surveyor of long experience, finds that a comparison of recent surveys with the government survey of 1835 indicates a recession of certain high cliffs of fully one rod. Many of the land-marks of the former survey are unsatisfactory and the work was often inaccurate, but the evidence from a considerable number of comparisons is consistent.

Shore currents moving by it are narrowed and accelerated, and their transporting power is thereby increased. Hence the shore drift removed should exceed that which was brought, but a pier of piles, though unable to resist the pushing of the ice, has checked the transportation of shore drift and retarded the cutting at the base of the cliff. The cliff was formerly quite bare and as steep as the uncompacted till could lie. Weathering tends constantly to reduce this slope and vegetation is constantly striving to gain a foothold but the efforts of both were neutralized by the ceaseless sawing away of the base. But for the protection afforded by the boulders which fell from the face of the cliff and formed a line at its base, the retreat of the cliff would have been much greater. This wall of defense has been re-enforced by artificial breastworks of stumps and brush, all of which contribute to the stability of the promontory and delay the progress of its destruction. Trees and bushes are now beginning to protect the cliff from weathering. Between the foot of this cliff and the descent to deep water, is a platform which is the stump of the former headland, widened a little perhaps by the waste of the cliff. This platform is covered with heavy stones which offer little suggestion of beach transportation, but the relations of a neighboring beach ridge, to be mentioned later, show that the transportation of lighter gravels along shore is effected between these larger stones.

Cedar point, east of Williams bay, is similar in form and features to Camp Collie on the west. An occasional cliff on the south side of the lake is equally raw, and one just west of the Narrows notably so. Black point near the center and Manning's point at the east end are so improved and artificially protected by walls that their natural cliff faces do not appear.

Along most of the shore, not hereafter mentioned as building, cutting shores are the rule, though such raw exposures as the one just described are exceptions. The long cliff between Camp Collie and the west end of the lake is interrupted at places by flats a few yards or rods in length. The bluffs behind these low areas are often quite as abrupt as are those at the water's edge, the flats being laid down by the waves in the crenulations of a former cliff. When the lake first began to do work upon its shore, cliff cutting was practically universal. It was only after

Camp Collie, Lake Geneva.

some labor had been spent upon the making of a beach (Ch. II, p. —) that cuttign was abandoned in the small reentrants and concentrated upon the salients. These old cliffs now stand like deserted diggings behind the accumulations of later activities. They are records of the lake's pioneer work. Another cliff, cut in a more youthful stage of the shoreline may be seen east of Glenwood Hotel about one-fourth mile east of the mouth of Fontana creek. This cliff is forty feet high and its steepness is not much reduced by weathering since the time when the water stopped cutting at its base. It is now several rods from shore, the shoreline being cast in larger curves. The south shore of the Narrows is against a broad flat, with a former cliff lying several hundred feet behind. The flat will be considered later, among forms due to deposition.

In the case of a lake so youthful as Geneva (in its new cycle inaugurated by the building of the dam) it may well be assumed that a large part of the material already cut away from the headlands has been used in the construction of the shelf necessary to the beach profile. Only a part has been carried alongshore and built into structures which are visible as wave-built forms. But these deposits are nevertheless large and the forms thus built are among the interesting and attractive features of the lake. The forms best illustrated on Lake Geneva may be described under the heads of bars, hooks, cuspate forelands and wave-built terraces.

The large bars of Lake Geneva are all now raised above water and have become parts of the coast, the bays cut off being filled to the stage of swamp or meadow. With the exception of one instance to be mentioned under hooks, there are now no considerable embankments in the unfinished form of spits. The reentrant curves of suitable size and conditions to be spanned by bars in the present stage of the lake's development are already abandoned in favor of the broader curves upon which the completed bars lie. The remaining bays, such as Williams, Geneva, and Buttons, are too large, deep, and open to currents, to be attempted by the bar-building agents at the present time. The four large bars now dividing the lake from swamp or meadow are respectively at the west end, the head of Williams bay, the head of Buttons bay, and at the south curve east of the Narrows.

Their features and histories are so similar that a somewhat full description of one will make detailed accounts of the others unnecessary.

The beach at the head of Williams bay lies on the lakeward slope of a massive bar. There has been additional filling for the wagon road which follows the bar, but the volume of some hundreds of loads of gravel is very small in comparison with that of the broad ridge whose foundations are deep down on the original bottom of a once longer bay extending to the north. The ridge of gravel thirty or forty feet wide lying above the lake on the one side and the peaty meadow on the other is by no means the measure of deposit along this shore. Deposition began as a subaqueous bar on the bottom of the old bay some feet below the present water level, and the slope of the structure is so gentle that its base is now many hundreds of feet in width.

The material for this structure has come from the south along both sides of the bay, largely from the cliffs of the bay itself. Some, no doubt, has been enabled by currents of changing direction, to round the capes at Camp Collie and Cedar point and may have come a long distance from the east or west. That the material has come from both directions is shown by its greater coarseness near the ends with increasing fineness toward the center. The winds which cause currents to move north on one side would generally, though not always, cause a current in the same direction on the other side. This forestalling of horizontal circulation makes a strong undertow the only means of return. This drags the finer stuff far lakeward, leaving well assorted gravels to be added to the broadening beach. The laws which govern profiles will not suffer that any great advantage or disadvantage go long uncompensated. In this case the great strength of inbound currents on both sides of the bay gives to the undertow its unusual power, an advantage in carrying sediment lakeward. On the other hand the large amount of sediment dragged out into the bay has greatly reduced the slope upon which sediments must now be carried lakeward, thus favoring the deposit at the margin.

The fine beach at the west end differs but little from the one just described. The bar has probably been completed more recently. The bay behind is less advanced in its transformation to solid ground. The offshore slope has not been reduced to the same low grade by bottom deposits. All its differences may be due to the fact that the task was larger by reason of the greater depth of the basin and the greater width of the bay. There is somewhat more opportunity for horizontal circulation and a less absolute dependence upon undertow for the return of the water of incoming currents. The mouth of the small stream which enters the lake at the middle of this beach is not notably turned to either side, indicating that the supply of shore drift from north and south is about the same.

Buttons bay at the east end once had a long eastward extension. It was never so deep as Williams bay and the currents have been able so to alter the shore as to leave but a wide open reentrant curve where once was a deep reentrant angle. The mouth of the stream which enters here has been carried many rods to the north by the excess of shore drift from the south, or rather from the west. This excess of drift from the west is but the obvious result of the shape of the lake and the dominant westerly winds.

A short broad beach line across the hollow on the west side of Camp Collie is identical in form with the larger bars described. It is interesting on account of the abrupt change at its east end from its pebble-covered front to the stony shelf and bowlder line at the foot of Camp Collie cliff. As the pebbles when coming from the west must go somewhere and when going west must come from somewhere, it is plain that beach transportation is at work among the heavy stones, on the shelf whose appearance contains little suggestion of such a process.

The wide lowland east of the golf grounds (on the south shore one-half mile southeast of the Narrows is separated from the lake by a bar of somewhat different aspect. For most of its length from its eastern end, its appearance is similar to that of the bars already described. It is narrower, however, for reasons which are related to the broad, open form of the curve. The currents accommodate themselves to the curve, suffer little check by lateral expansion, and hence are not now widening the beach at a rapid rate. Behind the west end of the bar is an open lagoon which receives the waters of several small streams. This lagoon indicates that the features of this coast line are more recent than the corresponding features in the bays above mentioned. The bar here is broken by two passages, evidently kept open by the flood waters of the small streams entering the lake. (Fig. 24.) Despite these passages, however, shore drift is transported both east and west upon the front of the bar. Violent storms disregard such passages, temporarily completing the bar of traveling drift. (Compare Lake Mendota, p. 51.) At intervals the passages are reopened by the stream currents. This is a process associated with the typical barrier, a feature which is not often exemplified in the small lakes of Wisconsin.

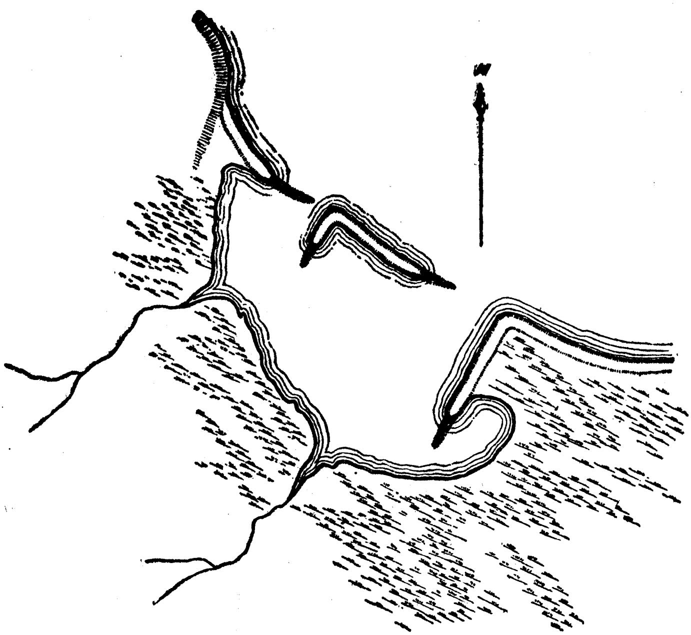


Fig. 24.—Hooks on south side of Lake Geneva. Scale 10 inches = 1 mile.

Where the northwest ends of the segments of this bar are terminated by the passages, they are turned at right angles in a southwest direction into the lagoon. (Fig. 24.) These hooks are the work of alternating currents, driven by onshore winds. The material has first been brought alongshore from the southeast, without which supply the end of the hook could not grow. Transportation in the opposite direction is attested by the spit which stretches southeast from the raw cliff at the golf grounds. This cliff is in line with the bar. The work of southeasterly currents is also shown by the submerged points heading across the passages in that direction. These points are of coarse gravel and cobbles, much heavier than the material from the southeast which has built the hooks.

Most of the bars described are becoming wider by the accretion of layers upon their lakeward sides; this process tends to broaden the ridge into a flat topped band, but there are certain parts of the shore where instead of this continuous widening the construction of one beach ridge is followed by the building of others at small intervals farther and farther to lakeward.

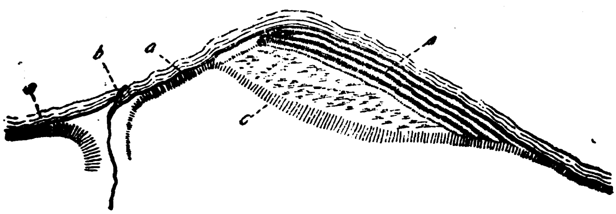



Fig. 25.—South side of the Narrows, Lake Geneva: a, Actively cutting cliffs; b, Mouth of stream turned eastward, showing the prevailing direction of shore drift; c, Steep slope marking original shore line; d, Wave-built terrace. Scale 3 inches = 1 mile.

The most noteworthy instance of this process is on the south side of the Narrows. Curiously enough, the effect of currents through this constricted passage has been to build the shore outward, narrowing the passage still further. (Fig. 25.) The dominant currents are from the west. A stream one-half mile to the west has already been deflected eastward and will be much more so when the present shoal pointing eastward from its west bank has been raised to the level of the water. At one time the bluff of the south shore was washed by the waves on its east side as it now is on its west side; but the strong currents following the shore from the southwest failed to make the turn to the southeast with sufficient promptness to carry their loads of drift close to shore. The first result was a shoal line, or broad subaqueous embankment, several hundred feet from the shore and stretching almost to the golf grounds. Later the processes which raise bars above water (see Chapter II, p. 28) converted this line into a beach. A second ridge was built later in front of the first, and then a third and a fourth, the whole making a terrace at least one hundred feet wide, with the crest of the second ridge six feet above water. Between the terrace and the old cliff the resulting swamp is rapidly becoming solid ground. The northwest end of the wave built terrace is being cut away as the cliff west of it recedes. At the same time the broadening of the outer ridge on the northeast side proceeds. Thus the foreland which indents the lake from the south is shifting eastward. Similar areas embracing a fraction of an acre, or at most several acres, are found at various places.

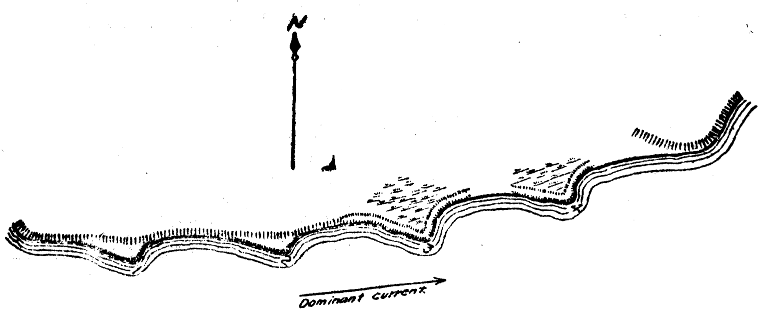
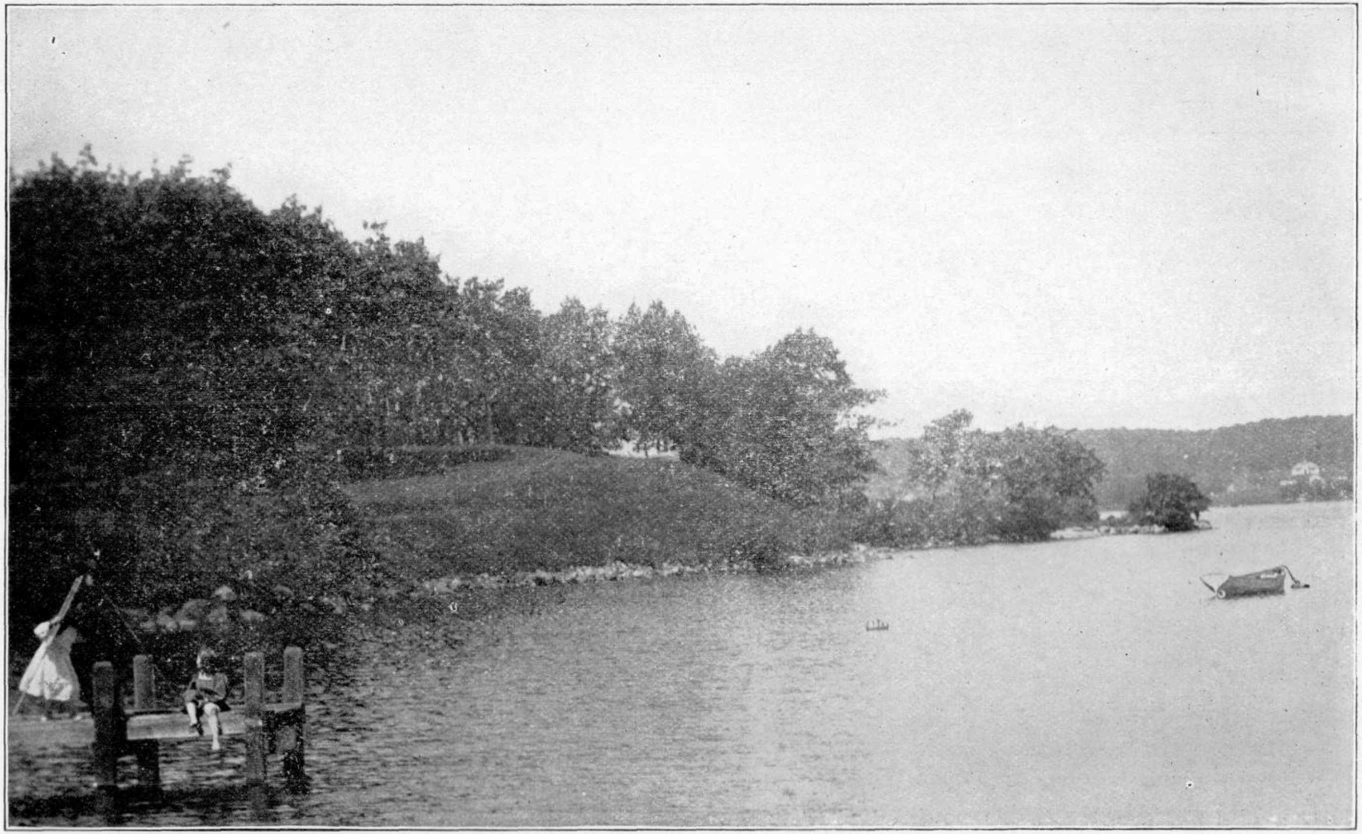



Fig. 26.—Cusps on north side of The Narrows, Lake Geneva: The third and fourth show beach ridges fronting low ground. The first and second have been altered for private grounds. Scale 3 inches = 1 mile.

A portion of the north shore beginning at the narrows and extending to the east is marked by a series of flat forelands whose form and regularity of interval entitles them to be treated as cusps or "cuspate forelands."§ (Fig. 26.) This designation has been applide to accumulations of drift in outstanding points whose position and form are determined by waves and currents instead of by the initial contour of the shore. It is also sometimes implied that these points of accumulation recur rhythmically. In the case in hand the points occur at nearly equal intervals, beginning with one-fourth of a mile at the narrows and increasing slightly toward the east. Four cusps appear of normal form and rhythmically spaced. At the place where the fifth should be expected is a headland whose horizontal plan is about

§ Gulliver, F. P., Shoreline Topography.—Proc. Amer. Academy of Arts and Sciences, Vol. 34, p. 180.



Lime Kiln Point, Lake Geneva, looking west. The flat point is a looped bar enclosing a swamp. The bluff on its left is the original shore.

the same as that of the cusps. A sixth and a seventh foreland which were built by the waves appear after successively longer intervals. There is not much evidence that these last owe their location to the requirements of rhythm. Most of these cuspate forelands have been much altered as private grounds. Those which have not been so altered are, in the main, V-shaped bars probably of the type described by Gilbert,* behind which is lower ground extending back to the original shore. The combination of currents and eddies leading to the formation of this series has not been worked out in detail. Studies of similar forms on the coasts of larger lakes and estuaries point to their very general association with currents through elongated passages.† Among the lakes described in this bulletin there is no other passage affording such favorable conditions for a series of cusps as does this one at the narrows, and there is no other example of rhythmically arranged forms.

Lime Kiln point (Plate XVII) east of Marengo park is a looped bar built mainly by currents from the east. In this case the volume of the ridge has been increased by the work of ice which has added to it bowlders from the marginal bottom. The original direction of the bar's growth was, no doubt, north of west. The bar was then turned to the south where it again joins the mainland. This turning to the south has been effected at three successive stages at intervals of a few yards, thus making a triple ridge on the west side of the point.

The work of ice in the formation of ramparts is visible at many places. No well formed ramparts extend for long distances, because there are no long stretches of coast having a shape favorable to their formation. (Chapter II, p. 33.) Gently sloping coasts capable of being pushed up into ridges by onshore shove, are interrupted by steep cliffs which successfully withstand the pushing. Occasional short ridges are so generally distributed, especially along the north side, as to make their enumeration inconvenient and unnecessary. Many short beach ridges along the generally cutting coasts are also deformed by the pushing of the ice.

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* Lake Bonneville, p. 57 and Plate VII.

† Gulliver, *loc. cit.*, p. 216; also Gilbert, *loc. cit.*

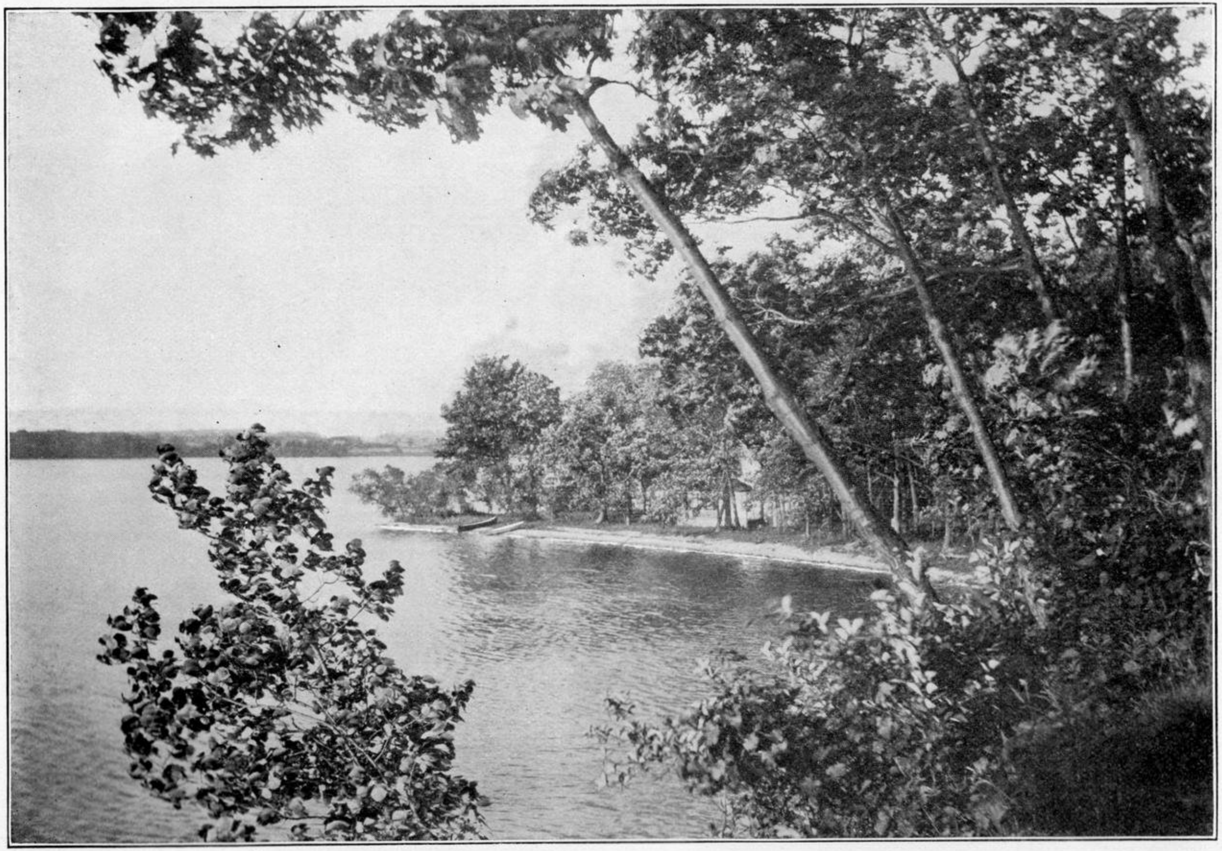
SHORES OF LAKE DELAVAN.

Delavan lake is fed chiefly by Jackson creek, which enters the north end of the lake. Its outlet continues the line of the inlet in a direction south of west. The general aspect of its shores is somewhat different from that of the shores of Geneva. The gravelly nature of the banks and their moderate height have enabled this lake to pass rapidly through the youth of its shorelines. A good beach profile is the rule, though the process of beach transportation is generally carried on among the heavier stones which have fallen from the cliffs and strew the surface of the beach below.

Cliff-cutting is still the prevailing feature of the shores, but abandoned cliffs appear at a considerable number of places, where currents are now depositing. For example, active cutting once extended almost around the peninsula which indents the southwest end. Now it is confined to the side which faces the open lake, while features of deposition, to be described later, occupy the sides. Old cliffs cut in the infancy of the lake lie behind the flats at Willow point, Cedar point, and Mettowee point.

At present cutting prevails on the southeast side from the swampy delta near the west end to beyond Point Comfort, and on the northwest side from near the west end to the Assembly grounds. At some places the cliff is steep and raw, but usually the rate of wasting permits a cover of vegetation. At other place equilibrium prevails between transportation shoreward and lakeward while occasional structures of deposition add variety to the view and interest to the observation. The very general cutting is indicated by the prevalence of stone walls on the lake fronts of private grounds.

The most widespread agency at work on the building coasts of Delavan is vegetable accumulation. The marginal bottoms and shallower portions of this lake support vegetation in unusual luxuriance and where protected from the active interference of waves and currents this vegetable accumulation encroaches rapidly upon the domain of the water. Fortunately the areas so protected, while large enough to show the vigor and physiographic importance of aquatic vegetation, constitute a



Willow Point, a V-bar in Delavan Lake, looking southwest.

small fraction of the whole lake area. There is compensation also for the disadvantages of vegetation in the great advantage which is thus afforded to fish. The two bays at the southwest end and the one at the outlet offer these conditions of security from interference by waves and currents and are accordingly retreating before the advance of the swamp. At places, as at the assembly grounds, the shore drift is carried along between stems of growing plants, as at other places it moves among larger stones.

The extent and character of filling on the bottom by the decay of vegetation was incidently revealed during the construction of the roadway across the outlet at the Assembly grounds. The water here was from five to ten feet deep and the roadway is a gravel embankment. When the dumping of the gravel was begun a very large amount seemed to disappear entirely before the level of the bottom was at all changed. When the dump was completed, there stood on both sides, parallel ridges of equal height, consisting of the muck of the bottom which the weight of the gravel had forced upward through a distance equal to the depth of the water plus the height of the embankment above.

The peninsula at the west end has suffered some interesting changes. At one time its southeast side was actively cut by a current which followed the curve of the bay on the south. This bay was somewhat larger and considerably deeper than at the present time. The material washed from this cliff on the southeast was carried part way around the head of the bay and built first into a spit, then into a beach, whose materials are gravel and cobble stones. Gradually the shallowing of the bay, and the improvement of profile on the front of the peninsula caused the currents to skip the unnecessary curve. They began to deposit where they had been eroding. The result already achieved is a wave-built flat three or four hundred feet wide on the southeast corner of the peninsula. Minor currents still enter the bay and keep the point of the growing flat turned westward. But for their agency, the point would by this time have been extended into a long spit or a bar across the bay.

The north side of the peninsula was similarly cut when the north bay was stirred by active currents. Now, however, the currents from the southeast are building their drift into a bar whose course leads straight across the bay. It has already advanced nearly half way across and is above the level of low water for much of its length. The currents which follow the opposite shore still enter the bay and are extending to the southwest a long spit which has become the shore line. When the bar from the peninsula is completed, this spit must cease to grow because the beach on its front will fall into disuse.

The bay at the outlet is being closed in exactly the same way. A bar is growing north from the Assembly grounds pursuing a course which will some day intersect a long and still growing spit on the north side which heads to the southwest. (Fig. 27.)

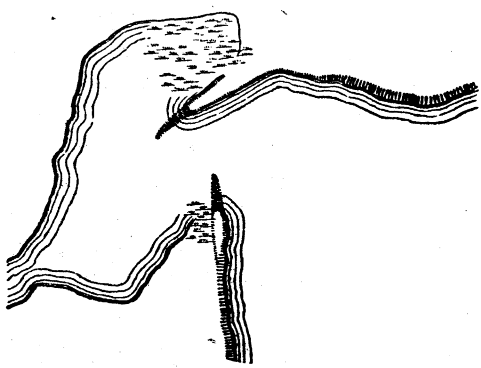


Fig. 27.—Spits at the outlet of Delavan Lake. Scale 2 inches = 1 mile.

This spit is built of the material cut from the low cliff west of Lake Lawn hotel. At some future time the bar from the Assembly grounds will have been completed, leaving only a sufficient passage for the outlet. Then the supply of material from the Lake Lawn hotel cliff will no longer be contributed to the spit on the north, but will travel south on the front of the bar.

A channel through the bar will be maintained by the outlet stream, but shoredrift will be transported across the channel when currents are strong. When this drift begins to come south, it is manifest that the proportion of load brought in, to load taken out, at the front of the Assembly grounds will be much increased. The same will be true of the Lake Lawn cliff, that is, the moderate cutting now in progress will probably be impossible. If any cutting does continue, the load thus given to the

FIG. 1.
Bar in front of inlet to Delavan Lake. The lake is on the left side.

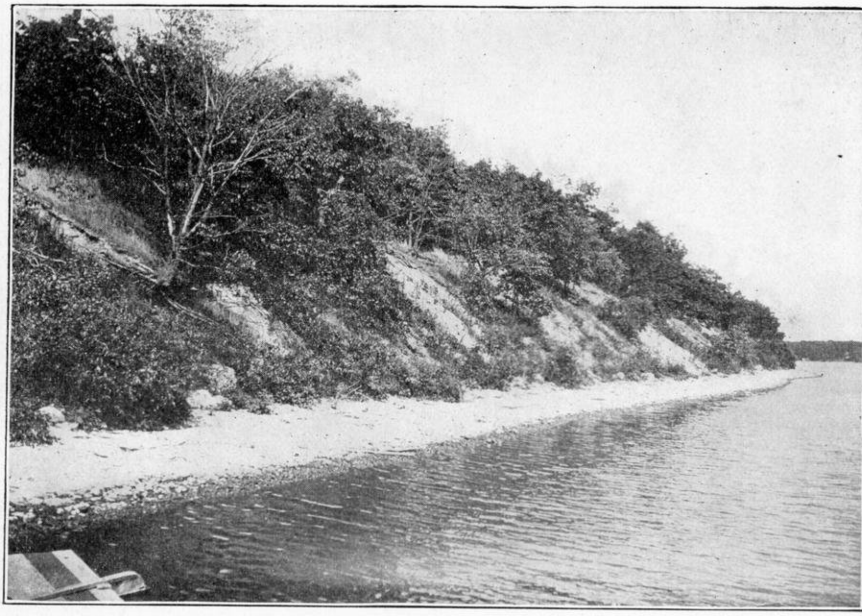


FIG. 2.
A cliff in gravelly drift, Delavan Lake. A strand of cobble stones at its foot.

currents may be carried long distances before being deposited. There will come a time when no more bays remain to be spanned. Then the shore drift which continues to be fed to the currents will be disposed of in two ways: a part will be used to broaden lakeward the beach structures already formed; the remainder will travel on and on, or back and forth, until, under the constant trituration it will all have been reduced to such a degree of fineness as to be carried out by the undertow beyond the grasp of incoming waves.

The strength of shore currents in comparison with small streams is well illustrated at the inlet. The dominant currents on this part of the shore are from the south. The mouth of the inlet was once at the bridge. The load brought down by the stream, or alongshore from the south was subjected, in the vicinity of the bridge, to the action of both stream and shore current. A glance at the map will show which current prevailed. The shore current has steadily built its bar along a curve of its own choosing for nearly half a mile. (Plate XIX, Fig. 1.) The stream has been forced to turn a right angle and follow the growing bar to its end, before being able to discharge its waters into the lake. The process can go farther now for currents from the west have built in the opposite direction a short embankment to meet the long one from the southeast. The two now form one beach line, cut by a passage, across which the current from the river alternates with shore currents. When the stream is high and its current strong, the passage is scoured open; when the waves and currents are relatively strong, drift is carried across the break. Even the sediment which is carried lakeward by the stream, may be recovered from the shallow bottom by certain types of wave action and urged shoreward again to resume its journey on the beach.

The mouth of the small stream on the south side near the west end, shows a somewhat different effect of current action. The stream once discharged its water into a small triangular bay. The natural course of bar-building would have been in an almost straight line on the lakeward side of the triangle. Owing, however, to the weakness of the shore currents and the narrowness of the bay, the current of the little stream was able to make itself felt, and as a consequence bar-building was directed obliquely outward in a direction which was the resultant of the two component currents. (Fig. 28.) As the shore currents from the east and from the west were of about equal strength this small bay has now such an obliquely directed spit on each side. Their courses intersect at a right angle and at the vertex of this angle the waters of the stream now reach the lake.

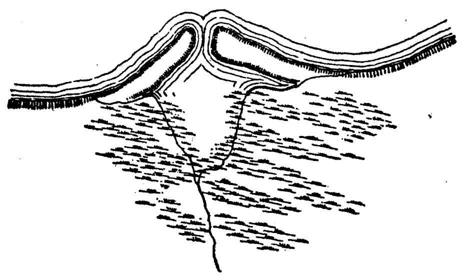


Fig. 28.—Bars at mouth of small stream, west end of Delavan Lake. Scale 3 inches = 1 mile.

At Mettowee and Willow points (Plate XVIII) the shore currents have diverged from the old shoreline, building wide triangular areas of sand and gravel. This is probably due in large part to a tendency to eddying provoked by the original shore contours. In addition, it is probably important to observe that in the present well developed stage of the beach, the shore currents are laboring with an excessive load of drift. These points now illustrate salients which are building instead of cutting, as it is customary for salients to do.

Cedar point is the prominent salient angle where the coast after running south from the Assembly grounds changes to a direction almost west. (Fig. 29.) Its construction involves the principles mentioned above but it has special interest on account of its size and on account of its preservation in its natural form. It was not built to the height of the bar by progressive widening, but is outlined by a ridge whose position has changed little from the beginning; this rim was built by shore currents, enclosing a lagoon which was then converted into a swamp. The point is a V-shaped bar, the largest and finest found on any of the lakes embraced in this report. Its south side is a heavy bar stretching for forty rods eastward from the cliff at St. Mary's. (Plate XIX, Fig. 2.) Its east side, or rather northeast, for the angle is acute, is twenty rods long and has been broadened by a reduplication of beach ridges. Independent of the point, the shore here changes its direction from almost east to north. The original salient coast whose base was

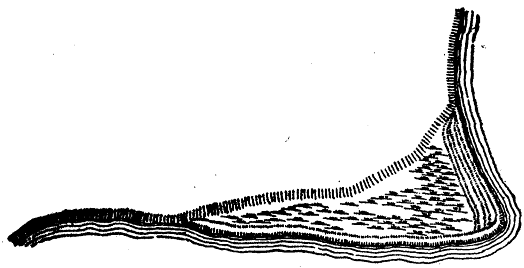


Fig. 29.—Cedar Point, Delavan Lake. Scale 7 inches = 1 mile.

once cut by the waves, now appears as a fading cliff behind the swamp. The growth of this V-shaped bar seems to have been chiefly by material brought from the west. An actively cutting cliff lies next to it in that direction. The coast to the north, with the exception of a faint cliff at the Assembly grounds, is not seen to be cutting.

# CHAPTER V.

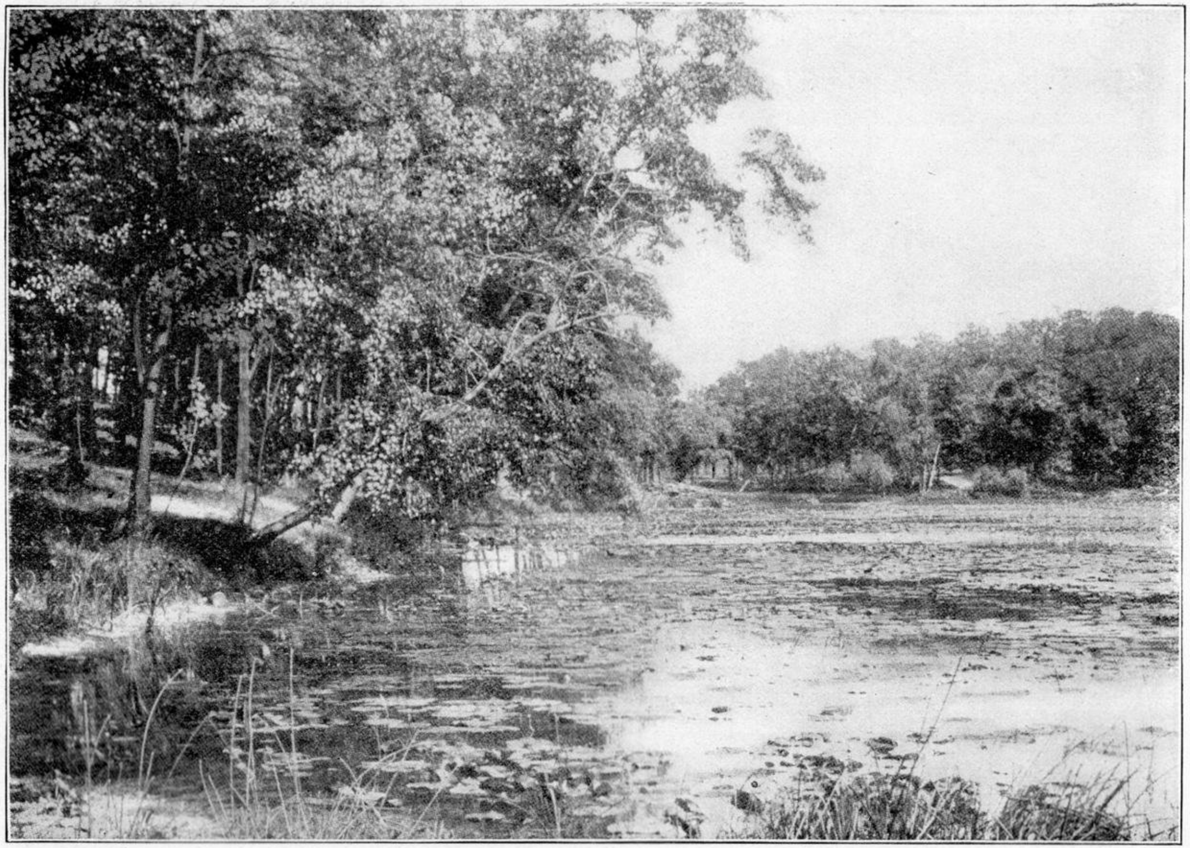
## LAUDERDALE AND BEULAH LAKES.

### THE BASINS.

These lakes in the northern part of Walworth county are on the east side of the Kettle moraine not far from the place where the interlobate portion divides into the two terminal moraines, that of the Green Bay glacier taking a westerly trend and that of the Lake Michigan glacier bearing off toward and south. Their location is therefore not only near to the edge of the Lake Michigan glacier, but near the actual limit of the later Wisconsin ice sheet. In this locality several lines of kames extend northeastward in the direction from which the ice came. Within this kame area is a considerable number of lakes due to the pitting of the surface by the melting out of ice remnants which were buried by the gravels.

The location of one of these strips of kames is marked by Beulah and Phantom lakes, the latter being near its northeast extremity. The Lauderdale group lies in the southwest continuation of the same line, a few miles from the axis of the Kettle moraine. The zone of kames and pitted plains associated with the interlobate Kettle moraine is here much widened on the side toward the Lake Michigan glacial lobe as it is in the Oconomowoc district on the side toward the Green Bay lobe. The plains are also terraced even more distinctly than in the latter locality (see Chapter VI, p. 107), the lower and later terraces in this southern district being on the southeast, while in the more northern district the descent is toward the west.

The depression containing the Lauderdale group is one of exceedingly irregular contour, as if a large number of ice remnants, each of irregular shape, had been grouped together in purely fortuitous arrangement, had then been buried by the



A corner of Lauderdale Lake, showing pond lilies.

gravels and subsequently melted out. The sole suggestion of order among the several parts is a rough parallelism of longer dimensions in a northeast and southwest direction, that is, in a direction approximately parallel to that of the Kettle moraine. It will be observed that the same is notably true of the Oconomowoc lakes.

From the soundings taken, the bottom, as it now exists, may be divided into two parts, the larger area being nearly flat and covered with less than ten feet of water. A somewhat smaller area is subdivided into three pits of almost equal depth, fifty and fifty-six feet being the extremes. If the water were drawn off to a depth of six or seven feet these three pits would be separated from one another, occupying the central portions of Mill, Middle and Green lakes. This was approximately the condition before the mill dam was built some sixty years ago. The long, shallow arms of the present lake were then for the most part grassed or wooded. The portions formerly wooded are now marked by stumps of the trees killed by flooding. The bottoms representing former meadows, where not covered by a subsequent deposit of mire, may be seen to be composed of the same tough mats of roots passing into peat, which compose the body of the floating bogs. In the west half of Middle lake, where this is best illustrated, the bottom is marked by vertical walled holes similar to those which may generally be found among floating bogs, or in swamps which rest upon a semi-liquid foundation.

Back of the time when these shallow extensions were swamps or meadows, there was another time when they were parts of the lake. Their depth at that time can only be known by piercing the accumulated peat. The depth of the deposit might even be comparable to that of the deeper central portions at the present time, for there are evidences that the local conditions are favorable to vegetation. These conditions, while favoring swamps along the shore and the accumulation of mire at the bottom, also foster the water lilies which adorn so many picturesque corners of these lakes. (See Plate XX.)

The southern extension of the lake presents a most instructive example of the work of vegetation in the work of lake extinction. Over much of its area the apparent depth is but one or two feet, yet the bottom may be pierced with an oar to a depth of four or five feet before any great resistance is met. Mosses, etc., grow on the bottom, each generation contributing its remains to raise the base on which future generations may grow. Leaves and flowers of pond lilies with lower forms of vegetation float on the surface and, dying, contribute their remains to the growing deposit below. Sedges and grasses advance from the shore, sometimes preserving their attachment to the bottom, sometimes floating as bogs. One deep hole south of Wilkinson's point is thus surrounded by advancing bog, which is limited by a perfectly definite front which goes down vertically into seven or eight feet of water. The vegetation is using all possible haste to accomplish once more what it had once carried almost to completion before the level of the water was artificially raised.

### LAUDERDALE SHORES.

*Mill lake.*—It is not to be inferred from these illustrations of the spread of vegetation that the shores and bottom of this picturesque little group are all so affected. The flooding of large areas which had once advanced to the condition of swamps or meadows has indeed been followed by a profusion of aquatic life, but the same elevation has also rejuvenated cliffs which began again to be cut back with the vigor of youth and to yield abundant supplies of gravel to the shore currents. Some freshly cut banks are seen on both sides of the bay at the outlet. A broken and indefinite bar lies in front of this bay, but it was probably built in the former and lower stage of the lake, and does not seem to be related to the present currents.

While the channels connecting the several lakes are so broad that the whole might be regarded as a single body of water, each lake has its own system of shore currents and there is but little circulation through the straits. This is shown by the well formed bars which cross the passages and divide the lakes from one another. Similar bar building must have gone on in the early history of the lakes, but whether or not these present bars were begun before the existing level was assumed, they are actively growing now.

The bar between Mill lake and Middle lake is built by the circulation of the former. Its curve and the curved shore of Wolf's point are mutually tangent. It is built by currents from the south which cross the passage from Wolf's point to Pleasant island, instead of continuing northward into Middle lake. (Fig. 30.) The cliff from which it springs is on the southwest side of Wolf's point. It appears at first sight remarkable that a bar of such vigorous growth should have derived so much heavy gravel from so short a cliff; a closer examination shows that Dunham's bay, south of the point is also spanned by a bar along which the waste of the longer cliff south of the bay is transported northward and contributed to the embankment which is heading toward Pleasant island. This so-called bar between the lakes is more properly a spit reaching little more than one-half way to the distal side.

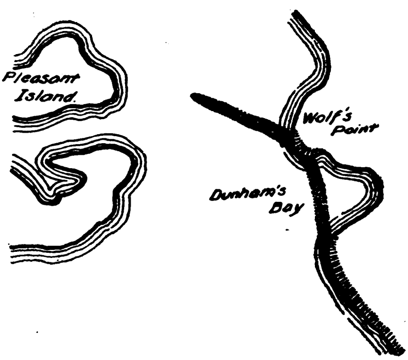



Fig. 30.—Bar forming between Mill and Middle Lakes, Lauderdale Group. Much of its material comes from south of Dunham's Bay. Scale 4 inches = 1 mile.

Wavé cutting and beach action on the west side of Mill lake are less vigorous. No bars are found across the two long, narrow bays shown on the map, either of which could be spanned by a much shorter embankment than those referred to on the east and north sides. Apparently their sheltered position, especially from the more effective west winds, is the reason for this youthful aspect of the shore.

*Middle lake.*—Middle lake is comparatively small if the long, shallow, westward extension be omitted. This shallow and comparatively isolated portion contributes but little to the size of waves, and probably does not participate at all in the currents of the deeper part of Middle lake. Cliff cutting in this lake is, therefore, less marked. The south side of Stewart's bay shows more vigorous cutting than any other shore of this lake. Green island is also cutting a little on its south side. It is to be expected from this absence of pronounced erosion that structures due to deposition should be correspondingly wanting. It has already been pointed out that the passage between this lake and Mill lake is being closed by the drift of the latter. The passage

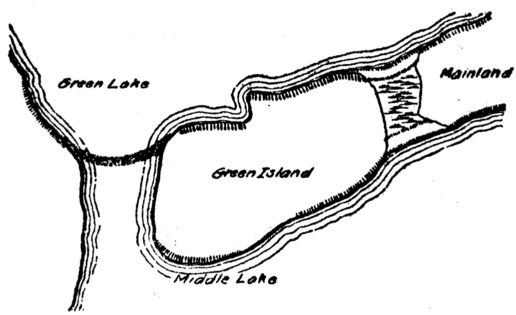



Fig. 31.—Bars uniting Green Island with the mainland, Lauderdale Group. Scale 5 inches = 1 mile.

to Green lake on the north has been similarly spanned by currents of that lake. The narrow passage which once existed east of Green island has indeed been spanned by a poorly formed bar on the side of Middle lake. The same passage has been closed at the other end by a much stronger bar built by the currents of Green lake. (Fig. 31.) Here, then, is the interesting case of an island tied to the mainland by two bars between which complete filling has converted the one-time lagoon into dry land.

*Green lake* owes comparatively little of its area to the artificial raising of its level. Practically the whole surface of the lake participates in the wind driven circulation which is, therefore, stronger than that of either of the other lakes. Both its northwest and its northeast sides show cliffs which have been cut so rapidly as to be entirely bare of vegetation. Most of its shores are steep.

From the shape of the east shore it is to be expected that the currents which follow it should move south instead of north. This is exemplified in the spit which is growing from Tratt's point, at first southward but gradually curving to the east. Here again, as at the north end of Mill lake, the source of the material is not at once apparent. The west shore of Tratt's point, with which this pit is continuous, is artificially protected from erosion and is not now supplying the gravel of which the growing spit is composed. Immediately north of Tratt's point is a bay which is spanned by a good bar which places the beach on the south in communication with the long and rapidly wasting gravel cliff north of it. This cliff, then, is the source of the material not only of the bar which spans the small bay, but of the growing spit beyond Tratt's point.

The west side of this lake furnishes one small but very clear example of deposition by currents at a salient angle. Such a headland near Ewing's landing is too sharp to be turned by the shore currents without some dissipation and consequent loss of load. A flat foot or terrace has therefore been built which gives to the shore line a curve in place of an abrupt angle. There is no indication here of the co-operation of two sets of currents as in the making of hooks and loops. (Compare Limekiln point, Lake Geneva, Plate XVII; also Cedar point, Delavan lake, p. 92.) West of this point the shore continues steep and high, as at many other places in this group not mentioned in detail. The topography is very hummocky and the woodlands are especially beautiful.

## BEULAH LAKE SHORES.

Beulah lake is similar in origin and history to the Lauderdale group. It has the same extreme irregularity of shore line. The banks of the basin rise abruptly to the plain above, but are at many places separated from the water by flats built chiefly of vegetable remains. (See Plate XXI, Fig. 2.) The area now under water contains five basins from forty to sixty-seven feet in depth, separated and surrounded by shallows less than ten feet deep. In this case, however, the line along which the basins are ranged is in the direction of the ice movement northeast and southwest, and the entire depression has rather more unity than that which contains the Lauderdale basins. Mill lake is a separate and distinct basin at the northeast end. The waters of Beulah lake pass into this basin and out again by artificial channels. The drainage is northeastward to Fox river. The outlet is now held by a dam ten feet high but the actual elevation of the water above its former level is somewhat less than that amount.

Previous to the changing of the outlet and the building of the dam, the now single lake was subdivided into three separate sheets of water, corresponding to the parts now bearing the names of Upper, Round and Lower lakes. The intervening flats were in large part wooded, the same areas at present being marked by stumps standing in shallow water. Back of this stage was another, when the water stood at a level not very different from the present; when the shallows and stump-covered aras were deeper water with gravel bottoms; when the present headlands stood out farther into the water and the lake had many bays which are now cut off by beach ridges and overgrown with grass or tamarack. This older stage gave way to the conditions just preceding the dam, by the down-cutting of the outlet, the aggressive encroachment of vegetation and the normal beach processes which are now at work simplifying the still highly irregular shore line.

That the present level of the lake is not very different from that at which it stood when it first began work on its shores is indicated by several features. If it were lower now than the level at which much work was accomplished the contours of the shore line would show broad, smooth curves, because the smoothing of the contours of the offshore bottom is begun very early in the cycle. (See Chapter II.) If it were much higher than the level at which its former work was done the water should now enter all the former bays, for their cutting off and extinction was a work requiring a much longer time than that which has elapsed since the building of the dam.

The south shore line of Lower lake, opposite Buck island and west of Broad bay, still affords the best illustration of the extreme sinuosity of the line which water assumes when it rises upon an area of kames and pits. (See Fig. 32.) The line of

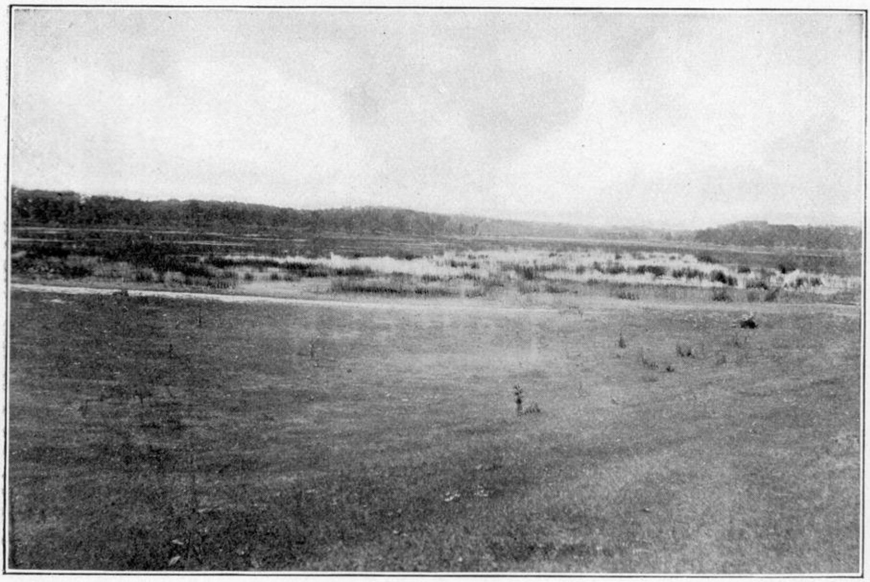


FIG. 1.
Lake Holden, a lake nearing extinction.

FIG. 2.
Beulah Lake. The flat in the foreground was a part of the lake in its early history.

the present water's edge is already much simplified from its former still more sinuous form. If the line were followed behind all the former minute indentations now filled and in front of the former positions of headlands, now partly cut away, it would be perhaps twice as long as that shown in the figure.

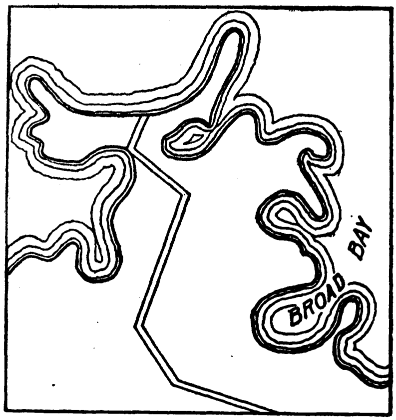



Fig. 32.—Shore line against a kame area, Lake Beulah. Scale 4 inches = 1 mile.

As in all lakes whose levels have been recently raised, cutting of the more exposed shores has been renewed with vigor. The controlling influence of exposure is well exemplified here in the freshness of the cliffs on the east side of the Lower lake where they face both the westerly winds and the largest expanse of water. The cliffs south of Lake View hotel and on the west side of Beulah island are kept fresh and bare of vegetation by rapid cutting, while the reentrant curves on the east shore have fine, sandy beaches. Below these cliffs are fine examples of the breaker terrace, the characteristic accompaniment of fresh cutting in kame gravels. (See Chapter II.) The terrace at these places is composed of clean and well assorted cobble stones, its gently sloping top often carrying finer gravels and its steep front resting on a sandy or gravelly bottom about six feet deep. The east end of Twin islands is also much exposed and shows the same features. Even in Mill lake, which is small and protected from winds, the effect of a considerable rise, against a steep bank of uncompacted gravels is seen in a new terrace several yards in width, resting with a steep front on the old bottom now six or seven feet deep.

It is not in all cases possible to tell of the depositional forms to what extent they are the work of the present stage of the lake's history and to what extent they were built before the erosion of the outlet lowered the lake's level. In the case of those features which were built at the low water stage, they may be known, if preserved, by their situation at a depth at which the water is now powerless to work. Such, for example, is the old bar extending northwest from Wilmer's point. Not only has it lost the clean-washed character of its gravel and been buried under eight or ten feet of water, but the present outline of the shore does not give rise to currents which could make a bar in this position.

On the north side of Upper lake at its east end is a small peninsula extending eastward in front of the area occupied by stumps. This peninsula is a former island now connected by a bar with the mainland on the west. The drift along both sides of the lake at this point is eastward and must always have contributed to the clogging of the passage to Round lake. Twin islands at the north end of Round lake are similarly connected with each other and to the main land by bars which are now above the surface of the water.

From the east-facing cliff of Twin island a spit is vigorously growing toward the northwest. This, like the former one from Wilmer's point, is growing directly toward the dominant winds. This, in both cases, may be partly due to return currents of a horizontal circulation which is originated by movement in an easterly direction. This factor, however, does not seem to be very important. The controlling conditions are, no doubt, the protection from west winds by high wooded banks, and the unimpeded sweep of winds from the opposite direction. A correspondingly small fetch of the waves from the west and long fetch from the east intensify the condition favoring the growth of spits toward the west and northwest.

At two places in the Lower lake the same conditions are fulfilled and with like results. The one is on the west side of Beulah island (peninsula) where the fine, gravel cliff gives rise to a long bar directed northwest into Brooks bay. This cliff is washed alternately by west-bound and east-bound currents. The presence of the protected bay enables the west-bound currents to stow away a part of their plunder at a place where the east-bound currents are too feeble to recover it. The east-bound currents carry the waste of the cliff beyond the point of the peninsula and are vigorously building a spit across the protected bay on the east side. The other case of a northward pointing bar is that of the one which springs from the beach in front of the Lake View hotel and is directed into the protected bay east of Beulah island.

The long, high bank extending north and south from the vicinity of Buck island yields to the currents a limited amount of drift. Midway between Buck Island and Twin islands the currents run tangent to the shore and have built a bar connecting a small island with the mainland. At the other end of this cliff the drift is building a sandbar across the head of Brooks bay.

Gaskel's bay at the southeast corner is spanned by a bar which betrays its origin by the coarser material at its west end showing that it has grown chiefly from that direction.

*Mill lake*, northeast of Beulah, is an almost simple pit one-half mile long and half as wide and more than fifty feet deep, having steep, high banks of kame gravel. *Booth lake* is likewise a nearly simple pit without bays and twenty-five feet deep. Its shores are of sand and gravel comparatively free from swamp. *East Troy lake* is similar to Booth lake, but its shore line is more scalloped with minor indentations.

# CHAPTER VI.

## THE OCONOMOWOC LAKE DISTRICT.

This district comprises a rectangle of fourteen miles east and west, by nine miles north and south, having its center about thirty miles west of Milwaukee. It contains twenty lakes whose hydrography has been published and as many more not without their beauty and interest but not systematically studied. Those surveyed range in size from Pewaukee with an area of three and two-thirds square miles to Garvin, with an area of twenty acres. There are in all perhaps one hundred miles of good lake front suitable for summer residences. Much of this is now occupied for that purpose. The roads of the district are uniformly good and the delights of driving from lake to lake give an added advantage to the group. If among so many lakes of similar origin there can be no great contrast in the style of scenery, there is a beauty which is characteristic of a landscape thus interspersed which does not spring from the features of any one lake.

### GEOLOGY OF THE DISTRICT.

*The moraine.*—This lake district lies in and adjacent to a break or sag in the Kettle moraine. The existence of this gap or sag is emphasized by the fact that two parallel streams flow through it across the course of the moraine ridge. North of Beaver and North lakes the line of the moraine is marked by a distinct ridge several miles wide, trending east of north. It rises more than a hundred feet above the adjacent country and two hundred above the level of the Oconomowoc district. South of Nagawicka lake the ridge is seen again trending west of south, though with less prominence than it has to the north.

Within this gap the kames and pitted plains which are characteristic attendants of the interlobate phase of the Kettle moraine have an extraordinary development, and the belt which they occupy is locally broadened.

The ground moraine on the east extends west to the west end of Pewaukee lake. From that point the boundary between it and the kame area extends south in a waving line and also in an irregular line east of north. In this area the curves of the ground moraine are broad and flowing. A tendency to linear arrangement, giving to the hills a distinctly drumloidal aspect, is quite noticeable. The hills have their greatest length in a direction which is approximately parallel with Pewaukee lake. This was substantially the direction of glacier movement.

*The underlying rocks.*—The drift in this belt is not very deep. The underlying Niagara limestone appears at the surface at various places east of the lake. It is quarried at Zion's dell south of the west end of the lake and is reached by shallow wells. At Rocky point it occurs at the water's edge.

West of Rocky point the limestone does not occur at the level of the lake, though it is seen at higher levels several hundred feet back. Before the drift was deposited the Niagara stratum was so roded as to form a large V-shaped indentation in its western border, which has in the main a north south direction. The angle of this V is near Waukesha beach; its one arm reaches west to Delafield, the other northwest through Hartland. Between these lines the drift rests directly on the Cincinnati shale.

Erosion of strata in this form indicates plainly that a preglacial stream or streams flowed across the outcrop. In this case the direction of flow was, no doubt, west or northwest, to join what then corresponded to the Rock river, following the base of the Niagara escarpment, however, instead of turning west toward Watertown. The length of these tributaries from the east was probably not great. The Niagara limestone dips to the east and its scarp ridge doubtless formed the main divide of this region.

*Origin of Lake Pewaukee.*—The glacier moved down this valley to the west and not only failed to fill it with morainic deposit, but may even have helped to deepen it. The glacial deposits on the west were built higher than the modified watershed on the east. This portion of the river valley thus became a lake basin with the direction of its drainage reversed. The lower part of the old river valley was buried and completely obliterated. Pewaukee lake is the only lake in this area of ground moraine and is thus distinguished by its origin from all the other lakes of this district. The effects of this difference in origin will be noted later in a contrast of coast lines.

*The area of kames and pitted plains.*—West of this ground moraine of the Lake Michigan glacier lies a broad strip of kames and pitted plains. The features which demand attention in order to interpret its origin are: (1) The materials,—underlying rock and drift; (2) the topography,—terraces, pitted plains, and lakes.

The underlying rock is rarely seen in this belt. The Niagara limestone is quarried at Delafield on the very edge of the area under discussion. Here the strong Niagara limestone no doubt stood in a high cliff looking both west and north over valleys cut in the easily eroded shales. A fourth of a mile from the quarry a well was sunk one hundred and thirty feet without reaching the rock. At no other place in the area was bed rock found to lie less than one hundred feet below the surface. Even much deeper wells commonly fail to pierce anything but glacial deposits. If the drift could be removed there would appear an eroded surface of Galena limestone and Cincinnati shales with a relief amounting to perhaps one hundred feet.

The drift of this region is characteristically gravelly. The stones have all sizes up to small bowlders and are as a rule fairly waterworn. Very few exposures fail to show the co-operation of water at the time of deposit, though few show well assorted strata. Foreign bowlders are not infrequent, but typical bowlder clay, such as is found in the bodies of the ridges of the Kettle moraine, is seen at few places in this lake district west of Lake Pewaukee.

Of equal significance with the nature of the materials of the drift cover, is the topography of its surface. Of this topography the element which first arrests the attention is the prevalence and striking abruptness of the so-called kettles or pits. They may lie isolated below an otherwise plane surface, or crowded in such confusion as to lose their individualty with the disappearance of their normally even-topped rims. While no considerable portion of the area is without them, they are most abundant on the borders of the lakes, especially in narrow areas between two or more lakes. The road from Oconomowoc to Delafield traverses a sharply pitted area south of Oconomowoc lake. North of the same lake to Okauchee lake and eastward toward Nashotah the kettles also abound. They have also a striking development south of Lower Nemahbin lake. Although these hollows are characteristically associated with otherwise level areas which are then styled pitted plains, they show in this region a special fondness for the margins of the gravel terraces described below. This is the case around the borders of the lakes where the lake bottom represents one level and the surrounding plain the other. Similar off-sets of level attended in the same way by a pitted margin of the higher level are noticeable features of the land surface.

If to a close view the most striking feature of the landscape is its pits, to a more general view the levels beneath which these pits fall is no less an attraction. These levels are preserved with notable continuity for considerable distances. The lower ones often give way to the higher by a narrow slope, so that to a general view the aspect of the topography is distinctly that of broad terraces.

The highest of these terraces are isolated patches and lie on the east side of the belt. Some of the levels lying to the west have escarpments on their east as well as their west sides; being entirely surrounded by lower levels; but generally speaking the descents to the west are greater than those to the east, giving a resultant slope to the west. Measured by the surfaces of the lakes, this slope is about fifty-seven feet from Beaver lake on the east to Lac la Belle on the west, intermediate lakes showing a regular descent.

*Glacial history of the area.*—The features of this lake district may then be summed up in the following items: (1) One or more transverse valleys carved in the underlying rock by preglacial streams coming from the east. (2) A break or gap in the ridge of the Kettle moraine now used by two streams which flow in a southwesterly direction across the trend of the range. (3) A great abundance of water-washed drift. (4) A large number of lake basins and countless pits which were prevented from filling by the presence of large or small isolated and buried ice blocks, while the water-laid deposits were being made. (5) A terraced arrangement of plains whose total slope is toward the west.

In interpretation of these facts it is inferred: (1) That upon this low area adjacent to the junction of two or more preglacial streams was a concentration of drainage from the melting glaciers. (2) The drainage, which was chiefly along the line of the ice front, was relatively stagnant at this place; hence the abundance of water laid deposits. (3) The higher terraces on the east are along the line of the earlier drainage. They were formed by the aggrading of stream courses while the ice held the ground now occupied by the lower terraces. (4) This main drainage line shifted westward, following the retreating front of the Green bay glacier. As the ice retreated it uncovered ground lower than the much aggraded stream channel, hence the stream found a lower channel farther west. The repetition of this shifting gave rise to the glacial terraces now seen.* (5) The lower part of the glacier which was heavily charged with sediments, often failed to follow the retreat of the upper layers of ice. This resulted in the burying of many blocks whose melting gave rise to the basins of lakes and pits. (See p. 4, also fig. 3, p. 5.)

By this interpretation, the lake basins are seen to be simply larger pits in the much pitted plain. Such hollows present all sizes up to that of the largest lakes of the area. They all agree in three things: (1) Their sides are steep; (2) they are sunk below an otherwise level surface; (3) the surrounding material has been last handled by water. Some of the larger ones, (and Okauchee to a remarkable degree), show a sub-division into smaller basins or arms at the edge. This is due chiefly to original irregularity of the ice mass or masses.

The glacial deposits on the western margin of this lake district do not show the omnipresent agency of water, as do the deposits of the area farther east. The roads show the presence of a

* This conception of the making of these terraces was in part received from Professor T. C. Chamberlin.

stiffer soil. The slopes of the west coasts of Lac la Belle and Silver lake are not, like those of the lakes farther east, the abrupt slopes of hollows in a pitted plain. The upward slopes from the shores of Lac la Belle, sometimes sixty feet in a quarter of a mile, are gradual and rounded, with curves to which a moving glacier might well have adjusted itself. The bottoms, however, of this lake, as well as Fowler and Silver, are seen to be pitted with the same narrow hollows which characterize the lake basins farther east.

### PEWAUKEE LAKE.

As indicated in the description of the topography of this area, the basin of Pewaukee lake is in the main an erosion valley passed over in the direction of its length by the Lake Michigan glacier and blocked at its west end by the stratified drift associated with the Kettle moraine. In harmony with this origin, its banks, though at places high, have not the steepness which marks the banks of kame lakes. The curves on its border are everywhere such as could have been conformed to by a moving sheet of ice. Along more than half of its north coast there is a gradual rise, amounting to nearly one hundred and fifty feet in the first half mile. Most of the south coast has a similar topography, but the elevation is much less. Occasional portions of the coast, especially in the valleys of the small streams, are low and swampy.

The waters of the lake are derived partly from these streams but a considerable supply is also furnished by springs, especially from the north side. The level of the lake is now maintained by a dam at the outlet. This dam raised the lake seven feet and is accountable for the eastern half of the lake whose depth is for the most part less than seven feet. Before the building of the dam, this half of the basin was a swamp, and a wagon road is said to have been maintained across the swamp, east of Rocky point.

The two halves of the lake show scarcely less contrast in appearance than in history. Vegetation abounds on the bottom of the entire eastern half. Away from the shore it is kept from rising to the surface by annual mowing in the interests of the ice crop. Near the shores the vegetation encounters no opposition except from the waves and currents, whose strength has already been much reduced by friction on the bottom. Fields of bog, consisting of matted grasses, cover large areas. They rest loosely upon the bottom or are buoyed up by the water. They enlarge their areas by the annual growth at their edges, which appear as vertical faces going down to a bottom from six to eight feet deep. In strong winds portions are dislodged from the field and become the so-called floating bogs.

The western half of the lake has comparatively little vegetation of its own, though often visited by floating bogs from the other half. Waves and currents act with vigor upon its shores, the deeper water permitting unimpeded movement, except upon the marginal bottoms. The shores of the western half are especially desirable as summer resorts. The lake owes to the less picturesque features of its eastern half its well deserved reputation as a fishing and hunting ground.

The comparatively recent raising of the level of Lake Pewaukee set its waters to work at a new horizon which had long been above their reach, if indeed, the level had ever before been so high. This recent change of shore line is the reason for the activity of cliff-cutting observed at some places. (Compare Geneva lake, p. 78.) A short distance east of Lakeside a considerable bed of peat had accumulated when the level was lower. This is now being cut away on its lakeward side. In windy weather fragments of this peat may sometimes be seen floating far to leeward.

Most of the north coast of the west half is cutting a little. At Lakeside the progress is very active and the cliff is correspondingly steep and raw. A few rods to the east the waste of this cliff is building a spit which indicates the eastward course of its movement. A similar embankment lies just west of the cliff. Its material is derived from cliffs still farther west. Alternating currents have turned its point landward making a hook. (Plate XXII, Fig. 2.) Shore drift does not pass by such a growing embankment but is added to its end. This requires that the next spit to the east be built entirely of detritus worn from the intervening cliff.

The beach at Audley park (on the north side of the lake near

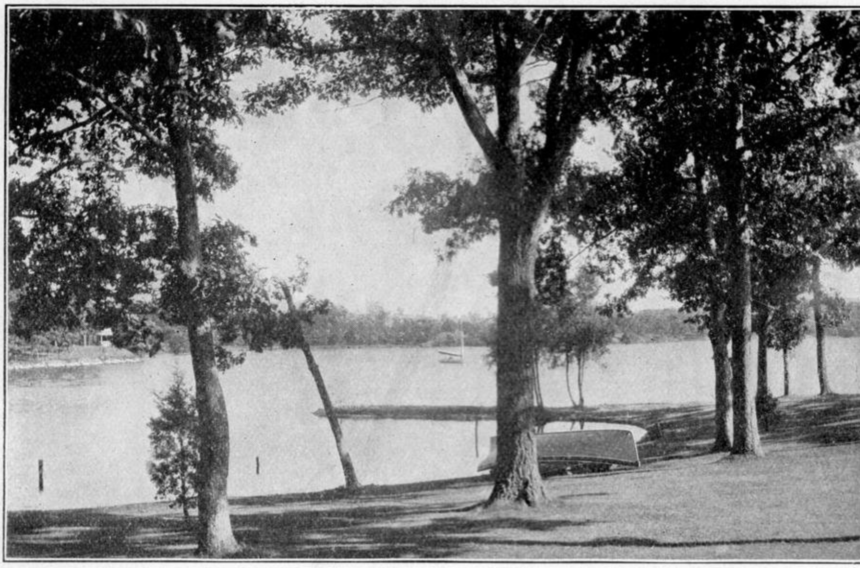


FIG. 1.
Spit in Lake Nagawicka. The point is growing toward the land on the left. When completed it will isolate the bay in the foreground from the lake.

FIG. 2.
Hooked spit, near Lakeside Hotel, Lake Pewaukee. The waves may be seen refracting around the end and extending the hook shoreward.

the west end) is sandy, as is commonly the case with beaches near the narrow ends of small lakes which are much elongated. At this place the currents from the west are too weak to transport anything coarser than sand; those from the east are checked by running into the narrow end of the lake and are thereby forced to deposit their load.

Most of the south side as far east as Rocky point is faintly cutting. That this process should extend well into the shallow bays is due to the youth of the shore line in its present cycle. When the small irregularities of the shore line and marginal bottom have been smoothed out, the currents will be able to distinguish between the larger salients and reentrant curves. Cutting will then be confined to the former, while the latter will be the places of bar building or of broadening beach terraces. Waukesha beach occupies a landward curve of the coast in which the latter form is already developing.

### NAGAWICKA LAKE.

Two nearly parallel rivers, the Oconomowoc and the Bark, flow southwestward to the Rock river, through the area of kames and pitted plains and share about equally the drainage of the lakes. It will be convenient to consider these lakes in the order in which they occur upon the streams, beginning with the course of the Bark river.

The basin of Nagawicka lake is the mould of at least two ice blocks, the northern end being a distinct pit, having a depth of forty-five feet, connected with the larger lake by a strait only a few feet deep. The larger basin has a depth of ninety-five feet, the deepest sounding in the Oconomowoc group, though Pine and Okauchee lakes have nearly the same. About half of the coast shows the characteristically steep kame slope; this includes stretches on both the east and west sides of the south end and at various places around the north end. The shore on the east side for more than a mile south of the inlet is against a plain but a few feet above the lake level. Much of the border near the inlet and outlet is of a marshy character, the vegetation pushing its way into the shallow water. This is characteristic of the north end and most of the west side. A similar swampy area at the south end is cut off by the artificial embankment constructed for a roadway.

The Bark river following a devious trough in the newly made glacial deposits found this basin in its course. The valley of this stream after leaving Nagawicka is steep-sided, twenty feet or more in depth and from an eighth to a fourth of a mile wide between Delafield and the Nemahbin lakes. This resemblance to a large stream cut valley is seen again along the same stream after leaving the Nemahbin lakes. There is no reason for thinking that the present river under present drainage conditions has cut the whole or even the larger part of this valley. A similar trough connecting the Genese lakes with Otis lake and extending northeast from the latter does not contain a stream. These and other similar valleys which have too much linear continuity to be ascribed to ice blocks may owe their forms to drainage during the presence of the glacier.

As shown by the presence of stumps in the water this lake stood for a long time at a lower level. The change of level was approximately equal to the height of the present mill dam, where the fall of the water is never less than six feet. The new level occasioned by the dam is of recent occurrence in the life of the lake. Youth is written plainly upon its features, especially on the profiles of its east side. The south half of this side has high, steep coasts and a somewhat sudden descent to deep water. It is probable that cutting and building never succeeded in producing a bench at the foot of these cliffs, much wider than was necessary for the exercise of beach functions. When the horizon of cutting was raised the work had to be begun anew, for the old shelf was drowned far below the reach of the waves which could be produced on so small a lake.

The new cliff is steep and at intervals perfectly bare of vegetation. The new platform rests upon the old in the form of a terrace about ten feet wide. In this width its fall is less than one foot. Before going another ten feet from shore, depths of four or five feet are found. This steep slope or front is composed of clean cobble stones almost unmixed with fine material. Its edge is usually clearly marked; it is seen to rest upon gravel, sand, or mud. The gently sloping top of the terrace is covered with gravel of various grades.

This is a normal feature of a shore upon which the horizon of cutting has recently been raised. (Compare Green lake, page 157.) The gravel and sand under the edge of the water is carried alongshore in milder weather but in storms it is dragged out over the front; it is soon replaced by the waste of the cliff. Its steep sloping front, composed of clean cobbles, is the conclusive evidence that storm waves are strong enough to remove all smaller stones and that heavy material is carried out by the undertow and lodged beyond the reach of incoming breakers. This is the essential feature of an unfinished beach profile on a cutting shore. Beyond this front the finer products of the present waste are spread out. If these strata were pierced, the heavier stones of the former shore would doubtless be found.

Some of the east shore which is not actively cutting is protected by artificial bowlder walls, indicating that it is to be classed as a cutting coast. The coast south of the outlet is in part so protected. Here also are ice ramparts, partly cut away in the improvement of private grounds.

A few depositional features on this lake are also suggestive of its history. North of Rogee's peninsula which indents the middle of the east shore is a shallow bay. Bar building from the south is going on actively in front of this bay. At present a spit of coarse gravels reaches some hundreds of feet northward. Farther east within the bay is another spit extending much farther north. It is broader than the first, covered with finer material, and ends in an indefinite shoal. Plainly this spit is not now growing; the beach of which it was the continuation is not now in use. It was built when the lake was young and had about the same level as at present, though the windings of its coast were somewhat different. When the level fell, forests covered the bay, as may be seen by the stumps which remain. When the level was again raised the current flowed on a line farther lakeward, building the present spit. The bay south of Rogee's peninsula is being spanned by a spit growing southeastward. (Plate XXII, Fig. 1.) The shallows which connect the island with the mainland near the outlet are an original feature of the bottom not produced by the agency of the water.

THE NASHOTAH–NEMAHBIN LINE.

These four lakes from Upper Nashotah on the north to Lower Nemahbin on the south, form a connected line about three miles long. Between the several lakes are low marshy passages constricted by kames. Here was a line of ice blocks whose direction, as also the longest dimensions of the several blocks, is parallel to that of Nagawicka lake and to the position of the front of the retreating Green bay glacier.

The Bark river enters Upper Nemahbin lake from the east and leaves Lower Nemahbin at the west. These two lakes and Lower Nashotah have the same level. Upper Nashotah lies two feet higher. The Nashotahs are fed by springs and discharge their waters southward into Upper Nemahbin.

*Upper Nashotah.*—On the banks of this lake steep kame slopes alternate with flats which have been produced in kettles of the ordinary type by the accummulation of swamp deposits in their bottoms. Rather, it may be said that the kame slope is continuous around the whole but is more sinuous than the shoreline, so that at some places the two lines agree; at others they separate, leaving flats between. A characteristic steep kame slope may be seen at the Mission. (See Plate XXIII.)

The amount of erosion has not been sufficient to supply material for large beach structures. The largest is a sandy beach ridge which lies on the flat coast within the largest bay on the west side. It is built of detritus from the cliff on its north side but before its completion the sinking of the lake level or the shallowing of the bay so enfeebled the currents as to cause the building along this line to cease.

*Lower Nashotah* has a more uniformly steep coast, especially on its west side. The north end of the east side has been sufficiently cut to show a decidedly convex profile. At the foot of most of its cliffs are gravelly slopes a few feet or a few yards wide, so that the base of the cliff lies a foot or more above the level of the water. Such dry strands are an indication of a falling level. The cliffs of this lake do not, as a rule, show recent cutting.

*Upper Nemahbin.*—The coasts of Upper Nemahbin were originally of the same character as those of the two lakes north

Upper Nashotah Lake: The Mission. The slopes are typical of basins in the kame areas.

of it. The extent of low or swampy ground on its border where the steep kame bank leaves the shore is not great. A low strip extends north from this lake to Upper Nashotah and may once have formed a direct connection between these lakes east of Lower Nashotah. A similar flat area at the south end includes both the inlet and the outlet and connects this lake basin with that of Lower Nemahbin.

The effect of the larger size of this lake, as compared with the two Nashotahs, is at once evident in the amount of shore work. The northern extension was first crossed by a bar. This bar assumed the functions of a beach and has since been broadened into a terrace by the addition of three successive ridges upon its front. The position of this structure is seen to be favorable to the wave built terrace (See p. 29). The forms of the several ridges have been much disturbed by ice push. Similar current-built and ice-pushed ridges cross several hollows on the east side. Near the inlet a prominent headland is reached by a ridge of unusual size from the north. The headland was once an island; the ridge was at first a bar; wave action and ice push raised it nine or ten feet above the present water level. The falling of the lake level and the accumulation of vegetation combined to make a swamp of what was once a bay behind the island and bar.

*Lower Nemahbin* has some good ridges on its southeast and southwest coasts. These seem, however, to have been built when the level stood a little higher. The bluffs show former cutting but not much at the present time. Much of the lake is shallow and vegetation interferes greatly with wave action.

The expansion of the ice on these lakes has not produced ramparts. It has already been referred to as deforming some of the beach ridges. In addition to this it has quite generally produced at the foot of cliffs the low bench or terrace described in chapter II as the ice-push terrace. This form, as seen here, is a level bench from two to ten feet wide, running along the foot of a cliff and lying two or more feet above the lake. (See Plate XXIV.) On Upper Nemahbin lake, between the inlet from Lower Nashotah and the north end of the lake, an addition to one of these features has been made so recently as to show beyond question the manner of its making. For a fourth of a mile the fresh gravels* have been pushed up to an almost uniform height, varying little from thirty inches above the water. At places this band of gravel was laid up against the steep cliff itself as the first contribution to the feature in question. At other places the new contribution was added to the front of a previously existing bench or terrace of the same height. This ice-push terrace is quite commonly associated with a band of freshly laid cobbles under the margin of the water. Such a band must always result from the new beginning which the waves must make in the adjustment of the beach profile after it is disturbed by the pushing of the ice.

### GENESEE LAKES.

These two lakes may be included among those drained by the Bark river because of their situation within its basin, although they have no stream connection. They are two simple ice pits separated by a ridge of sand and gravel. The massiveness and height of their breach ridges above the present level indicates a higher level when these forms were constructed. The most prominent ones lie east of the separating ridge, are continuous with it and are of the same height and material. The top of the ridge itself, several hundred feet wide, is composed of the same material. Other ridges of beach origin more or less modified by ice push, lie along the west sides. The ridge between the lakes must have been the gathering ground for a part of the sand with which to build the dune ridge east of the lower lake. This dune ridge is nearly twenty feet high, and one or two hundred yards wide. Its dune character is seen in its hummocky topography and in its pure sands exposed by the cutting of a road through its northern end.

These lakes have neither stream inlet nor stream outlet and it is therefore impossible to control their levels by a dam. The water of the north lake is now one foot higher than that of the other. That of both doubtless escapes by percolation to the south. Such lakes are subject to great changes of level, which

* This is reported to have occurred in the winter of 1898–1899.

implies a corresponding broad zone which is subjected to beach processes. This is one of the reasons for the large beach features of these lakes.

## BEAVER LAKE.

This is the highest lake to be described in the district, and lies at the head of a drainage line which is tributary to the Oconomowoc river. Its waters flow first into Pine lake and thence through Mud lake into North lake.* Here they join the waters of the Oconomowoc river. Beaver lake is fed by springs and in some seasons receives a supply of water sufficient to make a considerable stream at the outlet. This outlet has incised its channel at least a few feet, as will be seen from certain beach structures which could cnly have been built when the water stood a few feet higher. If this lake should rise four or five feet higher it would spread out into many small bays and arms. At the heads of these it would reach steep kame slopes similar to those which now characterize its salient curves. These scallops are lateral pits bordering the two great pits, which together constitute the lake basin. At a former time when the water stood higher and the bottoms of these side pits had not been filled with mud and vegetable remains, the lake occupied these scallops and showed a much more sharply curved shoreline. At present the coast is about equally divided between steep bluffs on the salient curves and flat or gently sloping land behind the reentrant curves. This land, where flat, often lies two or three feet above the lake level. This exceeds the amount which the water surface has fallen since it left its first records of level on the shores, because these flat areas have been somewhat raised by the remains of many generations of vegetation.

Along almost all reentrant curves are high ridges which have the graceful curves of bars. Some of them are such, unmodified. Along the south side are some exceptionally fine ridges of this character. The long ridge at the east end is in the main a beach ridge, though ice has no doubt altered its form and

* The overflow from Beaver to Pine ceases after a period of dry weather and Pine Lake has not been known to overflow for some years.

added some heavier materials. The majority of these ridges owe their location to the processes which determine beach lines, but many of them owe their height to materials pushed inward from the bottom by the ice. Along the north side some are seen to contain many bowlders, others have a sharp irregular crest, and others still have both these evidences of ice origin. One large ridge at the northwest corner is composed at one place of bowlders and a few feet away of marl, showing the entire impartiality with which the ice uses the material of marginal bottoms and adjacent shores to build ramparts.

A considerable amount of cliff cutting has been done and a large part of the bluffs show a convex profile. (Chapter I, p. 6.) Most of these bluffs are just at present protected from further cutting by the presence of ice-push-terraces at their bases (see Chapter II, p. 34, also compare the Nemahbin lakes, p. 115). The waves are unable to carry away during the open season what the ice pushes in, in the winter. The lake is thus kept busy working over its own shore drift and since the fall of its level, is temporarily prevented from reaching the base of its cliffs. The constantly renewed dragging out of the gravels pushed shoreward by the ice keeps a belt of clean cobbles under the edge of the water. These features are seen in their relations with exceptional clearness in Beaver lake.

## PINE LAKE.

The basin of this lake is chiefly one large pit, reaching a depth of ninety feet, below the water level. The depth measured from the surface of the adjacent country is from twenty to forty feet more. Like the borders of other lakes of this district, the slopes of Pine are deeply and minutely pitted. Some of these pits lie low enough to form bays, a few of which are well shown on the hydrographic map. Other similar bays have already been cut off in the process of simplifying the coast line. Several such at the south end are now filled with peat.

The water of this lake comes chiefly from small springs and seepage from Beaver lake and that which is not evaporated passes north or west in the same manner. In exceptional seasons the lake may still overflow to North lake. The level is said

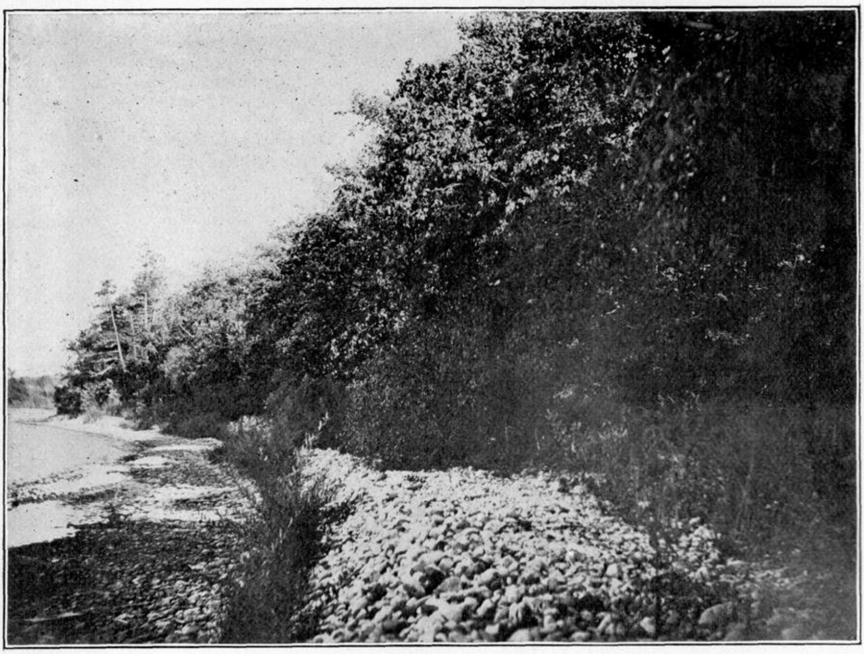


FIG. 1.
A fresh ice-push terrace, east side of Pine Lake.

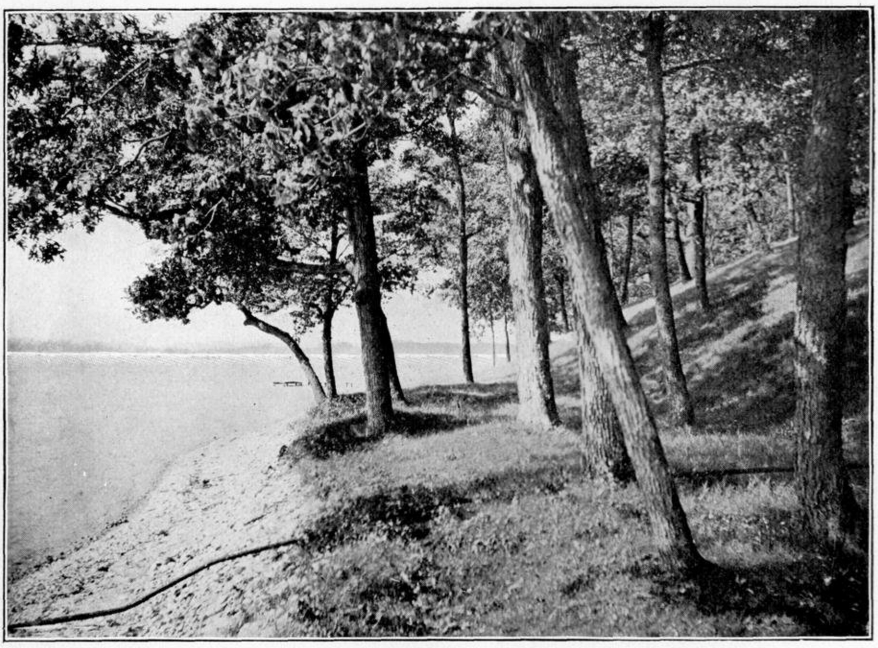


FIG. 2.
An old ice-push terrace, Oconomowoc Lake.

to be steadily falling. When the lake was visited in September, 1901, the level was two feet lower than the horizon at which its present cliffs were cut. Between the base of the cliffs and the water's edge there is a slope covered with gravel and cobbles formerly washed by the water and belonging to the shore drift. As the lake does not usually overflow, its height can not be maintained by a dam. Its fall indicates a general sinking of the level of ground water in the vicinity.

The records of cliff cutting during higher stages are distinct. Where cutting has simply nipped the base of the kame slope, there is seen the characteristic convex profile, as on the east side of the south end. At other places the waves have worn back the bluffs for some yards, as in the case of a few headlands on the west side. At such places the slope is due entirely to undercutting and weathering and shows none of the original features of the ice pit except its even top.

Some shoals lying forty rods or more from the shore at Pine Lake park are covered with bowlders. These are former elevations cut down to their present level by the carrying off of the materials which waves and currents were able to handle. Whether these elevations ever stood out as islands must be a matter of conjecture.

The quantity of material built into beach structures is small in comparison with the amount carried away from the cliffs. This is in entire accord with the form of the basin; its abrupt descent from the shore line makes it necessary that much waste from the headlands be first used in building the marginal shelf and paving the way for beach transportation. But despite the large consumption of gravel for this purpose, some of the small bays of the original basin have been cut off by bars now raised above the water level; others are being spanned by bars or spits not yet so advanced in their development.

The directions of spit building near the ends of the lake show the vigor with which surface currents may set toward the ends of a narrow lake and their feebleness in the opposite direction. The island at the east side of the south end is being extended southward in a long submerged spit of coarse gravels. The island at the east side, north of the middle, has a similar point at its north end, while erosion at its south end has produced a steep cliff and a subaqueous shelf some rods in width. The outlines of this shelf resemble those of the original island.

The fall of level, amounting to one or two feet, in a very few years has brought about a feature in this lake which is not in general associated with a falling level. This is the clearly defined marginal band or small terrace of clean cobbles, bounded on its front by a bed of gravel, sand, or mud. It belongs to a recently inaugurated nipping of a coast composed of kame materials; it is therefore characteristic of rising lake level. When the water surface falls, the margin is commonly located on a bottom whose slope is gentle. The barrier is, therefore, much more frequent than the new cut-and-built terrace. But where the lakeward slope has been very steep and the beach profile incomplete, the falling level may locate the new shoreline on the steep front of the marginal shelf. In this case cutting is renewed and the formation of a new shelf begun. (Fig. 33.)

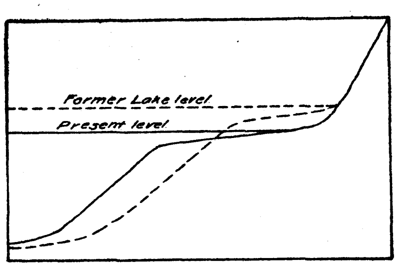



Fig. 33.—Profile of a steep shore (Pine Lake), showing how a falling of the lake level may revive cutting. The dotted line represents the former terrace, the solid line the new terrace.

These conditions are fulfilled along a considerable portion of the east side and at the north end of the west side of this lake. Where the offshore slope is very steep, as in the passage east of the island, the band becomes a shelf with a steep front, the typical breaker terrace.

Where the slopes of the coast are comparatively gentle, ice ramparts stretch for long distances. In the improvement of private grounds, they are often cut through, revealing the heterogeneous nature of their material which distinguishes them from beach ridges. At places the cobbles have been gathered by the ice from the broad strand and pushed into terraces at the foot of the cliff, which has been abandoned by the sinking lake. (Plate XXIV, Fig. 1, see also p. 34.)

### NORTH LAKE.

The basin of North lake consists of two large pits. At the present water level the rim between the two is but slightly submerged and plainly visible from the shore. In addition to the waters of the Oconomowoc river, this lake receives two small streams from the tamarack swamps on the north and some strong springs on the south. These springs represent the seepage from Pine and Beaver lakes, whose levels are above that of North lake. From the swamps at the north end, vegetation is advancing into the lake, thereby interfering with currents, detaining silt and narrowing the water area. More than half of the shore, however, including the entire east side, is against steep cliffs, or the familiar kame slope. Even where the ground around the west basin is low the lake is bordered by beach and not by swamp.

Along the steep slopes mentioned, cutting has been quite general. With a gradually sinking level, however, many of these cliffs are now protected from the waves by the presence of ice-push-terraces, notably on the east side. At the south end of the west basin the old cliffs lie far back from the present shore line. Southwest of the ice houses at the north end of the lake the former shoreline lies behind a swamp and is marked by old ice ramparts many rods from the present shore line.

Large ice ridges of the same kind occur at places along the present shore of the east basin. At North Lake post office a heavy ridge of this kind extends northward from the cliff on the east side and reaches far into the swamp. Such a position belongs to spits and bars rather than to ice ramparts. This is one of many cases where the location of such a ridge was determined by the convenience of currents. The material, which is largely bowlders, could only have been pushed inward from the bottom by the ice, probably after some sinking of the lake level. At the outlet is a similar feature which owes its location and horizontal form to waves and currents, while its height and abundance of bowlders are due to ice. (Fig. 34.)

The most distinguishing feature of North lake is the marl of the west basin. It is the sole material of the beaches which surround the basin. Its appearance on the beach is that of a white gravel passing into sand of the same color. Across former bays the currents have thrown bars of the same material. By a reduplication of the same process on the southwest side, there has been constructed a terrace several hundred feet wide composed of successive beach ridges of marl. The long slender points and partly exposed ridge which nearly separate the two parts of the lake are structures of the same material superposed upon the ridge which separated two ice pits.

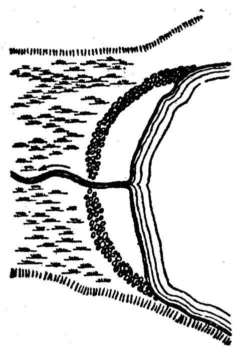


Fig. 34.—Outlet of North Lake, showing ice-rampart of bowlders built on the line of a bar. Scale 12 inches = 1 mile.

MOUSE LAKE.

Mouse lake occupies a narrow deep pit whose high banks are unbroken by swamps and but little indented by bays. It is not connected with any stream. It is fed by springs on its east side where the bluffs are from forty to one hundred feet high. Beyond these highlands, one mile away, lies Pine lake, whose water surface is seventeen feet higher than that of Mouse lake. The movement of underground water in this area is toward the west. In the few hundred feet between Mouse lake and Okauchee, the underground water has a further fall of four feet, the level of Okauchee being that much lower than that of the former lake. Accordingly no springs enter Mouse lake from the west, but on the opposite side of the separating ridge, many springs discharge into Okauchee.

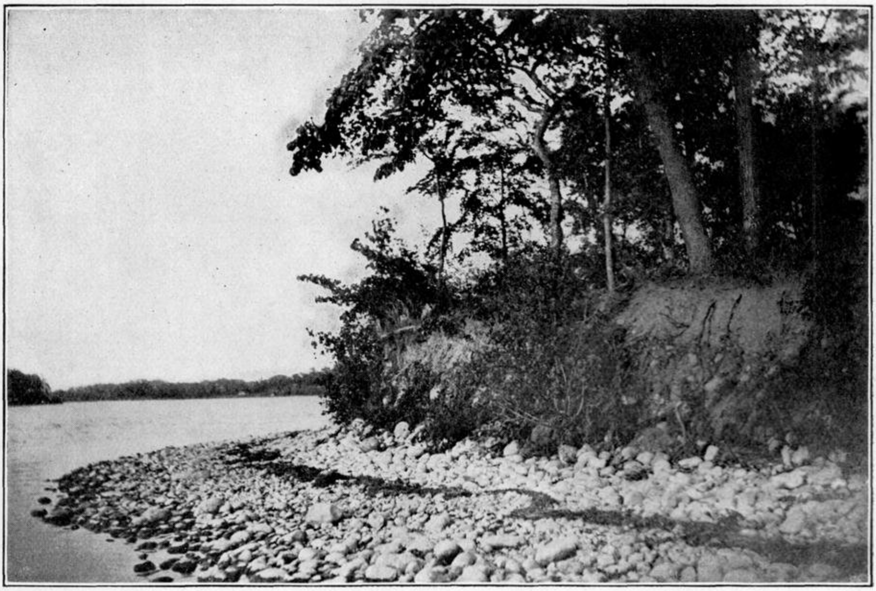


FIG. 1.
Cliff in kame gravels, Okauchee Lake. Actively cutting.

FIG. 2.
An abandoned cliff, Silver Lake.

The cliffs of this lake show considerable cutting, but most of the work has been done at a horizon two feet higher than that at which the water was working when the lake was examined in September, 1901. At the higher level, the base of the former cliff is distinctly seen. The waves are now cutting away the bench which lies at the foot of those cliffs. At some places this has been accomplished and the original cliff is again being driven backward. The abrupt descents to deep water have not permitted much of the waste of these cliffs to be used in contructing spits or bars even at the few places where the curves of the shore line might favor such structures. One small hollow at the north end is spanned by a good ridge. Recent dredging of the two bays at the south end may have destroyed the beginnings of embankments.

## OKAUCHEE LAKE.

The basin of this lake presents the most irregular contours to be found on any lake in the group. Its origin is not to be explained by the incorporation of a single block of ice in the water--laid deposits. The positions of two principal blocks may be pointed out with some assurance, but around the edges of the two main pits thus formed are arms, bays and attendant basins of all sizes and all degrees of separation from the central basins. The hydrographic map shows the larger irregularities which are not above the surface of the water; but even the present jagged shoreline has been somewhat smoothed by shore processes, from a still more irregular form. A rise of the water above the beach structures would give to the shoreline a new set of minute curves similar to those which belonged to the first shoreline.

A dam in the Oconomowoc river at the outlet holds the level of the lake about eleven feet higher than it would otherwise be. The long continuance of the lower level has left its evidence in the submerged stumps of trees which abound in the shallow arms of the lake. The comparatively recent beginnings of shore work at the higher horizon is also evinced by the shore profiles. (Compare Nagawicka, p. 112.)

Many of the cliffs of this lake are quite bare of vegetation. (Plate XXV, Fig. 1.) On the east side this condition is uninterrupted for a long distance. Generally, however, the closely crowded curves of the coast show an alternation of cutting headlands with small bays which are filling with swamp or beach deposits. Under the water the breaker terrace of coarse gravel and clean cobbles is present wherever the currents are at all active. It widens at places to twenty or more feet and its limits may then become less clearly defined. Its habitual narrowness and distinctness, however, still indicate a youthful shore line, whose beach profile is far from completed. Within the more open bays finer gravels are widening the incipient beaches, building lakeward as the salients are being pushed landward.

When once the beach profile has been well established and the gravel worn from the cliffs can no longer be carried out to the front of the marginal shelf, the many indentations will offer abundant opportunities for bar building. A number of such structures were partly or wholly completed while the water stood at its former low level. The long bay extending southward is partly crossed by an old spit from the east at its north end. The building of this spit has been suspended since the lake was raised and the system of currents changed. Between the island west of Garvin lake and the adjacent headland is a bar composed largely of heavy stones, showing that a part of its height is due to the work of ice. It rises nearly to the surface of the water, but it is not now in use, and the present currents are destroying rather than building it. A more notable illustration of the same kind is found in the long bar of heavy stones which connects the smaller island farther north with the adjacent shore. It is now from two to five feet below the surface of the water, and the entire shore with which it was connected is actively cutting back, showing no suggestion of even a spit at the place from which the former bar sprang. A spit was at one time built to the northwest from the cliff in front of the two hotels on the south side; this would in time have produced a bar across the long arm leading to the outlet. This piece of work is also abandoned for the present. The coarse materials of the structure are seen four or five feet below the surface, where wave action is powerless to affect them while the lake is at its present level. Its relation to the present level is made clear by the large tree stumps which it carries. It was constructed as a subaqueous embankment and raised above the water by beach processes during the time of low level before the outlet was dammed. During that time it was covered with large trees. Had the dam raised the lake by a less amount, building might have been renewed at this point; as it is, the currents passing in and out of the bay are too strong to permit its being raised.

The prominent point seen on the map north of Garvin lake is not a beach structure, but a ridge of kame materials, actively cutting on its lakeward side. The shallows which approach each other from the opposite shores and make a separate basin of the northwest portion of the lake have a similar constructional origin, though the passage may have been still further narrowed by beach deposits when the lake was low.

OCONOMOWOC LAKE.

This lake, like Okauchee, occupies a basin consisting in the main of two large pits; their connection is by a shallow strait over a ridge whose crest is a few feet below the water level. While completely surrounded by pitted plains, the slopes around the lake do not all have the steepness of the typical pit. On the west side, between the lake and the plain above, is a hummocky slope; on the south side the shoreline crosses swamps and kame ridges alternately; the outlet also is bordered by flats. But in spite of adjacent low ground and the existence of considerable shallows along the shores, vegetation is not much in evidence in this lake. The marginal waters are comparatively free even from rushes, and shore currents are unimpeded except by friction on the bottom.

As in the case of Mouse and Okauchee lakes, the springs of Oconomowoc lake are on its east side. Spring Bank is well named on account of the large number of springs issuing there. It lies on the side toward Okauchee lake which is less than a mile away and whose surface is twenty feet higher than that of Oconomowoc.

The cutting of cliffs on this lake is not active as compared with Okauchee and others whose levels have recently been raised by dams. Where the salient curves both east and west of the narrows face the west or southwest, there are small spots where the cliffs are devoid of vegetation. At few other places are the cliffs wasting fast enough to prevent the growth of grass and trees.

Beach functions are for the most part active, and beach structures are correspondingly prominent. High ridges extend for long distances in front of the swampy areas on the south side. These ridges were built as bars and imply a correspondingly large amount of cliff-cutting to furnish the material for building. They have since been much disturbed by ice push. Ridges of a similar nature border much of the east end of the lower basin. A massive one crosses the hollow east of Spring Bank, and another crosses a similar hollow east of the inlet. The last mentioned has grown lakeward by the deposit of shore drift until it may more properly be called a wave-built terrace. There is also a looped bar on the north side of the narrows. Beyond this passage in the smaller basin the currents have built low triangular points, one on each side. There are no similar points on the south side of the passage, the courses of shore currents here being more neatly fitted to the shore.

The pushing of ice has already been mentioned as deforming some of the beach ridges. It has also raised ramparts for most of the distance along the west side. This feature has been obliterated in many places in the improvement of private grounds. On the north side, just west of the narrows, is an ice-push terrace of exceptional beauty. (Plate XXIV, Fig 2.)

## LAC LA BELLE.

A look at the hydrographic map will show that the basin of Lac La Belle consists essentially of three ice pits arranged in a line whose direction is northwest to southeast. A six foot fall of the lake level would separate the northwestern pit from the other two, just as Fowler lake on the southeast is now cut off. The whole valley may have been used as a drainage line by glacial waters.

The slopes south and west of the lake show the topography of ground moraine. They rise gently from the water and their broad curves give no suggestion of a plain. At the middle of the northeast side are seen some kames which extend northwest along what was doubtless a drainage line when the glacier cov-

FIG. 1.
An old cliff on Lac La Belle. At its foot are found, first grass, farther out sedges, then water lilies, and lastly rushes, which are now invading the lake, seen in the remote background at the left.

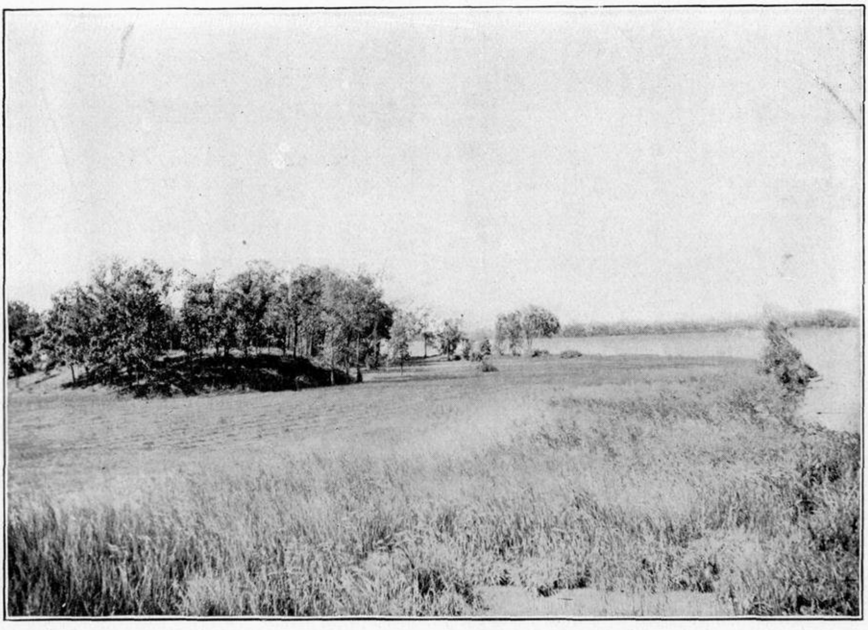


FIG. 2.
Land added to the shore of Lac La Belle by vegetable accumulation. The original shore was against the kame at the left.

ered the valley. (Plates V and XIV, Fig 2.) Where these form the coast the banks show characteristic steepness.

The peninsulas and salient curves shown on the map are for the most part being cut at the base and show distinct cliffs. Very few cliffs. however, are wasting so fast as to show facets bare of vegetation. A few wihch are cut in the kames on the northeast side show a convex profile where the kame slope above merges into the steeper slope of the cliff below.

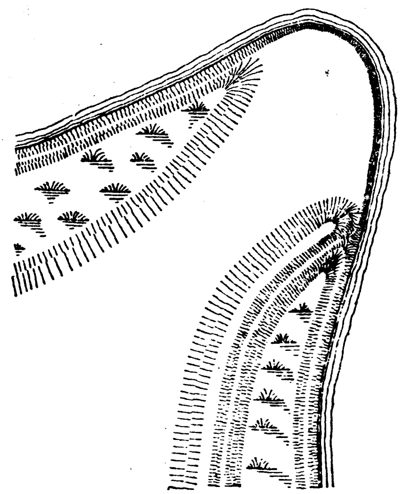


Fig. 35.—Bars from headland in Lac la Belle. Scale 10 inches = 1 mile.

The peninsula which indents the south shore near the west end is actively cutting away and stands with an almost vertical face. Alternating currents have carried the detritus from this headland both south and west. Both ridges have been subjected to much pushing by the ice which has added bowlders from the bottom to the gravels which were brought by currents. The cutting back of the headland did not stop when the ridges were formed, but its further cutting required that they should be shifted in position. Two ridges are now visible on the east side. The inner and older one has a sharper curvature. The place where it once joined the cliff is now covered by the lake. As the cliff retreated the proximal end of the ridge was cut away. The present ridge with its broader curve intersects the line of the older. (See Fig. 35.)

The south shore of the bay west of this peninsula was once a vigorously cutting cliff. The old cliff is now well covered with grass, which also covers a narrow flat band at its foot. Beyond this belt of grass come other zones of sedges, cat tails, pond lilies and rushes in the order named. (Plate XXVI, Fig. 1.) The last named are leading the advance into the clear waters of the lake.

The lowlands bordering the bay north of Buzzard point are fronted by large beach ridges, which broaden at the north end into a terrace. The marginal bottom is very gently shelving to a distance of some hundreds of feet. At this distance it is not more than four or five feet deep, but free from vegetation. The presence of occasional cobbles in the sand suggests lower stages of water with the shoreline farther out.

Ice ramparts are seen along the west and northwest shores. At one place an ice made ridge consists of marl. The effects of ice in deforming beach ridges is quite generally observed on this lake.

## FOWLER LAKE.

Fowler lake is a single deep pit whose level is held by a dam, at a height seven feet above Lac La Belle. Cutting would be quite general around this lake if the artificial walls of stone and piles were removed. The curves upon which these are built do not always agree with those which the currents find it convenient to follow. Accordingly the walls are washed vigorously in some places, while an occasional beach of gravel is beginning to build where the currents diverge from these artificial boundaries. The channel of the Oconomowoc river between the lake of that name and Fowler lake has been enlarged and made navigable for the steamers in use on Oconomowoc lake. The river has a fall of somewhat more than two feet in this interval. The level of the latter lake is preserved by the two locks in the channel.

## SILVER LAKE.

If a line were drawn limiting the ground moraine on the east it would lie a little east of Fowler lake; trending a little west of south it would divide the basin of Silver lake giving the eastern part to the strip of kames and pitted plains and the western part to the area of ground moraine. The eastern slopes of its basin are steep and kame-like, both above and below the water surface. Above the basin lies a pitted plain of the most pronounced character. The topography on the west is like that west of Lac La Belle, passing by swamps and rounded hills into the typical drumlin area farther west.

The features of interest on this lake are connected with its falling level. Between the road and the north shore a cliff two and one-half feet above the water level may be distinctly seen. For much of the distance, may be seen offshore, a typical wave-built barrier (see Chapter II, page 30). This characteristic feature of sinking levels is separated from the former shore of this lake by lagoons which are analogous to those which separate the inner from the outer shore line on much of the Atlantic coast. The bases of other fading cliffs which lie nearer to the water are seen on the east side. (Plate XXV, Fig. 2.) On the east and south sides the hollows are crossed by gravel beach ridges of large dimensions. One on the west side of the peninsula which indents the south side is especially typical in profile.

# CHAPTER VII.

## LAKES OF WASHINGTON COUNTY.

### TOPOGRAPHY OF THE REGION.

The peculiar characteristics of the kettle moraine are nowhere more strikingly displayed than in the vicinity of the lakes of Washington county. A most impressive view may be had from the hill one-half mile west of the Schleisingerville station. The village to the east is seen against the background of a range so abrupt and complex that it may well be described as a pile of hills. To the west, more than a hundred feet below the observer, stretches the gently rolling ground moraine. A band several miles wide between the Kettle moraine on the east and the ground moraine on the west is low and partly covered by swamps, with an occasional group of kames. These same topographic types constitute the features of the landscape as viewed from any exposed point on the margin of this portion of the Kettle moraine. Its height, one hundred and fifty to two hundred feet above the adjacent plains, its confusion of abrupt hills and equally steep-sided undrained basins, and its marked topographic contrast with the rolling plain, above which it rises, are sources of interest and pleasure to the sightseer as well as to the student.

This so-called range is not a single ridge but an assemblage of ridges, which may continue rudely parallel for some miles, but meet and merge at low angles. Their heights also vary within short distances; a ridge may come to an end at a transverse valley or at the border of the range. The number of constituent ridges in a cross section in this vicinity varies from three to five. There is the same lack of continuity in the valleys between the ridges, some uniting with transverse valleys, others opening on the outer lowland and still others being entirely enclosed.

It will be remembered that this kettle range is the combination of terminal moraines of two glaciers. (See Chapter I.) In this vicinity the ice movement was from the east on the one hand and from the northwest on the other. Each ridge marks the position of the front of a glacier while the ridge was being formed. This front alternately advanced and retreated, but the ever-changing sinuosities of its outline occasioned, upon each new advance, a pushing of the old ridge at some points and an interval between old ridge and the ice at other points. Thus a new ridge would be formed which at places appeared as an independent feature.*

While these ridges were forming, the drainage from the constantly melting ice was necessarily in courses along the ice fronts, that is parallel with the ridges. As any one valley served as a drainage line only while the ice stood at one or both of its sides and there was thus a constant supply of morainic material upon its slopes, these valleys should not now be expected to present the features of well developed river basins. The latest of such drainage lines on the side of the Green Bay glacier was along the low strip bordering the western base of the moraine. It is now partly occupied by swamps and includes the basin of Pike lake (see fig. p. 133). At the east base of the moraine the last drainage line for the Michigan glacier, is now occupied in part by Silver creek with the series of lakes and swamps through which it flows. The depression along the same line is also well marked south of Silver lake.

During each recession of the ice front, its wasting edge was generally the seat of some kame building. These kames, sometimes few and small, sometimes in extraordinary development, lie on the floors of all the valleys and on the flanks of the ridges. The massive knob in Schleisingerville, partly consumed for gravel for the Chicago, Milwaukee & St. Paul railroad, is of this origin. A similar mass two miles north of the village is being cut away by the Wisconsin Central railroad. Kames lie at intervals on the low strip west of the moraine, or appear as islands in the swamps. They are similarly developed along the drainage line at the east base. A very prominent kame area reaches

* Geology of Wisconsin, Vol. II, p. 207.

southeast in a tongue between Little Cedar and Silver lakes, abutting at the northwest against the high moraine ridge. The plain which lies east of the Silver creek line is at places deeply and beautifully pitted. Such a pitted area lies on the east side of Silver lake. On the site of this plain the remnants of the retreating glacier became isolated blocks of ice. The interspaces were filled to a plane with sand and gravel from the glacier on the east.

### THE LAKE BASINS.

The trough which is partly filled by the waters of Big Cedar lake is one of those already described as involved in the structure of the moraine. Kame gravels partly filled it to a plane above the level of the lake and it is probable that the whole valley would have been filled to the same depth, had not the present lake basin been occupied by a mass of ice. On the west side lies a ridge whose crest is from one hundred and fifty to two hundred feet above the lake. On the east side of the lake the shoreline south of the outlet cuts diagonally (NE. to SW.) across the trend, truncating a ridge and a valley east of the ridge. North of the outlet a more easterly ridge with the same trend slopes less abruptly to the water than does the one at the south end.

If the depth of the water, about one hundred and five feet, be added to the height of the enclosing ridges the bottom of the trough will be seen to be two hundred and fifty or three hundred feet below the rim on the west side and somewhat less than two hundred and fifty feet below the rim on the east side. The trough continues to the southwest beyond the limits of the lake, but it is here filled with gravels to a height of thirty or forty-feet above the lake level. Farther to the southwest it descends to the swamp which lies outside the limits of the moraine. The lowest point in the rim of the lake is on the east side where a transverse valley connects this trough with that which contains Little Cedar lake. Through this opening the waters of the larger lake are discharged into the smaller.

This accident of enclosure between the morainic ridges and the partial occupation of the trough by an ice mass are the only factors in the origin of this basin which are now known with certainty. Near Big Cedar lake the underlying rock surface is too deeply buried by the drift to be reached by wells and there is therefore no satisfactory knowledge of the pre-glacial topography. The Niagara limestone lies close to the surface of

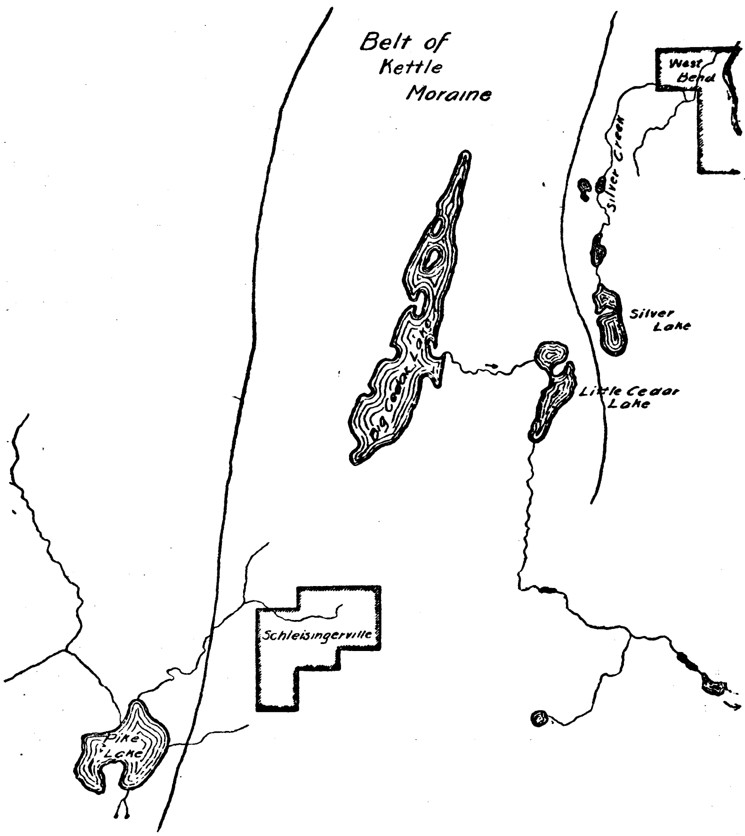



Fig. 36.—Vicinity of the lakes of Washington County. Scale ½ inch = 1 mile.

the ground at Hartford six miles to the southwest and on both sides of Little Cedar lake the same rock is found only ten feet below the level of the water or about thirty feet below the level of Big Cedar. The surface of the bed rock under the valley of Big Cedar lake is therefore much lower than the surface of bed rock at the sides of that valley. What the nature or shape of that depression may be is uncertain and it does not appear to have had anything to do with locating or causing the lake basin except to make a greater depth possible.

The basin of Little Cedar lake is similar and had the same origin. Its bottom lies below the level of the bed rock near its shores, but its immediate cause was the accident of an undrained trough between the morainic ridges, the depth of the trough at this place being preserved by a temporary filling of ice. The topography of its shores has not been to any great extent controlled by outwash from the ice. Viewed from the higher bluff to the north, its slopes, like those of Big Cedar, are seen to be the characteristic slopes of ridges of terminal moraine.

The basin of Pike lake on the west of the range and that of Silver lake on the east have already been referred to as the lower places of former drainage lines when the melting glaciers discharged their water along lines between their fronts and the ridges of their own building. These sags in drainage lines present no difficulty if three circumstances are borne in mind. The first is the shortness of the period during which these courses were used and their consequent immaturity of profile as drainage lines; the second is the constant dumping of debris from the front of the ice and by small tributary glacial streams; the third is the presence of isolated ice blocks whose subsequent melting always impresses upon the topography a character which is the opposite of that which running water tends to produce.

The basin of Silver lake presents a conjunction of features which is highly instructive. Standing on the kame peninsula at the south end and looking north the observer sees on the west side the broken slope of the high moraine ridge rising one hundred and twenty-five feet or more above the lake. On the east side he sees a plain thirty or forty feet above the lake, pitted in places and falling off to the lake with the steep slope, which is characteristic of kames and of pits due to ice blocks. This basin has, therefore, on its west side the distinctive feature of the basin of Big and Little Cedar lakes, and on its east side the features of ice pits or lakes of kame areas. While the plain to the east was being built by the outwash from the Lake Michigan glacier, whose front had retreated eastward, it may be conceived as reaching to the foot of the high ridge on the west, but on the

Pebbly Beach, Big Cedar Lake.

sie of Silver lake the deposit included some blocks of the basal ice of the retreating glacier. The melting of these blocks caused the basin of Silver lake and the other small lakes and swamps of the same line. Essentially the same features, the plain on the east, the longitudinal valley, constricted at places by kames, and the high moraine on the west are maintained for some distance both north and south of the Silver lakes. For nearly the entire distance to West Bend, Silver creek is merely the overflow from lake to lake or from swamp to swamp along this line.

All the lakes of this vicinity are fed by springs issuing from the glacial deposits, Little Cedar receiving also the waters from the springs, which discharge directly into Big Cedar. The many undrained areas of this vicinity, of which the kettles are often but the narrow and picturesque bottoms, divide the rain which they receive, giving the smaller part back to the atmosphere by evaporation, and the larger part to the earth, to supply the needs of the soil or to issue again as springs.

## DEVELOPMENT OF SHORE LINES.

The shores of Big Cedar lake present many features of erosion and construction by waves and currents. Since the shoreline nowhere is on the solid rock, a large part of its extent passed rapidly through its youthful stage and has now a completed beach profile. Along this beach is a succession of slowly cutting cliffs and wave-built features.

This is true in general of the west shore where the initial slope from the water's edge to the deep basin was not steep. Here, by a very little nipping of the coast, the waves carried out enough material to build a beach upon which transportation alongshore could proceed; that is to say, the initial slope being small, a small amount of detritus carried outward from the coast, went a long way and the waves soon found themselves unable to drag to the front of the growing shelf any material except that which was sufficiently fine to be handled by a much enfeebled undertow. The larger pebbles which were thus subjected to a continual alternation of dashing in and dragging out were carried alongshore by the currents and used to fill the smaller reentrants.

The part of the shore showing the least development of beach profile lies on the east side between Pebbly beach and the south end, notwithstanding the fact that this is probably more exposed to storm waves than is any other portion. The reason for this youthful aspect lies chiefly in the abruptness of the initial slope. Even now after some spreading of waste upon the bottom and some cutting back of the land, a depth of more than eighty feet is reached at little more than one hundred yards from the shore. The slope of the land is still steeper. Such a slope aids the waves greatly in dragging out stones, and a large amount of filling must be done before the edge of the dump grows out to quiet water and its growth is thereby checked. This stage of growth has not yet been reached in the strip described, hence large cobble stones are still carried out beyond the depth from which they can be recovered by incoming breakers. This lake, like many others, has had the youth of its shores renewed in recent years by a low dam.

The small amount of cutting which has already been done, has loosened the supports of many bowlders which have fallen down and now impede the work of the waves. The ice keeps them pushed landward and they are sometimes seen to be pressed deeply into the cliff of moraine. So effectual is this defense in retarding the work of cliff-cutting that the present cliffs are nowhere bare. Everywhere the wasting of their faces is sufficiently slow to allow grass and trees to grow. This vegetation in turn contributes to the stability of the bluff.

Among the bowlders and the heavier cobbles, smaller stones and gravel are carried alongshore by lighter waves and currents which find the present width of the platform quite sufficient for beach transportation. This material traveling southward is building a small spit at the south end of the cliff, which is near the extremity of the lake. That which travels north adds to the width of the beach ridge already constructed across the former swamp south of Echo point. The assortment which this material has undergone has suggested the name of Pebbly beach. (Plate XXVII.)

Echo point, though now protected by an artificial bowlder wall, has cliffs which have furnished shore drift both to Pebbly beach on the south and to the bar which now borders the bay

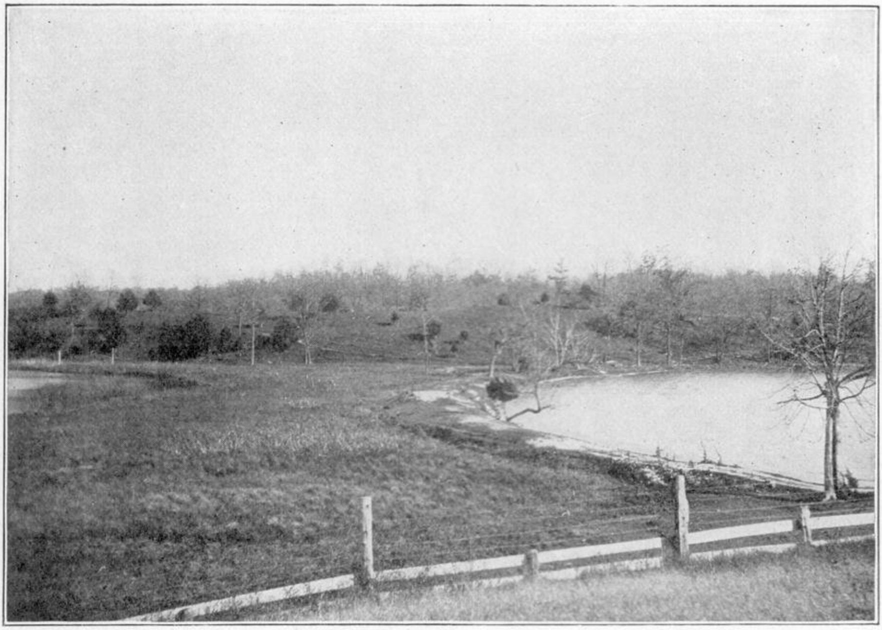


FIG. 1.
Bar connecting island with mainland, Big Cedar Lake. Looking east to the island.

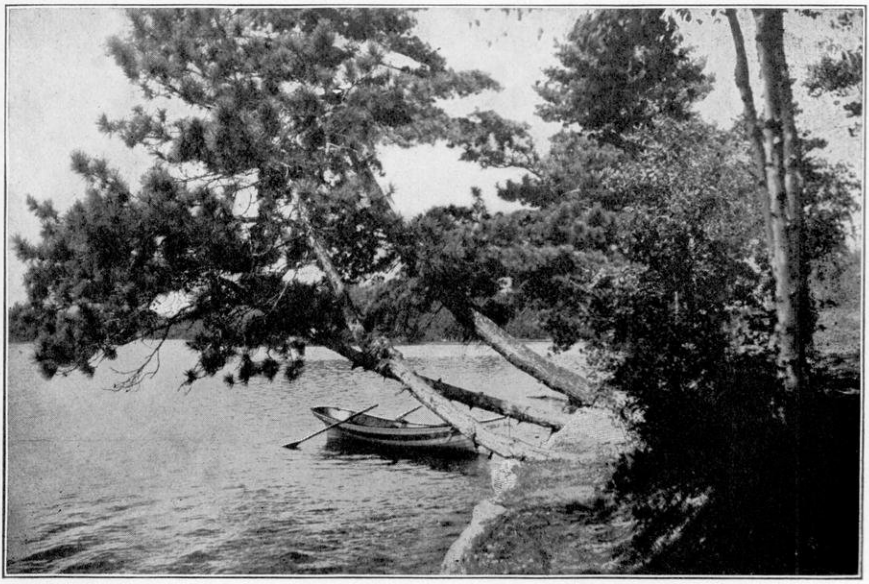


FIG. 2.
Rainbow Lake, Waupaca Chain. Trees undercut by waves. In their endeavor to maintain an upright position, they have curved upward in process of growth.

east of the point. The ridge which borders this bay contains some history. The part on the south side was built eastward by material from Echo point. The part on the east was built southward from the cliff south of the outlet. Each part has coarse material near its cliff, becoming progressively finer until sand alone is brought by the currents to the southeast corner. The ridge on the east is five or six feet high and forty feet wide near its extremity. It is older than the other and extends south past the corner of the bay. The broader expanse of water necessary to that building may even have passed over to Pebbly beach, leaving Echo point as an island. At a later time the other ridge advanced from the west, intersecting the first and stopping the growth of its point.

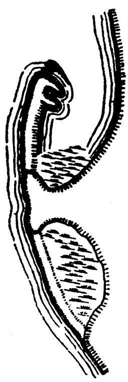


Fig. 37.—Point Lookout, Big Cedar Lake. Scale 7 inches = 1 mile.

Point Lookout is partly but not wholly a wave-built structure. The course of its growth embraces a former small island or peninsula of bowlder clay from which a long ridge, which is mainly the work of ice, extends southeastward to the mainland. North of the nucleus of bowlder clay a spit makes the point proper. (Fig. 37.) Currents setting toward the mainland have made a hook of this spit. The hook itself once occupied a position farther south, but the currents from the south built too rapidly for the currents from the northwest and the reversed point was obliged to take a new position farther north. A third tooth still farther north is already outlined by an embankment of gravel, not yet above the level of the water.

Linden Point is a perfect illustration of an island tied to the mainland by a bar. (See hydrographic map, also Plate XXVIII, Fig. 1.) The island is a glacial ridge thirty-five feet high, whose base shows distinctly the effects of wave cutting. The cutting on the west side was done when currents from the south flowed freely through the channel more than an eighth of a mile wide between the island and the mainland. In the progress of shore development the north and south currents were caused to use the larger channel east of the island and the relatively quiet water behind the island received the waste won by currents from the island and the cliffs to the south. Beginning as spits from the mainland and island, the embankment became continuous when the spits met. It now swings in a beautiful curve adjusted to the currents on its south side.* The edge of the water on its north side being left stagnant has filled with rushes and swamp grasses.

Bar building between islands has been done on a still larger scale at the north end of the lake. Gilbert lake was once a part of Big Cedar. At its south end was a small glacial island and on its east side a larger island. Currents from Big Cedar continued their courses into Gilbert and did some work upon its shores, but the currents which pursued a course outlined by the islands did more work and, against the opposition of cross currents, succeeded in building bars spanning the passages. These bars are now broad and dry, covered for the most part with trees.

This end of the lake, and especially Gilbert lake, show a rapid advance toward extinction. The mud which is washed in by rains from the surrounding hills, shallows the water. The growth of rushes impedes the already feeble currents and prevents disturbance of the silt. Grasses are closing in upon the retreating lake and are followed by trees at no great distance.

Little Cedar lake shows one excellent example of shore work. The point at the north end which separates the two parts of the lake was once an island.* The currents from the southeast

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* At the right, in Plate XXVIII, Fig. 1.

* See map, Fig. 36, p. 133.

passed through the east channel to the north basin. The record of this stage is a spit directed to the northwest through the old channel which is now closed. Later the currents from the southeast found the channel too small and passed to the south side of the island, building a bar. The isthmus thus formed has been broadened by swamp growth in the quiet water on the north side. Currents suffer a check in the bay east of this peninsula and have built a gently shelving sand beach upon which bathers may go out two or three hundred feet.

# CHAPTER VIII.

## ELKHART LAKE.

### GEOLOGICAL HISTORY.

This lake in Sheboygan county lies about half way between Lake Michigan and the south end of Lake Winnebago. The dominant topographical feature in the vicinity is the Kettle moraine. Its crest is just east of Elkhart lake. North of this place its trend is north-northeast, but just south of the lakes it turns more to the westward and for some miles its course is more west than south. It rises from one to two hundred feet above the general level on its west side and nearly twice that amount above the country on the east. Notwithstanding its conspicuous height it does not constitute a water parting for any but the smallest streams. The drainage is controlled by a much older and more uniform ridge formed by the outcrop of the gently dipping Niagara limestone. (See Chapter I, p. 1.) This ridge runs along the east side of Lake Winnebago, its steep, west-facing escarpment forming the east wall of that lake basin. Its long and gentle east slope begins but a few miles from the lake and it is down this slope of thirty miles that the small streams flow into Lake Michigan across the trend of the Kettle moraine. This was also the course pursued for geological periods before the glacial invasion. The slope had been furrowed by valleys and its topography influenced the behavior of the ice.

The course of one such valley included the locality of Elkhart lake. Well borings have not found bed rock at less than ninety feet below the surface of the lake, and the fact that some have gone much deeper without finding rock indicates that the surface on which the drift was laid down was far from even. On the other hand the rock crops out only a few miles to the north. It is quite probable that the valley whose former existence is revealed by these borings, occupied a position similar to that of Sheboygan swamp which lies west of Elkhart lake and is much elongated in the direction north of west. This direction has a rough agreement with that of the movement of the ice of the Green bay glacier. The valley might have been eroded deeper by the glacier instead of being partially filled had the same conditions occurred farther back from the limit of the glacial advance. As it was, the glacier had no eroding power, neither was there any exit for the waters of the melting glacier where they could escape with sufficient power to carry away the load brought to this basin. The result was a partial filling of the valley.

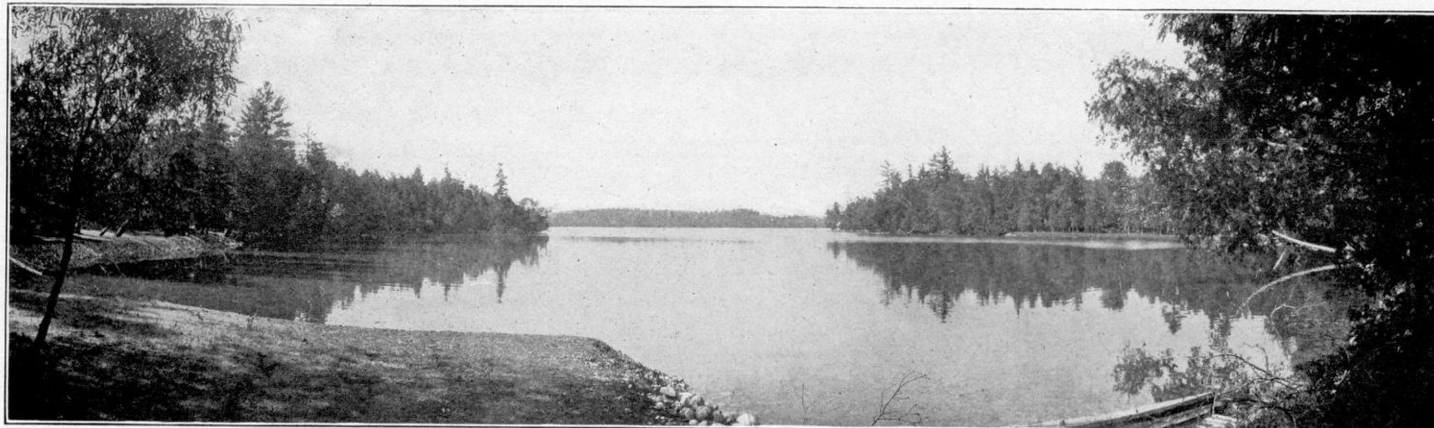
The filling of this valley was by two distinct processes and with two kinds of material, resulting in different topographies. The area subject to these two processes may be roughly separated by a line drawn north and south just west of Elkhart lake. Between this line and the steep slopes of the Kettle moraine on the east the material appearing at the surface has been for the most part handled and laid down by the water issuing from the melting glacier. West of this line the material is that which lodged below the ice. East of this line are kames; on the west side are the broad curves of the ground moraine, except where swamp filling has since built the surface to a flat. There are depressions east of this line and the largest one contains Elkhart lake; but all such depressions must inevitably have been filled with the abundant gravels carried by the streams between the two glaciers, had they not been filled for the time being with remnants of the glacier. West of the line indicated, there was left a wide and shallow basin in the ground moraine itself. On the withdrawal of the ice the latter became a lake some miles in extent. Its remnant is now Sheboygan swamp.

As the front of the Green bay glacier retreated westward from the line of the Kettle moraine, the trough left between the ice and the moraine was for the most part filled with gravels to a height of thirty feet or more above the present level of the lake. Some kames were built much higher than this; a line of such hills on the south and west sides of the lake rises from one hundred to one hundred fifty feet above the water. They are of very heavy gravels, the individual stones sometimes reaching the size of small bowlders. They indicate drainage from the glacier and deposition in the corners or recesses of the ice front.

## SHORES OF ELKHART LAKE.

As is common with lakes of this origin, Elkhart lake has had steep banks from the beginning. (See Chapter I, p. 4.) A very large proportion of them are also being cut at the present time, their steepness being thus preserved or increased. Being high, a small amount of cutting at the base furnishes a large amount of material to be disposed of by waves and currents. This and the limited power of the waves on so small a lake are conditions for a slow retreat of cliffs. The steep slopes are, therefore, well wooded, a circumstance which still further retards wasting while it conduces greatly to the charm of the scenery.

The youth of the shore line is emphasized by the prevalence of cutting, even in bays where a vigorous circulation may not be supposed to reach. This is true of Turtle bay (Plate XXIX), which would seem liable to be cut off by a bar, and to become filled with sediment and vegetation in an early stage of the lake's life. No such bar, however, appears; on the contrary the west shore of this bay is not only not receiving sediment at the water edge, but it is kept clean and fresh by a small amount of cutting. An examination of the shore confirms what is suggested by the map namely that the shore west of this bay does not yet afford a sufficiently smooth path for currents, to make bar building possible at the mouth of the bay. There remain minor reentrant curves to be filled or headlands to be cut away before the shore currents can bring drift from any great distance. At the present time the current from the west is dissipated and its load lost in shallowing a considerable area in front of the bay. The shore conditions are more favorable to the the building of a bar from the east side, but east winds in general lack the power of west winds, hence currents from the east bring less load. Notwithstanding this adverse condition, there is much more shallowing at the mouth of the bay on the east side than on the west. The currents fail, however, to run tangent



Turtle Bay, Elkhart Lake; looking toward the lake.

to the shore in one constant direction, hence the sediment is spread out over a shoal instead of concentrating into a bar.

Currents have done more reconstructive work at the northeast corner of the lake than at any other part of the shore. The ground between the present roadway and the shore is for the most part a beach deposit. Several ridges of this origin may be distinguished. Some of the filling near the water's edge is artificial. The sandy beach, however, and subaqueous terrace of sand extending out nearly forty rods from shore, indicate that the widening of this beach by artificial means is only anticipating the work which the lake itself would do if allowed a little more time.

West of this corner to Turtle bay and south to Echo bay are cliffs from twenty to thirty feet high, well wooded and retreating very slowly. The east side of the lake, being most exposed to the strongest wave action, should show the greatest effect of cutting, but the marginal shelf, most of whose width is probably due to deposition, rarely exceeds five rods in width. Near Echo bay, where the slope of the bank becomes less steep, the ice has raised ramparts of the kame material to a height of seven feet. It is significant of the durability of these features that one of these ridges in which small bowlders are involved, and which has still much of the ruggedness of youth, lies entirely behind some gnarled spruce trees, the largest of which are at least eighteen inches in diameter. These trees have grown up in front of the ridge since it received its last push. A smaller and lower ridge at the water's edge seems to have been made at a lower stage of the water.

Echo bay, at the southeast corner of the lake, is in every way similar to the northeast bay. The wave-built terrace at its head is covered with a fine, dense growth of cedar and the area of dry land is constantly growing lakeward by additions on the front of the sandy beach. The situation of this bay is favorable to the production of a wave-built terrace inasmuch as surface currents driven by west and northwest winds are quite likely to set toward the head of the bay along both sides. The escape of the water is then entirely by undertow, and the load which the currents carry is left on the beach in the bay.

From this place to beyond Talmage point, the shore is against the high ridge of kames mentioned above. The three headlands represented on the map are outstanding masses of this ridge. Talmage point is seventy feet above the water and parts of the ridge farther southeast are nearly twice as high. Some deep kettles in this kame area border the lake and formerly made scallops in its outline. To cut these off has been among the first tasks of the currents, though the large bays remain as in the infancy of the lake, and even within the deep reentrant curve south of Talmage point are evidences of cutting. A fine kettle having a history similar to that of those on the west side, is found on the east side of Turtle bay. It is separated from the lake on the south by a single ridge, whose position and shape might seem to be that of a wave-built point. Its resemblance to the latter is purely fortuitous. Its character is that of an original kame ridge. Between Turtle bay and this kettle, now containing a swamp, is a beach ridge much disturbed by ice push. Ice pushing on the west side of the lake has also been general. For a considerable distance between Talmage point and the Outlet bay, the combined action of beach processes and ice pushing has raised a strong ridge which has been artificially modified into a walk.

The outlet is at the west end at the extremity of a narrow bay which has at one time been wider than it now is. The original level of the channel has been lowered a little by erosion but further down-cutting is now prevented by a wooden sill. On both sides of the outlet are flat strips behind which lie the steep bluffs whose bases were at one time cut by the waves. This condition was associated with a more youthful stage of the shore. It may also have been associated with a higher stage of the water. No doubt the most important condition of this wave action was the union of Elkhart lake with the large lake on the west which was the predecessor of Sheboygan swamp.

*Sheboygan swamp.*—A swamp, fifteen or twenty square miles in area, is but one of many evidences of a former large lake west of Elkhart. The location of its shores at one stage (probably not that of its greatest extent) are found about forty rods west of the outlet of Elkhart lake. Here are (or were until recently) two broad gravel ridges several feet in height and trending north and south. (Fig. 38.) About a quarter of a mile to the north, the more easterly one of the two, indicating the greater extent of Sheboygan lake, runs tangent to the western base of a hill which formed the eastern shore of the now extinct lake.

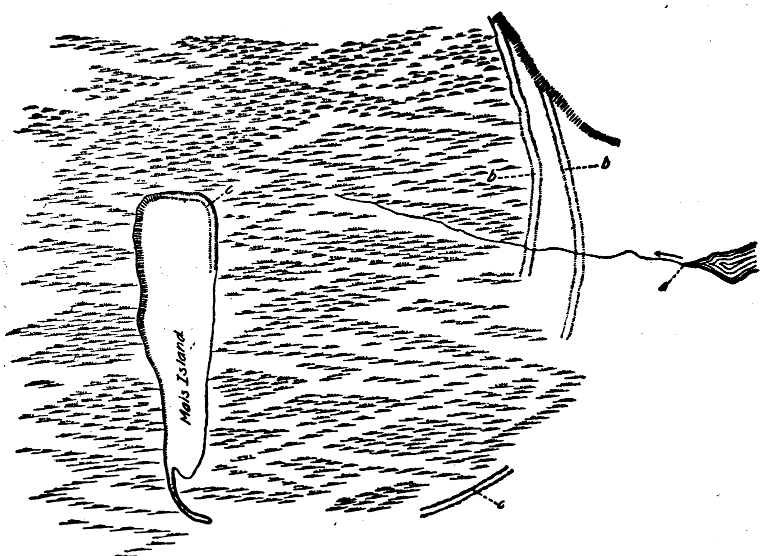



Fig. 38.—East side of Sheboygan swamp: a Outlet of Elkhart Lake; b, Beach ridges of former Sheboygan Lake; c, Ice ramparts. Scale 2 inches = 1 mile.

The other ridge which lay west of the first, has been cut away for gravel. Its course merges with the contour of the same high ground but farther to the west and north. Both lines may be followed south beyond the stream but are there lost in the wooded swamp. It is evident that the former Sheboygan lake once washed the base of the hill to the north and that a bay reached eastward to the narrow passage into Elkhart lake. The currents of the western lake were strong as might be expected from its size. They ran tangent to the high bank at the north, cut a cliff at its foot and with the material thus gathered, built a bar in front of the bay. The second and larger ridge (now cut away), is due to a repetition of the same process when the shore lines had attained greater maturity.

About one-half mile south of this place at the south side of the swamp, are found good ice ramparts, built when the now densely wooded swamp was an open lake. Two miles to the north the same feature is seen just west of the road and at the border of the swamp. Beach action may have helped to make the ridge at this place as it certainly did at some places farther west. The ridges are of large proportions and indicate vigorous shore action.

The horizontal dimensions of this body of water were similar to those of Lake Geneva or Green lake and its depth at places was not less than forty-five feet, as shown by deposits of muck. The power of its waves is best shown around the island owned and farmed by Adolph Mais. This island is one mile directly west from Elkhart lake and was exposed to the full power of the waves raised by the westerly winds. (Fig. 38.) The island, like the shore of this western lake, is of bowlder clay, a mere rise in the ground moraine. On its west side is a cliff ten to fifteen feet high, parts of which are still almost bare of vegetation and the whole of which has suffered little loss of steepness since the lake gave way to swamp. At its foot is a bowlder line similar to those found along the cliffs of Green lake or Lake Mendota. At the south end of the island is a long hook (fifty rods or more) built partly of bowlders which the ice pushed up from the shallow bottom and partly (especially near its point) of the shore drift carried south from the cliff described above. The east and north sides of the island were less exposed to waves, but their more gentle slopes were less able to withstand the pushing of the ice which here made ridges of unusual magnitude. The large proportion of heavy bowlders gave them a framework which has suffered little change since their making.

*Cedar lake.**—A mile south of Elkhart lake is Cedar lake (Plate XXX), whose origin was similar to that of its northern neighbor. It is surrounded by a higher level beneath which it is deeply sunk. The two beautiful islands are isolated kames and indicate that the ice remnant which preserved the basin from filling with kame gravel was not continuous. The level of this lake is said to be twenty-two feet above that of Elkhart lake, a mile away. Apparently it is slowly falling and is now several feet lower than the level at which the main cliff cutting was

* Residents now call this Crystal Lake.

Cedar Lake, Sheboygan County. Looking east to the main ridge of the Kettle Moraine.

done.† The lake is therefore surrounded by a considerable strand of gravel and cobbles. Both the islands are connected with the adjacent mainland by bars which at ordinary stages of the water are submerged.

† As the level of this lake is subject to seasonal fluctuation its permanent fall may still be questioned.

GREEN LAKE.

## CHAPTER IX.

Green lake is an imposing body of water. It has an area of eleven and a half square miles and is much the deepest of all the Wisconsin lakes surveyed. The appearance of its clear, cold water two hundred and thirty-seven feet deep suggests the name which it bears. This dark hue is intensified in the shadows of its rock walls and by the reflection of high forested slopes. The coast presents a succession of cliffs cut in rock, cliffs cut in glacial till, long wooded slopes, sandy beaches, and gently rising farm lands, with relatively few swamp areas. Its margin shows all gradations from rock benches floored with large angular fragments and plunging into deep water at a few feet from land, to sandy beach where bathers may go out one or two hundred yards. The lake is small enough to make rowing generally safe and pleasant, and large enough to exhibit the power of waves and currents in rough weather.

### SURROUNDING TOPOGRAPHY AND ITS HISTORY.

The surface of the adjacent country is fluted with great ridges, sufficiently continuous to be a most noticeable feature of the topography. They are roughly parallel, having an east-northeast direction and rising one hundred to two hundred feet above the level of the lake. These ridges have broad, gently rolling tops occupied by farms. Their sides are often quite steep, exposing occasional ledges of sandstone and limestone. The intervening troughs are sometimes occupied by streams, occasionally by shallow lakes or swamps or by flat meadows which have once been swamps; frequently, however, by the rolling topography of a ground moraine.

These ridges are not in the main of glacial origin. The drift is generally thin, often revealing the rock core which constitutes the mass of the ridge. The larger features of the topography were carved by running water before the ice came on. The streams occupied valleys corresponding in a general way with those now seen between the ridges. There can be little doubt that the direction of this drainage was westerly, the smaller, nearly parallel streams discharging into a larger, which followed the base of the Lower Magnesian escarpment. The glacier found here an area in which the streams had cut steep-sided valleys in a moderately flat upland, the area of the residual uplands being at least as great as that of the valley bottoms.

The effect of an ice sheet, moving nearly in the direction of former drainage lines, was still further to emphasize their parallelism. The tendency was to preserve the larger longitudinal valleys, to fill the smaller transverse valleys and to abrade transverse ridges and jutting crags.

A large part of the glacial deposit in the vicinity is of sand, worn from the local sandstones. It was easily rubbed off, and was often deposited in great confusion. Such a deposit is seen northeast of the lake in a ridge trending east-southeast, which is composed mainly of sand, and which has the hummocky topography of a terminal moraine. At the opposite end of the lake the deposit is similar in material and in the manner of its deposition. At some places foreign material predominates, producing a more typical bowlder clay.

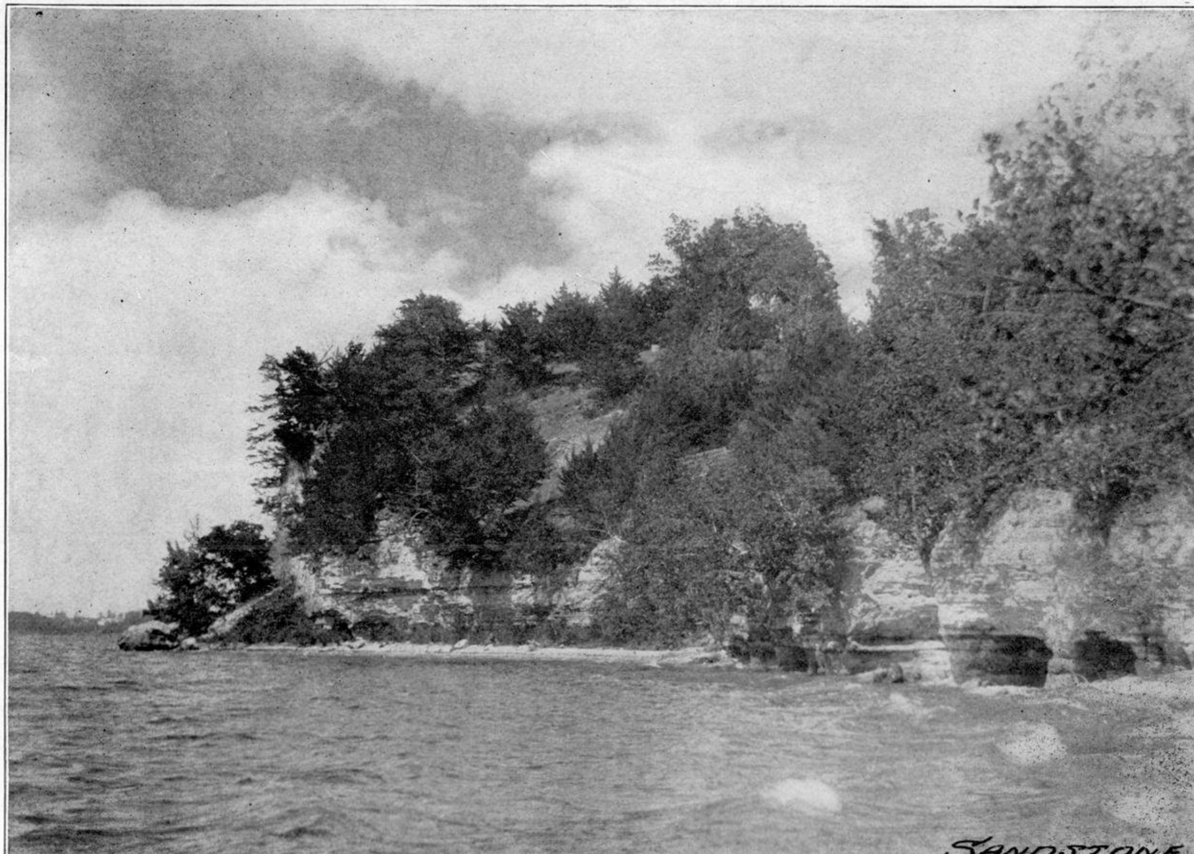
The largest one of the troughs mentioned is occupied by Green lake and the valley of Silver creek. Except for the drift deposit west of the lake, the valley is continuous with that in which Lake Puckaway lies. Similar valleys of less depth are occupied by Twin lakes and their outlet, Spring lake and its outlet, Dartford bay with the swamp northeast of it, and Norwegian bay. The axes of all these valleys would intersect at small angles. Between them lie the long ridges whose axes have similar directions.

*Stratified rocks.*—The bed rock of this region, as has been said, is more or less covered by drift, but outcrops are common and the areas occupied by the several formations below the drift are known with some degree of precision. In general the dip of all strata in this region is south of east, so that the outcrops of the rocks of successive epochs form stripes with ragged edges, trending north-northeast and south-southwest, with the older rocks to the west dipping under the younger strata to the east.

The belt of Lower Magnesian limestone is somewhat wider than the length of Green lake and, in a large way, includes its area, extending beyond it both to east and west, but the western margin of this belt is indented by a large reentrant angle corresponding to the Green-Puckaway valley, and Green lake should rather be conceived of as lying within this angle or occupying a valley of erosion which is the cause of the reentrant.

This region was once overlaid with the Lower Magnesian limestone and its remnants still dominate the topography. Many of the long ridges owe their existence to plates of this strong rock which have shielded them from the attacks of water and ice. At other places its remnants form typical monadnocks such as Sugar loaf. (Plate XXXII, Fig 1.) This peninsula is a residual mass rising one hundred and forty feet above the lake and one hundred feet above the plain to the west. Of the same nature but less conspicuous is the highland back of Lone Tree point. At Lucas bluff the Lower Magnesian is falling in huge blocks from the top of a cliff nearly one hundred feet high. (Plate XXXI.) The nearly level surface of this hard plate of limestone was once, no doubt, at least as high as the top of Sugar loaf is now. At present it not only caps the high levels mentioned, but may be found as the bed rock over much of the area around the east end of the lake, where the land rises gently from the shore.

The next higher formation, the St. Peters sandstone, outcrops in a narrow winding line between the Lower Magnesian belt and the belt of Trenton limestone still farther east. The features caused by this St. Peters band are due to its extreme weakness. It is shoveled out for building sand at many places. Nature has done much similar shoveling under the edge of the strong Trenton limestone, sapping the latter and causing its uplands to terminate abruptly with steep hillsides. This process may be seen at work in Mitchell's glen, a beautiful gorge,




Lucas Bluff, Green Lake. Waves are eroding caves along jointing planes in the soft Madison sandstone. At the top is the hard lower Magnesian limestone, which furnishes the large fragments at the base.

through which the formative stream takes a short cut from Trenton limestone to the Lower Magnesian. It was the St. Peters sandstone which gave the very sandy character to the till west of its outcrop.

Below the Lower Magnesian limestone lie the Madison sandstone and the Mendota limestone, the topmost stages of the Potsdam. The Madison is best seen on the west side of Lucas bluff where its full thickness of about twenty-five feet is exposed at the base of the cliff. The style of weathering of this sandstone base is initiated by jointing cracks. It suggests a colonade of low stout pillars. (Plate XXXI.)

The Mendota consists of alternating layers of sandstone and limestone. The sandstone is calcareous and the limestone arenaceous and each lacks uniformity both vertically and laterally. The sandstone often contains a green layer several feet thick and very friable; or it may be a rich brown, or speckled with green and brown. Frequently thin-bedded, calcareous layers are purplish or motted with purplish brown. When not of this color a partly crystalline structure is often shown by the play of light upon a fresh surface. The whole wears a distinct appearance easily recognized when once learned, as characteristic of the closing stages of the Cambrian. The vari-colored rocks are perhaps the best shown in the fine cliff extending a mile east from Dickinson's bay. For some distance along this cliff a former undercutting and a peculiar slump have propped great rock slabs against the cliff in a position which the waves find it most difficult to attack. These rocks are also seen in their colors on the south and east side of Sugar loaf and west of Lone Tree point. They appear in ravines and small cliffs at various places west of Dartford.

The depth of this lake places its bottom much below the level of the Mendota limestone, and several hundred feet in the Potsdam sandstone, but the latter does not appear along the shores. Its outcrops are all west of the lake.

*Origin of the basin.*—The history of this lake basin is to a great extent the history of the surrounding topography. Its rock walls and slopes, its length, its arms and tributaries, occupying nearly parallel valleys, all indicate that it is one, although the largest one, of many similar troughs. It is a stream-cut valley, modified by the ice and dammed by glacial drift.

The direction of glacial movement over this valley was somewhat south of west in a line not differing much from the axis of the valley. Before the ice invasion the sides of the rock valley were scalloped by tributary valleys and pointed with projecting headlands. The heavy grinding of the ice smoothed off the crags and filled the smaller side valleys, leaving the main valley with broadly curved contours not very different from its present form.

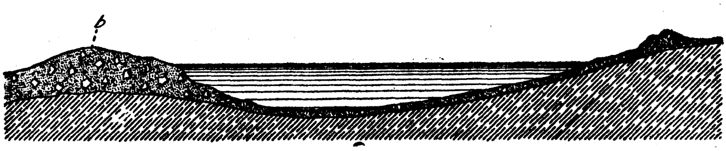


Fig. 39.—Ideal longitudinal section of Green Lake, supposing a basin to have been eroded by the ice: a, Bedrock; b, Drift.

No doubt another effect of the ice was the ploughing out or scooping of material from a considerable part of the lake basin. Like the smoothing of rock hills into lenticular form this process is known qualitatively rather than quantitatively; that is, it is inferred from the forms which are found in glaciated countries. As in the case of Lake Mendota (p. 41) it does not follow that this scooping affected the *axis* of the pre-glacial valley. For ought that is now known, the channel of the former stream may have been either higher or lower than the bottom of the lake. Deep wells west of the lake may some day determine whether there is a basin in the rock itself independent of the morainic dam, and if so, how high the rock rim on the west rises above the bottom of the lake. (Fig. 39.) The amount of scooping thus determined would be the minimum, for on the one hand it is not to be supposed that there were pre-glacial lake basins in this region, and on the other hand the rim itself may have been lowered by the ice. This trough offered conditions most favorable to scooping. (1) The ice movement was about parallel with the axis of the valley; (2) The side ridges were protected by their hard tops; (3) The bottom even before the invasion of the ice, was upon the easily abraded Potsdam sandstone.

Lastly, the capacity of the basin is mainly due to a dam of moraine thrown across the valley and added to the height of whatever rock sill may have been left after the scooping.

The basin thus formed receives the drainage of a considerable area, the largest tributary basin being that of Silver creek to the east. The waters of many springs reach the lake in this way. Others discharge their waters directly into the lake. These springs belong chiefly to the group* whose geological horizon is the junction of the Potsdam sandstone and the Lower Magnesian limestone.

The outlet of the lake is a considerable stream passing out from Dartford bay, flowing for a mile to the northeast in one of the characteristic furrows of the region, then turning northwest through a transverse valley and joining Fox river. Some years ago it was dammed for mill purposes at Dartford. The fall at this dam is from five to six feet according to the stage of the water in the lake. This change of level has had important effects on the shore features to be noted later. The topography about the outlet indicates that the present level at which the water is held by the artificial dam is very close to the level at which it was held by its natural dam when the basin was new; that in the course of the lake's history its outflowing waters had succeeded in cutting a small notch in its rim, and that the present dam destores the rim to its former completeness.

### DEVELOPMENT OF SHORE FEATURES.

*The beach profile.*—When the waters of Green lake first filled its basin they rose to about their present height, spreading out over a topography having the aspect of ground moraine, or lapping the sides of thinly veneered hills. The appearance of the shorelines was much the same as would now be produced by partly inundating the valley of Silver creek. On the characteristic rolling slopes the shoreline would mark a contour in broad curves. Here and there headlands would be formed by the bolder or more isolated hills. Occasional bare ledges of rock

* For horizons of springs of Eastern Wisconsin, see Geology of Wisconsin, Vol. II, p. 142.

would be partly submerged, and at places the supposed lake would form bays in wide spoon-shaped valleys but slightly drowned, whose slopes above water would be gentle and marshy.

The etching of the waves soon discovered rock, if not already bare, where it has been mentioned as outcropping at the water's edge. Since then the waves have been diligently sawing their way inward at the base of the cliffs. As explained below considerable progress in the development of shore profiles must have been made before the artificial raising of the water level. Since that change the shores have again the marks of youth. Generally at the foot of cliffs the outrush of water after the heaviest breakers is still carrying large stones out to the edge of the beach, dropping them beyond the limits of beach action. The stones now seen upon the rock benches are angular. They have not traveled far and will probably be carried out to the steep front of the shelf on which they lie. The rock cliffs of Green lake are in that stage where the beach has sufficient width to support fragments at the water's edge, thus permitting them to be used as tools against the base of the cliff, but not sufficient width to prevent coarse materials from being dragged out to its front in heavy storms. That is to say, the beach profile is not yet perfected.

But while most stones do not travel far alongshore, as shown by their angularity, and the presence of large stones on the front of the shelf shows that waves are able to drag them out, there is still some transportation alongshore even at the foot of the steep cliffs. The waves and currents in lighter weather are able to move some stones which they are not able to drag out to deeper water. Finer material may thus travel some distance among the coarser material. In this way some beach transportation is going on on the south side of Sugar Loaf, where heavy storm waves are still engaged in broadening the shelf. The products of eastward transportation have been built into a gravel flat at the southeast corner. (Plate XXXIII, Fig. 1.) These have been much distorted by ice push but the material shows plainly its beach origin. On the north side of Lucas bluff, where the waves have succeeded in driving back the cliff but very few feet, and the narrow rock bench is very steep and covered with heavy fragments, some finer drift accumulates on the west side of large

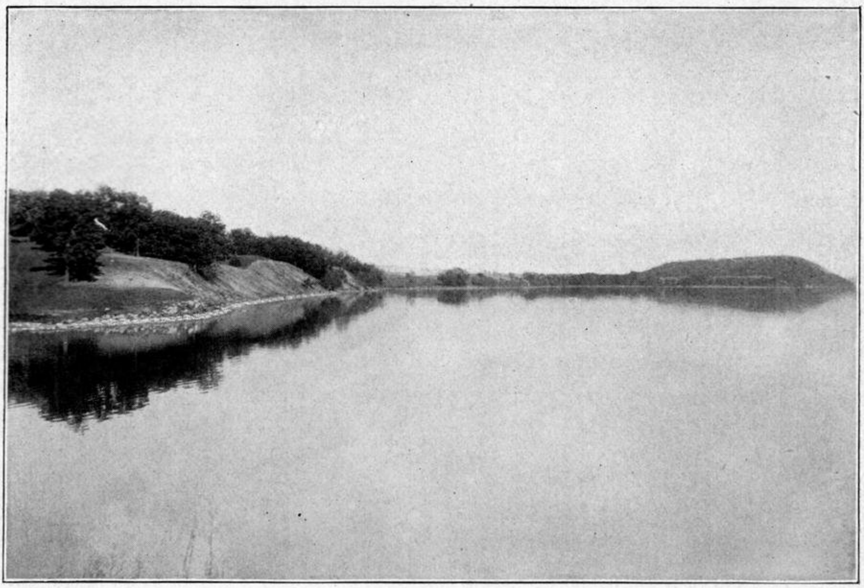


FIG. 1.
Green Lake, looking east from Quimby's Bar. The cliff is cut in sandy drift. Sugar Loaf in the distance is a monadnock of lower Magnesian limestone.

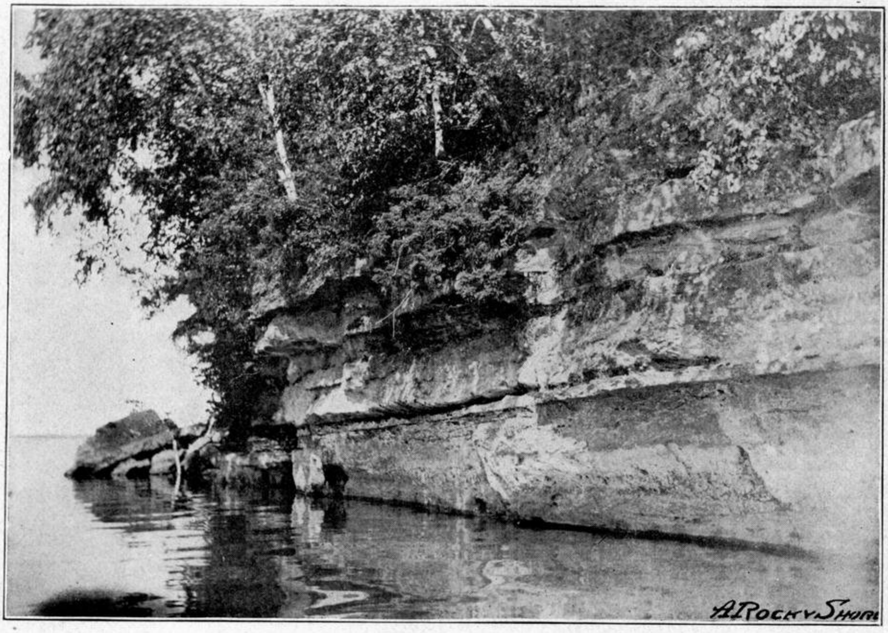



FIG. 2.
Cliff on Green Lake. A youthful shore.

bowlders, piers and other obstructions. Along the fine cliff east of Dickinson's bay, and the similar one west of Lone Tree point, a little such beach action is in progress in the same manner.

Before the mill dam restored the level of the lake, a more advanced beach profile must have existed below these rock cliffs. The slope of the rock shelf was doubtless more gentle and the energy of the waves was more largely expended upon the shore drift and less upon the solid wall. When the water surface was raised, the line of attack was carried upward and shoreward, and the first duty of the waves was to raise the level of the platform. This it is now doing by building outward with the material won from the cliff. This process temporarily restores the youthful steepness of the shelf and the size of the fragments which cover it.

*Recession of different rock cliffs compared.*—The width of the terrace offers some instructive suggestions. A comparison of the sudden descent into deep water on the north side of Lucas bluff and the relatively broad shelf on the west side calls for explanation. Perhaps the waves beat a little harder upon the west side and no doubt the bottom of Wood's bay has been shallowed by waste brought from the long till cliff to the southwest. The undertow is more powerful in a reentrant curve, carrying out more detritus to be added to the front of the shelf. Probably, too, there was an original gentler slope which occasioned a reentrant curve at that place. But it must not be overlooked that the waves have a good hard limestone to beat against on the north side, with sandstone in its place on the west side. This is due to the local southerly dip. The resistant layer of Mendota limestone which is seen at the water's edge on the north is carried by the dip below the zone of attack on the west. Above it is the Madison sandstone which is wasting rapidly and allowing the Lower Magnesian limestone above to fall into the water.

The bench on the south side of Sugar Loaf, cut out of a weaker limestone than that at Lucas bluff, is nevertheless narrower than the corresponding feature east of Dickinson's bay, where the rock is a friable sandstone, and therefore more easily eroded. It is also narrower than the same feature cut in the sandstone west of Lone Tree point, despite the fact that the latter is more protected from west and southwest storms.

The shoal at the east end of Sugar Loaf is partly a cut bench, the necessary correlative of the east facing cliff, but it is too broad to allow it to be ascribed to this process exclusively. The lake, no doubt, found an initial shoal there. This is consistent also with the slopes of the hill which has on its east side a low foot which might well be expected to extend lakeward as a shoal. In all these examples the variation of initial slopes is recognized as an unknown quantity but with good reason supposed not to be large enough to obviate their use as illustrations.

*Cliff-cutting in the till.*—Where cliff-cutting in glacial deposits has been in progress there is, generally speaking, a more advanced beach profile, with correspondingly more transportation alongshore. The one element which prevents a more marked contrast is the protection afforded by bowlders. As cutting proceeds, bowlders fall from the cliff and the pushing of the ice keeps them lined up for resistance at the water's edge. (See Plates XXXIV and VII, Fig. 1.) This resistance may be very effective, preventing erosion to a large extent, while the bowlders on the beach interfere seriously with transportation.

The coast line of glacial drift east of Lucas bluff is thus protected from erosion and while its beach profile is well developed, the form of the coast and the narrowness of the subaqueous shelf show that comparatively little cutting has been effected. The same is true of the high till cliff extending for a mile southwest from Tuleta hills. This coast is exposed to the heavy waves raised by westerly winds. The materials of the shore show that coarse gravel and finer materials are being carried alongshore among the larger stones; but the retreat of the cliff seems to have been little greater than that of the sandsone cliffs to the west.

At the west end for a half mile on each side of Quimby's bay high cliffs are cut in very sandy till and have sand beaches of perfect profile. This coast is not exposed to the most violent storms, but the shelf at the foot of the cliff east of the bay is much wider than the rock shelf on the south side of Sugar Loaf and wider than that along the very exposed till cliff west of Tuleta hills. This is due to the easily erodable character of the

FIG. 1.
Gravel point now growing on the east end of Sugar Loaf, Green Lake; looking south.


FIG. 2.
Lone Tree Point, Green Lake. A small ridge of boulder clay is being wasted by the waves.

sandy drift. The fine cliff itself is expressive of the rapidity with which the waves are cutting at its base. (Plate XXXII, Fig. 2.) South of Quimby's bay the shallow margin is probably more dependent upon initial slope and deposition to be mentioned later.

Steep cliffs are cutting on the north side for a mile or more at Sherwood forest and from Oakwood hotel to Pleasant point. At the foot of each of these cliffs there is a belt forty rods wide on which the water is less than twenty feet deep. This, however, is not to be ascribed to the cutting back of the shore, for the same belt is still wider at other points where no cutting has been done. The hill slopes on this north side of the valley are comparatively gentle, and the descent to deep water is rather uniform, agreeing well with the supposition that these larger features of the bottom are due to the agencies which formed the basin and not to wave action.

For a mile east of Dartford bay, may be seen in typical development the characteristic breaker terrace which accompanies the till cliffs of this lake and many others. In front of the bare cliff is a cordon of bowlders; beyond these, a beach of cobble stones with gravel in their inter-spaces. The upper edge of this beach mingles with the bowlders several feet above water. (Compare Plate XXXIV.) At fifteen or twenty feet out from the water's edge, it falls off with a steep slope, having a front built of large cobbles free from gravel. The angle of this shelf, where its steep descent begins, is under one or two feet of water. Its steep front of cobbles goes down to a sand (or sometimes gravel) bottom three and a half or four feet deep. A gently falling sand bottom forms a second belt of about equal width. Between this belt and deep water is a third and wider belt of cobble stones and bowlders. Going east toward Pleasant point, the bottom becomes more shelving and the belts, except the first, widen greatly.

The explanation of these bands lies in the former lower horizon of shore action. The heavy stones of the outer belt lay upon the former lower beach; the belt of sand outside the present breaker line is the normal result of the undertow at work now; the steep front of heavy cobbles shows that the outrush following the heaviest breakers of the present cycle is still able to carry them out, letting them fall outside the grasp of incoming waves. The admixture of lighter gravels on the top of this beach is due to continuous supply from the cliff, and these gravels form the shore drift among the larger stones.

*Structures built by waves and currents.*—Having now sketched the progress of erosion and the production of the profile necessary for the transportation of shore drift, it is pertinent to inquire what the currents and waves have done with the large amount of material carried away in carving the cliffs or what they are now doing with the constantly discarded faces of these cliffs. That part which falls into deep water at the front of a widening platform has already been noticed. It would constitute a large part of all that has been eroded from the shores of this lake. Another part, chiefly sand, has been carried away by the undertow beyond this youthful shelf. The silt which settles slowly over the whole lake bottom forms a third part. But the large part that remains is built into shore structures which are readily identified and are often striking features.

Beginning with Dartford bay, a massive bar now spans, or nearly spans, its entrance. The top of this bar is thirty feet wide and its base much wider. It rests upon a bottom which is at places nearly ten feet deep and its top is from six inches to a foot below the surface of the water. It is divided into two parts by a natural channel east of the middle. (Fig. 40.) The western two-thirds is built of gravel and cobbles brought by shore currents from the long cliff which stretches west and north from Sherwood forest. At first there was a reentrant curve west of Maplewood hotel, which received the shore drift from the southwest. The accumulation of drift in a beach ridge spanned this reentrant and serves now to convey the shore drift from the cliff to the growing spit. This has developed in a graceful curve which leaves the mainland at Techura spring. The other third of the so-called bar is a spit which has derived its material from the east. It is interesting to note that these spits, if extended, would pass each other by fifty or seventy-five feet, instead of forming one continuous curve. The currents which have built the western spit, acting with different wind directions and at different times from those which have built the eastern one, have swung farther into the bay. The continued growth of the spit from the east has begun to interfere with the currents engaged in building the one from the west and the point of the latter is less well defined and contains finer material. The landward ends of both spits for many rods are already raised above water and have become the regular beaches. The heavier waves already break over the submerged bar; if let alone Nature will span this bay, with a beach of graceful curve, leaving only a sufficient channel for the outlet. The process, already begun, of filling the bay with vegetable remains, will proceed at an increased rate as the bar is perfected.

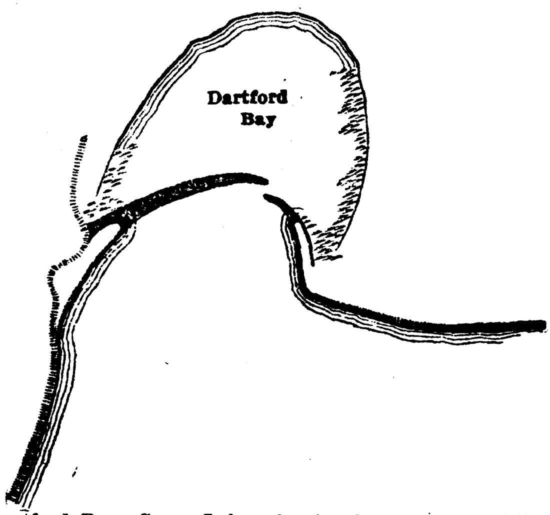



Fig. 40.—Dartford Bay, Green Lake, showing bars and the cliffs from which they sprang. Scale 3 inches = 1 mile.

The cliff between Oakland and Pleasant point is not always washed by a westward current as it is during the building of the bar to the west. The alternating eastward current is doing more work, for shore drift is seen to accumulate mainly on the west side of piers and other obstructions. Beyond Pleasant point cliff-cutting ceases and for more than half a mile the well formed beach lies against land of its own making. This land is a ridge of sand and coarse gravel, three feet above water, twenty feet wide, and bearing a few trees. A long marsh from one hundred and fifty to two hundred feet wide lies between this ridge and the steep sandy bluff behind. This bluff was once the shore of the lake and the ridge in front was built as a spit, in every way similar to either one of the spits in front of Dartford bay. The material of this spit came from the west and the structure is still growing southward, being traceable for a number of rods as a subaqueous embankment beyond that point

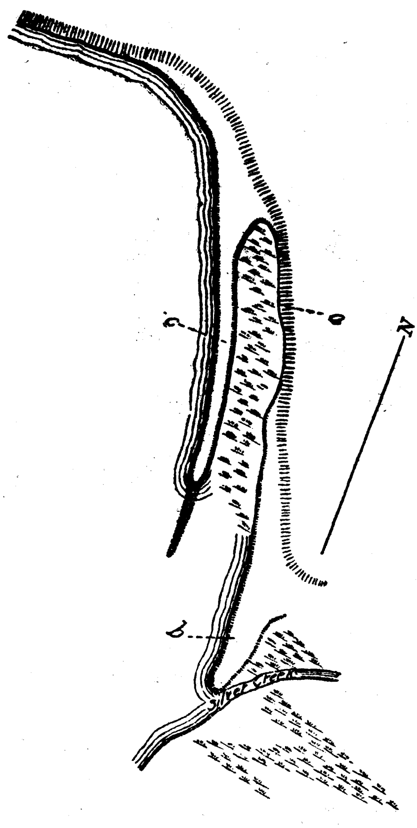



Fig. 41.—Terrace Beach, Green Lake: a, Abandoned cliff; b, Spit which sprang from the former cliff, turning Silver Creek southward; c, New spit. Scale 4 inches = 1 mile.

where it ceases to appear above water. (Fig. 41.) The older, northern end of this spit is wider and composed of heavier material. Cobblestones and coarse gravels are being handled on the beach and mingle in the ridge with the finer gravels and sand, thrown by dashing waves beyond the limits of beach action, Near the point of the spit, only finer gravels are traveling, and the exposed ridge shows little besides sand. The growing point, not yet raised above water, is composed of gravels alone, without the admixture of sand which enters so largely into the ridge above water. The process of sorting upon the beach causes the finer materials to undergo a division, a part being dashed inward beyond the reach of the waves, the other part being carried out by the undertow. Heavier pieces are not subject to either mode of removal. Thus it happens that the larger stones which are seen under the water within the breaker line are the ones which continue their onward journey, and are added to the growing point of the spit.

The presence of an old cliff behind the swamp points to a time when the currents brought less shore drift to this corner of the lake. They were therefore able to pick up more by cutting into the bank of sandy moraine. This was when the north shore was in its infancy. Its beach profile was not sufficiently advanced for the transportation of much drift. It was cutting actively but the waste was carried outward and dropped over the front of the narrow shelf, and beyond the reach of incoming breakers. The perfecting of a beach profile along the sandy bluff behind the present Terrace beach occupied a comparatively short time. When this was done the waste of the cliff was built into a broad sandy spit, running south in front of the mouth of Silver creek. The once active beach on the front of this spit lost its functions when the bar in front stopped the cutting of the cliff and thereby the supply of shore drift.

South of Silver creek the more active currents again come from the west. Westerly winds with a long fetch bring vigorous eastward currents along both north and south shores. The shorter fetch of easterly winds and the protection of the bluff give but little efficiency to westward currents. Several small ill-formed spits have been built by currents from the west, and one at Forest glen may be traced for twenty rods to the northeast, but there is no mass of shore drift here to compare with the large features north of Silver creek. The reason for this lack of building lies partly in the nature of the cliff from which the supply is derived. The low cliff between Forest glen and Spring grove, is cut for much of its length in limestone. Limestone fragments lie upon the beach both in and out of the water and the amount of shore drift is comparatively small.

A second reason for the small amount of beach deposition in the northeast corner, lies in the presence of the broad hollow west of Spring grove. The broad reentrant curve here once indented the coast more deeply. In spanning this bay with a bar the currents have used up a large amount of shore drift brought from the cliff to the west. The beach along this ridge is about half a mile long. The eastern half lies in front of a swamp behind which, about fifty feet from the front ridge, is a second ridge similar to the first. This second ridge, which was first in point of time, was built when the shore currents were following shorter curves, having done less to smooth over the inequalities of their beds and walls. The front ridge is deformed by the pushing of ice, which is well braced on the opposite side of the lake by the steep cliff.

Between Dickinson's bay and Blackbird point, the beach is well developed. At the latter place was once a long island of morainic material three to ten feet high. But the shore currents found the passage behind too small and therefore followed a course leading in front of the island and back to the mainland at the east end. Along this line, eastward currents deposited the waste of the island and westward currents the waste of the mainland, building a bar of sand and gravel, which now forms a causeway sixty feet wide between mainland and island. The passage behind the island being thus cut off entirely from the action of currents, became first a swamp, and is now rapidly becoming a meadow. Meantime the front of the island continues to be cut back. The currents, which are carrying its detritus to the west, are obliged to alternate with currents setting toward the mainland, and thus the spit which should normally extend westward is turned at right angles into a hook.

West of Blackbird point the currents are attempting on a grand scale the work of simplfying the shore line by cutting off a wide bay. They had, no doubt, fairly succeeded before the youth of the lake was artificially restored by damming the outlet. At about the point where the wagon road from the east reaches the lake, a submerged embankment leaves the shore.

A beach of coarse gravel, Green Lake.

and taking a westerly course curves broadly for more than half a mile. If the curve were continued for an equal distance it would intersect the west shore of the lake. This bar would in time be built above the surface of the water and usurp the functions of the beach, leaving several hundred acres of stagnant water to become swamp. This stage must have already been reached when the lake was low, before the dam at Dartford was built. At present the course of the bar is marked by patches of rushes and stumps of trees which grew in the protected swamp before the lake level was raised. This bar is built by currents flowing west, just as similar structures at the east end owe their origin to eastward currents.

West of the bridge, where the wagon road again leaves the lake, the effects of currents from the east along the south shore is lost. The dominant currents along the west shore are from the north. Both these currents and those from the east suffer much dispersion and check or are entirely lost at the southwestern corner of the lake, the return of the water being largely by undertow. The necessary deposition of shore drift which accompanies this dispersion and checking, together with the sand and mud brought in by the stream entering here, have so decreased the small initial depth as to make it difficult to bring even a small rowboat to shore. The widening beach at this corner illustrates the principle of the wave-built terrace.

Farther north at the west end, occur the largest and finest beach ridges on the lake. The present shore line is against a wave-built terrace which reaches a width of one hundred feet at the middle of the west side of the lake. It is here composed of three parallel ridges of pure beach sand, the inner and oldest being the largest. Back of this triple ridge is a belt which has once been a swamp, separating the one hundred foot terrace in front from a higher and broader structure, also built by the waves. This inner and older terrace has a maximum width of two hundred feet and height of five feet. It carries oak forest and its otherwise pure beach sand has received a darker color from some centuries of decaying vegetation. Following the inner massive ridge to the north, it is seen to join on to an abandoned cliff, three hundred feet back from the present shoreline. Fully one-fourth mile farther north, the outer ridge leads to the foot of a still actively cutting cliff. If the topographical relations of cliffs and beach ridges were not sufficient to establish the fact that the latter were built from the waste of the cliffs to the north, the testimony of the materials themselves would be conclusive. The cliffs are cut in a glacial deposit, whose transportable constituents are sand and gravel. The materials of the outer ridge show a uniform gradation from the coarsest gravels near the source of supply to the finest beach sands at the remote end. The profile of this ridge is beautifully typical in that portion which lies in front of the fading cliff. (Fig. 16, p. 27.) The conditions which have favored these large ridges are, (1) the long stretch of easily eroded cliff to the northeast; (2) a former shallow embayment behind the present beach ridges, and (3) the gradual retardation of southward currents.

Lone Tree point (Plate XXXIII, Fig. 2) is a small promontory built of moraine containing many bowlders. Its connection with the mainland is by a narrow neck having the height and form of a wave-built bar. The bowlders, however, which the ice keeps in line along this isthmus, indicate that the isthmus is either an original ridge of bowlder clay or that it has been built by the agency of ice which has gathered bowlders from the shallow bottom and crowded them along this line. If the point was once an island the depth of water in the strait was not sufficient to enable these bowlders to escape the grasp of the ice.

Between this point and the headland at the middle of Pigeon Cove, was once a much sharper reentrant curve. Currents from the east have added ridge after ridge, irregularly enclosing lagoons, while their dispersion and consequent loss of velocity have occasioned deposition which has greatly shallowed the water offshore. Behind the lagoons and sand ridges lies the first ridge, built partly of bowlders, pushed up by the ice, and now covered with oaks.

Ice ramparts are shown best in Malcolm bay. This bay is a wide curve consisting of three reentrant scallops, with two low headlands intervening. Between these headlands is a large rampart. For a few rods back from the ridge the ground surface is low and even swampy, but this association of ridges and low ground behind is not to be confused with the phenomenon of bar building and bay filling. The narrow flats are strewn with bowlders, showing that their surface has not been raised by swamp filling. The ridges in front, six feet high and having steep sides, are composed largely of heavy bowlders showing that they were pushed up by the ice and not built by currents. Other ramparts appear at the salient curve east of Sherwood forest and in front of the more gentle slopes east of Lucas bluff.

The life of Green lake is still largely in the future. Even before the damming of the outlet, the lake had not advanced very far toward its own extinction. The dam, if kept up, will greatly prolong the life of the lake by interrupting one of the processes leading to extinction. (See p. 11.) But the various modes of filling cannot be interrupted. The swamps, where the small creeks enter, testify to the mud brought in by these streams. Other swamps and meadows behind wave-built bars occupy ground once covered by the lake. It is true that some area has been won from the land by the cutting back of cliffs, but in the end the lake pays dearly for such accessions, since all the material of these cliffs, when not used to narrow the lake at some other point, is spread out upon the bottom. Such shallowing encourages vegetation even where no bars exist to restrict the waves and currents, as at the head of Norwegian bay and considerable areas at both east and west ends. Such areas are relatively small on Green lake, and as man counts years it will be a long time before the present expanse of water will be an expanse of meadows or farms. Admirers of Green lake may find satisfaction in the thought that this will be among the last survivors of the Wisconsin lakes.

# CHAPTER X.

## THE WAUPACA CHAIN-O'-LAKES.

This beautiful group is situated about forty miles northwest of Lake Winnebago. The principal chain comprises nine lakes, none of which has an area less than ten acres. Rainbow lake, the largest, contains one hundred and forty-six acres; it is separated from Hicks lake only in name, the two having an area of two hundred forty-three acres. The greatest depth, ninety-five feet, is also reached in Rainbow lake. All the lakes of this chain lies at the same level and are connected by channels which are passable to rowboats. A smaller chain of four lakes, west of Long lake, is connected with the larger chain through Beasley's brook. East of the main chain lie Dake and Miner's lakes which are united with each other by a passage but are unconnected with other lakes.

The peculiar attraction of these lakes is the ever changing and quickly changing field of view. In rowing the half dozen miles necessary to traverse the main chain alone, the shores in possible view at any one time change entirely at intervals varying from one-fourth of a mile to a mile. In the autumn the colors of the steep banks are variegated with the deep red of oaks, the bright red of maples, the yellow leaves and white stems of birch trees and the green of the conspicuous, overtowering pines. Hotels and teachers' rests have already followed these attractions and small parts of the lake front are occupied by summer residences. The Wisconsin Veterans' Home, in itself a village of some six hundred people, occupies a beautiful site on Rainbow lake. It is connected by electric railway with the city of Waupaca, four miles distant.

The lakes north and east of Indian Crossing (an historic ford between Round and Columbian lakes) are fed wholly by springs. The supply is barely sufficient to maintain a feeble


Looking west to Club Island, Rainbow Lake, Waupaca Chain. The left side of **the island** faces the open lake and is cut **away by the waves. Currents** carry the waste of the cliff into the **quiet** water on the right, **building a spit.**

current from Round lake to Columbian. Below Indian Crossing the lakes receive Beasley's brook which flows with considerable current, deep enough to accommodate a canoe if well managed. This brook, coming from the smaller chain, carries the waters of many springs which issue near the small lakes or not far to the west. Long lake also receives Emmons creek and various springs which enter it directly. The waters of all the lakes pass out through Arbor creek, a stream of considerable strength and ample for milling purposes. Its course is eastward, joining the Waupaca river.

## GEOLOGY OF THE DISTRICT.

The underlying rock in the vicinity of these lakes is the Potsdam sandstone. The nearest known rock of any other age is at the city of Waupaca where the pre-Cambrian rock appears. Some ten miles farther east the Wolf river flows south along the edge of the Lower Magnesian limestone which outcrops east of it in a narrow strip running north-northeast and south-southwest. (Plate I.) Before the deposit of glacial drift this limestone presented a more distinct escarpment to the west. The trough at its foot was no doubt a prominent drainage line in pre-glacial times as it is now.

The vicinity of the Waupaca chain has a generally level surface below which appear abrupt basins varying in size from that of the larger lakes to that of the familiar kettles. Above this same plane rise large isolated hills a hundred feet or more in height and a considerable fraction of a mile in extent. Cemetery and Fox ridges, Rural hill, Parfreyville hill, Ben Lomond and Summit hill are conspicuous examples. Their tops rise to approximately the same height, and when viewed from one of the summits, all are seen to be comparatively flat topped and steep sided. North of the north branch of Waupaca river, and south of the south branch, these hills are less isolated and strongly suggest that they are remnants of a former continuous upland whose surface was at or above the present level of their tops.

All these hills are now well covered with drift, often carrying great bowlders. Rock ledges are not discovered and well borings are infrequent. Their topography, however, leaves little doubt that they are remnants of a former upland which was dissected by the tributaries of a considerable stream which, in pre-glacial times, followed the approximate course of the present Waupaca valley. If the erosive and depositional work of the glacier could be undone these hills might now be very similar to the sandstone buttes which rise above the plain in the vicinity of Camp Douglas. (See Salisbury and Atwood; Bulletin V, this series, p. 71.)

The ice invaded this region from the east, rounded the corners of the friable sandstone hills and covered them with a thick sheet of drift. The last or Wisconsin ice sheet extended some fifteen miles west of the lakes, where the limit of its advance is marked by a terminal moraine. Its disappearance was not effected by one uniform retreat, but was interrupted at intervals when the ice front remained stationary for a time and smaller terminal or recessional moraines were built. A record is thus left of a halt made by the retreating front when it stood in a north-south line east of Rainbow and Hicks lakes. Here is a line of hills differing from the type before described. The Loyola ridge with its northward continuation is a terminal moraine whose irregular crest and hummocky surface contrast strongly with the more gentle curves and flat tops of Cemetery ridge and others of its type. The line of terminal moraine is continued southward in Maple island whose surface is typically and beautifully morainic. Continuing the line in the same direction, the characteristic topography is found on the mainland as far south as the southeast corner of Rainbow lake.

While the glacier lay in the valley of the Wolf river the drainage from the front of the ice found no exit by following the trough of former valleys leading eastward. It was obliged to follow the front of the ice or to escape by the lowest available col among the hills, flowing rapidly where the valley was narrow and sluggishly through ponds or lakes where the valley was wide. Such sluggish drainage characterized the old Waupaca valley. The overloaded streams from the glacier dropped their sediments here, often covering basal portions of the glacier. (See p. 5, also The Oconomowoc District, p. 108.) The subsequent melting of these ice remnants resulted in the lakes and pits. The materials both of the terminal moraine at Loyola ridge and of the pitted plain for many miles is extremely sandy. This would be expected from the fact that the glacier for twenty miles to the eastward was gathering drift from the friable Potsdam sandstone.

## SHORES.

The shores of all the lakes are characteristically steep as is to be expected from the origin of the basins. (See Chapter I, p. 4.) In some cases the steep bank is separated from the water by an intervening belt of grass or tamarack swamp. This condition is striking in Otter lake which is being steadily hemmed in to narrow limits by the eager advance of grass and trees, the former leading the way by invading the water's edge, and the trees following at a short interval. Beasley's, Bass and Young's Lakes are similarly environed and a part of the shore of Long lake and most of those of the smaller chain are of the same character. Such surroundings are naturally attended by an accumulation of vegetable mire on the bottom. This, with the shadows of the closely surrounding tamaracks, gives to the water of Otter and Beasley's and some of the smaller chain a peculiarly black appearance. This darkness of the water, the isolation by a wall of forest from the outside world, and the deep silence which reigns among the tamarack trees, give to the lakes so surrounded a beauty which is either enchanting or weird according to the mood of the visitor.

The modification of shores by waves and currents has been somewhat large despite the smallness of the lakes and the limited sweep of the winds, for the exceptionally sandy character of the plain makes cutting at their bases easy and a large load of material, readily transported, is thus supplied to currents. It is on this account, no doubt, that there is, generally speaking, around all these lakes, a distinct marginal terrace which is plainly the work of shore agencies. In the larger lakes, such as Rainbow, this terrace slopes gradually to a depth of four or five feet before the steeper slope to deeper water appears. Its outer and lower portion is often of marl mud so fine that it could not come to rest above the level at which wave agitation ceases.

It may be said, therefore, that for the larger lakes of the chain, wave-base is not more than five feet below the surface. The inner and upper part of these same shelves is commonly covered with, or composed of, sand and gravel.

The limit of downward extension of wave action is also indicated by shoals not connected with shores. The hydrographic map shows no less than five of these in the larger chain. All are paved with heavier gravels at a depth of from two to three feet below the surface. All have been cut down as may be seen from the assorted character of the gravels, from which fine materials have all been washed out. All may have been islands in the infancy of the lake. The uniformity of their present type indicates that at a depth of less than three feet the waves of the larger lake are unable to move the gravels which cover these shoals.

*Rainbow and Hicks lakes.*—The cutting back of cliffs is nowhere sufficiently rapid to expose any surfaces which are bare of vegetation. Club island shows definite evidences of wasting; a comparison of its south side (at the left in Plate XXXV) with its north side furnishes excellent reasons for inferring that its south side, which faces the larger expanse of water, has been cut back by waves and that the material thus acquired has been carried by currents to its north side and there deposited as spits, giving the island a crescent shape. (Only one of these spits appears in Plate XXXV.) This inference is verified by an examination of materials. The cusps of the crescent are growing northward by the addition of heavy gravels which can have no other source than the island itself. At the foot of the steep south-facing cliff is a shelf thirty or forty rods wide. Near the island this shelf is floored with cobble stones which dropped from the cliff as it receded northward and which the waves were unable to remove. While it is certain that the island has been wasting on its south side, it is equally certain that its area was never more than a small part of that of shoal, for all of the material, except mud, won from its south side, has been built into spits and shallows on its north side. The amount of this is probably not larger than the volume of the original island now remaining.

The west side of Maple island has been similarly cut. The shelf reaches a width of twenty rods at its broadest place. Most of this is built of mud, marl and sand, but its inner edge shows heavy stones which remain to mark the site of former land which has been cut away by the waves. A bowlder line at the water's edge fringes the west side of this island and of the headhand occupied by the Loyola Rest school where it has been artificially changed. Both of these cliffs are convex in vertical cross section as the result of recent cutting below. The other cliffs, which for the most part surround Rainbow and Hicks lakes are cut in a sand and gravel plain and have, therefore, fewer bowlders at their bases. Otherwise their appearance is much the same as of those described.

Deposition has also played some part in the production of the present shoreline. The northward extension of Club island has already been mentioned. Juniper (or Cypress) island is being similarly extended at the north end by the deposition of material cut from its south side. But the main result of deposition has been, not the making of points, but the cutting off of small bays. The bays which have thus far been spanned by bars are merely kettles which chanced to be connected with the lake basins. Such a one is seen in the bay north of the Jesuits' rest. Others are seen at the northwest corner and southwest corner of Hicks lake.

The work of ice on these lakes is everywhere in evidence. It is seen in the closely appressed bowlder lines at the foot of morainic cliffs; all sides of the lakes also show ridges wherever the form of the shore is favorable to their raising. At many places where the material of the shore could not be pushed up into a ridge, that of the bottom has been built by successive pushes into ice-push terraces. (See p. 34 and compare Nemahbin lakes, Chapter VI, p. 115.)

*Taylor lake,* except at its west end, is surrounded by lower plains than those which border the lakes farther west. This, in part, accounts for the exceptionally broad marginal terrace. The sandy plain on the south side averages not much more than five feet above the water. It is cut away with ease, even by so small a lake. On the northeast side the lake's original bottom shelves gradually into the swamp. At the front of this swamp is now a strong ridge of sand with a little gravel, the same material, no doubt, which has been won from the low, sandy cliff on the south side. Ice has helped to raise this ridge but the material is distinctly that brought by shore currents. The contrast with that of the purely ice-made ridge in front of the swamp on the northwest side is significant. The latter is composed largely of muck, the material of the shore. The broad shelf under the water's edge has sand to a depth of little more than one foot beyond which the waves seem too weak to agitate it, and the undisturbed, marly mud covers the bottom. The drop from this shelf to the central pit, fifty-five feet deep, begins at a depth of from two to three feet.

*McCrossen's lake* has just enough low shore to furnish opportunity for a beach ridge whose form is diagrammatically perfect. (See Fig. 16, p. 27.) The ridge is on the south side of the lake, two hundred feet long, thirty feet wide and four feet high, its steeper side facing a small tamarack swamp. This, and a few similar ridges whose symmetry of form and assortment of material show that they are the work of water and not of ice, suggest that the water level was once slightly above the present stage. The largest waves generated on these lakes are not able to build a sand structure four feet above the level of still water. There is nothing, however, either on the shores or along the outlet to indicate that the water has even been retained at a height greater than three feet above its present level since the disappearance of the glacier.

The passages at both ends of this lake are narrowed by wave-built points which approach each other from opposite sides of the straits. Such points are characteristic of the passages throughout the chain. (See Plate XXXVI.) They indicate a large degree of independence in the circulation of the several lakes so that the currents flow by, rather than through, the passages. If there were no current due to drainage from lake to lake these points might be expected to grow into completed bars.

*Round lake* is one of the larger lakes of the chain and its shores indicate waves and currents of about the same po᷊wer as those of Rainbow lake. Its marginal shelf has much the same dimensions and has material of similar coarseness. It is significant that the passage between this lake and McCrossen's lake is more than ten rods southeastward (toward McCrossen's) from the shoal ridge which separates the deep basins of the two


Entrance to Columbian Lake. The points are ends of beach ridges which constantly tend to grow across the passage.

lakes.. (See hydrographic map.) This anomaly may be in part due to the original form of the basin, but it is also favored by the more vigorous circulation of the larger lake. The forelands whose points narrow the passage could not grow out into the agitated water of the larger lake, where exposed to the dominant westerly winds, but their accretions on the other side are relatively protected, not only because the lake is smaller, but because they are sheltered from the stronger winds. The southwest arm of Round lake was formerly known as Lime Kiln lake because marl was taken from its bed and burned for lime.

*Columbian lake* is connected with Round lake by a narrow channel through which it receives the small overflow of the lakes mentioned above, in a current not sufficient in itself to keep open a channel of the present size. The feeble current through this passage is the most significant measure of the slow change of water through this chain as contrasted with the rapid change in the lakes south and west of Columbian. The old ford of this passage is known as Indian crossing. Looking from the bridge at this crossing to Columbian lake, one sees the same type of wave-built point or forelands which characterize the other passage in the chain. On the northwest side of the lake, cliffs have been slowly cut into the deeply pitted plain. The waste has been carried eastward, shallowing the northeast corner of the lake and forming the beach ridge which supports the point seen on the right in Plate XXXVI. South of Indian crossing the margin of the lake is stonier than that of the other lakes. This is due to the wasting of Perch point and of the shoal reaching southward from the point.

*Long lake* has on its west side and at Ben Hewdo the highest banks on the chain, excepting those formed by the moraine of Loyola ridge and Maple island. In the rapid passage of water through this basin the conditions here are similar to those in the lakes of the small chain to the west. Almost all of the water which passes out of the vigorous Arbor creek enters this lake from the west, most of it coming through Beasley's creek, whose headwaters traverse the small chain, with the exception of Marl lake. In the character of its shore, much of which is tamarack forest, and the abundance of its vegetation and the dark colored mire of its bottom, Long lake has also a closer resemblance to the lakes drained by Beasley's brook than to those of the large chain to the northeast. It is possible that the more rapid change of water and the character of the vegetation, with the resulting bottom deposition, may be found to be related as cause and effect. It is probable also that a minute study of bottom deposits would reveal a close relation with the character and life of the shores.

# APPENDIX.

## SITUATION, AREA AND DEPTH OF LAKES.

### OCONOMOWOC-WAUKESHA LAKES.

T. 7 & 8 N., R. XVII & XVIII E.

| Name. | Elevation,[1] feet. | Length, miles. | Width, miles. | Area, sq. m. | Area, acres. | Depth, feet. | Remarks. |
|---|---|---|---|---|---|---|---|
| Pewaukee | 268 | 4.50 | 1.20 | 3.61 | 2,310 | 45.3 | |
| Beaver | 328 | 1.10 | 0.44 | ........ | 148 | 47.6 | E. basin. |
| | | | | | 163 | 46.2 | W. basin. |
| North | 315 | 1.35 | 0.75 | ........ | 328 | 78.0 | E. basin. |
| | | | | | 126 | 73.6 | W. basin. |
| Pine | 320 | 2.30 | 1.05 | 1.20 | 768 | 90.0 | |
| Nagawicka | 308 | 2.75 | 1.12 | 1.41 | 902 | 45.0 | N. end. |
| | | | | | | 94.5 | Main lake. |
| Okauchee | 299 | 2.37 | 1.80 | 1.72 | 1,000 | 65.0 | N. E. bay. |
| | | | | | | 94.0 | Main lake. |
| Garvin | 299 | 0.31 | 0.19 | ........ | 20 | 36.1 | |
| Mouse | 304 | 0.82 | 0.21 | ........ | 91 | 66.3 | |
| Oconomowoc | 280 | 1.92 | 0.82 | ........ | 645 | 62.6 | S. basin. |
| | | | | | 174 | 49.2 | N. basin. |
| Upper Nashotah | 290 | 0.81 | 0.40 | ........ | 137 | 51.2 | |
| Lower Nashotah | 288 | 0.79 | 0.25 | ........ | 99 | 46.2 | |
| Upper Nemahbin | 288 | 1.05 | 0.56 | ........ | 273 | 62.0 | |
| Lower Nemahbin | 288 | 0.93 | 0.60 | ........ | 246 | 20.0 | N. E. basin. |
| | | | | | | 29.0 | S. W. basin. |
| | | | | | | 35.4 | S. basin. |
| Fowler | 278 | 0.94 | 0.44 | ........ | 87 | 50.0 | |
| Lac La Belle | 271 | 2.70 | 1.12 | 1.84 | 1,178 | 33.0 | N. W. basin. |
| | | | | | | 40.0 | S. E. basin. |
| | | | | | | 46.6 | Middle basin. |
| Silver | 282 | 0.97 | 0.50 | ........ | 236 | 44.0 | |
| Genesee, N | 283 | 0.51 | 0.42 | ........ | 104 | 36.4 | |
| Genesee, S | 282 | 0.40 | 0.30 | ........ | 64 | 47.6 | |

[1] Above Lake Michigan, which is 579 feet above the sea-level.

WAUPACA CHAIN O'LAKES.

T. 21, 22, N., R. XI, E.

| Name. | Length, miles. | Width, miles. | Area, acres. | Depth, feet. | Remarks. |
|---|---|---|---|---|---|
| Rainbow and Hicks | 1.12 | 0.53 | 243 | 60.0 | Hicks, E. Juniper Id. |
| | | | | 70.0 | Rainbow, bet. Maple and Club Island. |
| | | | | 95.1 | Rainbow, S. center. |
| | | | | 50.0 | Hicks, W. Juniper Id. |
| | | | | 50.0 | Rainbow, S. W. bay. |
| Taylor | 0.45 | 0.30 | 49.7 | 30.0 | Bay S. Maple Id. |
| | | | | 55.7 | Main lake. |
| McCrossen | 0.31 | 0.19 | 34 | 70.0 | |
| Round | 0.55 | *0.35 | 108 | 66.7 | Main lake. |
| | | | | 47.0 | S. W. bay. |
| Columbian | 0.49 | 0.34 | 86 | 66.6 | |
| Long | 0.94 | 0.36 | 110 | 67.5 | S. center. |
| | | | | 77.7 | N. Ben Hewdo. |
| | | | | 30.6 | Bay E. Ben Hewdo. |
| Beasley | 0.25 | 0.10 | 13.5 | 51.2 | |
| Knight | 0.34 | 0.14 | 21 | 40.0 | E. end. |
| | | | | 42.6 | W. end. |
| Mud | 0.13 | 0.06 | 4.5 | 32.0 | |
| Pope | 0.22 | 0 11 | 14 | 40.6 | |
| Marl | 0.30 | 0.20 | 21 | 60.0 | |
| Dake | 0.35 | 0.30 | 37 | 28.5 | |
| Minor | 0,34 | 0.34 | 39 | 46.6 | |
| Otter | 0.40 | 0.08 | 14 | 38.0 | N. end. |
| | | | | 40.0 | Center. |

* 0.49 including bay.

MEASUREMENTS.

| Name. | T. N. | R., E. | Length miles. | Width, miles. | Area, sq. m. | Area, acres. | Depth, feet. | Remarks. |
|---|---|---|---|---|---|---|---|---|
| Geneva ........ | 1 | XVI, XVII | 7.50[1] | 2.00 | 8.6 | 5,504 | 142.0 | |
| Delavan........... | 2 | XVI | 3.75[2] | 1.10 | 2.7 | 1,728 | 56.7 | |
| Lauderdale: | | | | | | | | |
| Green........... | 4 | XVI | 1.09 | 0.66 | ........ | 282 | 56.8 | |
| Middle............ | 4 | XVI | 1.60 | 0.45 | ........ | 282 | 50.0 | |
| Mill ............... | 4 | XVI | 0.75 | 0.49 | ........ | 304[3] | 50.0 | |
| Beulah: | | | | | | | | |
| Mill............. | 4 | XVIII | | | | 61 | 51.5 | |
| | | | | | | | 40.0 | S. E. basin. |
| Lower .......... | 4 | XVIII | 2.65 | 1.10 | ........ | 550 | 55.5 | S. W basin. |
| | | | | | | | 46.5 | N. E. basin. |
| Round .......... | 4 | XVIII | | | | 100 | 40.0 | |
| Upper........... | 4 | XVIII | | | | 260 | 67.0 | |
| Booth............. | 4 | XVIII | 0.58 | 0.43 | ........ | 125 | 25.4 | |
| East Troy ........ | 4 | XVIII | 0.50 | 0.39 | ........ | 81 | 16.5 | |
| Big Cedar......... | 11 | XIX | 3.64[4] | 0.64 | 1.48 | 948 | 104.7 | |
| Elkhart .......... | 15 | XXI | 1.10 | 0.79 | ........ | 304 | 87.6 | Bay. |
| | | | | | | | 113.2 | Main lake. |
| Green............. | 15, 16 | XII, XIII | 7.40[5] | 2.00 | 11.5 | 7,360 | 237.0 | |
| Mendota........... | 7,8 | IX | 5.90 | 4.60 | 15.2 | 9,728 | 84.0 | |
| Menona............ | 7 | IX, X | 4.16 | 2.39 | 3.9 | 2,496 | 74.0 | |
| Waubesa........... | 6,7 | X | 4.19 | 1.40 | 3.18 | 2,035 | 36.6 | |
| Kegonsa .......... | 6 | X, XI | 3.00 | 2.25 | 5.3 | 3,392 | 31.4 | |

[1] 7.70 mi. measured along axis of lake. Elevation 282 feet above Lake Michigan.

[2] 3.90 mi. measured along axis of lake.

[3] Including large marshy extension.

[4] 3.90 mi. measured along axis of lake.

[5] 7.65 mi. measured along axis of lake.


# PRE-GLACIAL TOPOGRAPHY

OF THE

# FOUR LAKES REGION

## DANE COUNTY, WISCONSIN

SHOWING ITS RELATION TO THE EXISTING LAKES AND STREAMS

Compiled by Fredrik T. Thwaites from data
collected by Wm. C. Alden, O. U. Stromme
and F. T. Thwaites

1902–1907

*Scale:* $\frac{1}{125000}$ *or about 1 inch = 2 miles*

1 ½ 0 1 2 3 4 5 miles

*Contour interval 50 feet*

*Datum is present sea level*

LEGEND

Present streams and lakes

Pre-glacial streams

Pre-glacial divides

Terminal moraine of Wisconsin Epoch

Outcrops of rock

.850 Wells reaching rock with elevation of rock surface

x790 Wells not reaching rock with elevation of bottom

*Elevations, etc., based on maps of the U. S. Geological Survey*

A. HOEN & CO. BALTIMORE.

# INDEX.