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A GEOLOGICAL RECONNAISSANCE ALONG THE NORTH SHORE OF LAKES HURON AND MICHIGAN
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OFFICE OF THE STATE GEOLOGICAL SURVEY,
Lansing, Michigan, Feb. 7, 1905.

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

Gentlemen: I transmit herewith for publication in the annual report of the Board for 1904 the report of Prof. I. C. Russell of Ann Arbor on his field work last summer with accompanying map. It gives not only an account of some interesting features, eskers and drumlins, which have hardly been noticed in that region before, but also notes on the soils and agricultural possibilities of the region. It is worth noting that according to Mr. Russell the drift coating over the bed rock surface is rarely thick, so that even in the sandy areas it is not probable that the ground water level is very far down. The unmitigatedly sandy areas he does not find to be very large, though all the till is sandy owing to the prevalence of sandstone to the north.

The presence of interglacial lake clays is both scientifically arid practically interesting.

With great respect I am your obedient servant,

ALFRED C. LANE,
State Geologist.

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INTRODUCTION.

The region discussed in this report includes a strip of country varying from about six to thirty miles in width, bordering lakes Huron and Michigan on the north, and extending from Drummond Island westward to the Michigan-Wisconsin line at the mouth of Menominee river. Its northern limit is an east and west line situated six miles north of the 46th parallel of latitude. The area thus defined is indicated on the index map forming Plate I.

The immediate occasion for a re-examination of the geology of the region designated above, was the preparation of a map of the surface geology of Michigan to be published by the Geological Survey of Michigan, on a scale of six miles to an inch, to be printed on nine sheets. Six of the sheets include the Southern Peninsula of Michigan, but overlap onto the Northern Peninsula in such a manner as to embrace the row of townships next north of the 46th parallel of latitude. In order to facilitate the publication of the sheets including Southern Michigan it became desirable to map the surface geology of the strip of country mentioned above. This task was assigned to me by A. C. Lane, State Geologist of Michigan, and occupied my time from July 4th to September 10th, 1904. The region traversed is indicated on the map forming Plate XVI which obviates the necessity of describing it in detail. Owing to the area of the country to be examined, approximately 2,400 square miles, and the comparatively brief time available for the work, nothing more than a reconnaissance could be undertaken. In judging of the value of the results obtained, the rader is asked to bear in mind not only the area of the region examined and the time devoted to the task, but also the fact that by far the greater part of the country traversed is still clothed in forest and much of it occupied by almost impenetrable swamps.

Favorable to geological exploration, on the other hand, is the fact that the portion of the Northern Peninsula under consideration, is crossed by several railroads; containg several cities, as Detour, Mackinac, St. Ignace, Manistique, Gladstone, Escanaba and Menominee, besides several villages, lumber camps, etc.; and at many localities on the shores of lakes Huron and Michigan is visited by steamboats. St. Ignace, Mackinac Island, Les Cheneaux Islands, Detour, etc., are frequented each summer by hundreds of people in search of rest and recreation, and contain a large number of summer hotels. These evidences of civilization, however, are not as great an aid to exploration as they probably seem to one who has not attempted to traverse the region indicated. The leading industry to the east of Gladstone and Escanaba is lumbering, inclusive of the cutting of pulp wood and railroad ties. As is well known, the practice in this connection even at the present day, is to fell such trees as are wanted and leave on the ground the branches and other portions not of immediate commerical value. Fires usually follow the lumbermen, and a dense growth of trees and shrubs springs up in the course of a few years on the fire-swept districts, which obscures the land and renders traveling even on foot exceedingly difficult.

The westward end of the portion of Michigan included on the above map is more favorable for agriculture than the part of the State bordering lakes Huron and Michigan on the north, and large areas particularly on Garden Peninsula, (situated between Lake Michigan and Big Bay de Noc) and in Delta and Menominee counties, lying principally to the west of Green Bay, have been cleared of their formerly dense forests, and are under cultivation. In this section wagon roads are quite numerous, comfortable farm houses abundant and the people, as is the case throughout the entire region traversed by me, most hospitable and obliging. Several railroads radiate

from Escanaba and Gladstone, which faciliate geological work not only by furnishing means of transportation, but on account of the numerous excavations made during their construction. Geological work can, therefore, be carried on to the west of Green Bay more satisfactorily than in much of the eastward portion of Northern Michigan.

While the present report is based principally on personal observations, the writings of previous students of the geology of the same region have been freely used. A brief account of these writings will I think be interesting to the reader.

Plate III. Outline geological map of Michigan.

PREVIOUS PUBLICATIONS.

The portion of Michigan adjacent to lakes Huron and Michigan on the north, is by no means a new field to the geologist. It was first systematically explored in reference to its geology in 1850, while yet a portion of the Lake Superior Land District of the United States, by Messrs J. W. Foster and J. D. Whitney. Associated with this survey, were Messrs E. Desor, James Hall and Charles Whittlesey, each of whom made important contributions to previous knowledge concerning the geology of Northern Michigan. Desor in particular devoted his attention to the sands and clays which form the principal part of the soils and sub-soils, and began the study of the old beaches which record former and great changes of level of the water in the Great Lakes basin. For this task he was well prepared by previous work in Europe, having been associated with Agassiz in the study of the existing glaciers of Switzerland, and taken part in the interpretation of the records of ancient glaciers in Germany and adjacent regions. It was about this time that the importance of glaciers as agents in modifying the earth's surface began to claim the attention of Agassiz, Charpentier, Forbes, Guyot, De Saussure and others in Europe, and the foundation was laid for a systematic study of the records left by ancient glaciers in various parts of the world. Desor fresh from the land where these matters first claimed serious consideration, came to America as did Agassiz, and Guyot, and with them assisted in stimulating an interest in glacial geology in this country which has continuously increased to the present day, and is one of the chief divisions of the earth's history now receiving attention from the geologists of both Canada and the United States. On arriving in America Desor became connected with the U. S. Coast Survey, and was thus enabled to continue the study of lake shore topography, etc., previously begun in Europe, which gave him valuable training and enabled him to recognize the significance of the several abandoned beaches which form such a conspicuous feature of the slopes bordering the Great Lakes. Desor was associated wtih Forbes and Whitney during 1849 and 1850, and was enabled to examine in a general way nearly all of the Northern Peninsula of Michigan, which was thus made classic ground to glacial geologists. Besides several papers dealing with the surface geology of Northern Michigan, published in the scientific journals of Europe and America, he furnished two reports on his observations, which were embodied in the reports made by Foster and Whitney to-the Commissioner of the General Land Office.[1] Much use has been made of Desor's observations while writing the present report.

In the second report by Foster and Whitney there is an article on the ancient and present beaches of Lake Michigan, and a chapter on the observed fluctuations in elevation of the surfaces of the Great Lakes by Charles Whittlesey, which contains many data of value not only in reference to the shoaling or deepening of harbors, but of use in demonstrating that a secular change in elevation, or a tilting, of the rocks of the region where the Great Lakes are situated, is in progress. The modern changes about the shores of the Great Lakes and the light thus furnished in reference to the history of the abandoned beaches now high above the surfaces of the lakes, were discussed by Whittlesey in "Contributions to Knowledge," published by the Smithsonian Institution and elsewhere.[2]

The geology of the stratified rocks, principally dolomite and limestone, beneath the surface covering of unconsolidated debris in the part of Michigan under consideration, was studied by James Hall during the Foster and Whitney survey, and later by Carl Rominger, State Geologist of Michigan. In the reports of Hall and Rominger, the positions which the rocks now occupy, the tract of county each formation immediately underlies, and the abundant records of the life of the time during which the several formations were deposited, received special attention. The writings of Hall and Rominger in reference to the older chapters in the geological history

of Michigan are fully as interesting and instructive as the story of the much more recent changes described and discussed by Desor and Whittlesey, and are important contributions to knowledge. The report by Rominger, in particular, dealing with fossil corals, and contained in volume III of the reports of the Michigan Geological Survey, should be of great educational value to the inhabitants of the Northern Peninsula, since it contains descriptions of the marine life which flourished in that region when it was covered by tropical seas. Fossil corals occur in abundance especially in the Garden Peninsula, where they not infrequently form a large part of the stone walls built about the fields of the farmers. These beautiful objects awaken interest even in the minds of the unlearned on account of their peculiarities of shape and structure, and attract the attention of children. With the aid of Rominger's report they can easily be made stepping stones to a knowledge of nature, as well as walls about meadows and pastures.

[1]Foster, J. W. and J. D. Whitney "Report on the geology and topography of a portion of the Lake Superior Land District, in the State of Michigan. Part 1.*Copper lands." Executive Document No. 69, House of Representatives, 31st Congress, 1st session. Washington, 1850, pp. 186-218.

"Report on the geology of the Lake Superior Land District. Part II. The iron region together with the general geology." Executive [Document] No. 4, Senate, Special Session, March, 1851, Washington, 1851, pp. 232-270.

[2]Reference to the publications of Whittlesey and Desor, may be found in, N. H. Darton's Catalogue and index of contributions to North American geology, 1732-1891, Bulletin No. 127, U. S. Geological Survey, Washington, 1896.

Since Desor and Whittlesey directed attention to the glacial deposits and old lake beaches of Michigan, much interest has been taken in the later chapters of the earth's history preserved in this and adjacent regions, by the people of Canada and the United States, and a large body of literature bearing on the subject has been published. While the results of nearly all of these studies have a direct bearing on the later geological history of the region described in this report, those most intimately connected with it are the writings of F. B. Taylor, of Fort Wayne, Indiana; who has devoted much time to the study of the abandoned shore lines of the Great Lakes and especially of the region about Mackinac Island and the northern border of Lake Michigan. The numerous papers by Taylor are for the most part listed in bibliographies of North American geology[1] and will be referred to many times in the following pages.

Of the many papers relating to the Great Lakes in general, and to their geological history, which refer to the changes recorded by former water-bodies about the northern shores of lakes Huron and Michigan, perhaps the most suggestive is one by G. K. Gilbert[2] dealing with the movements in the earth's crust which has recently affected the entire Great Lakes region, and are still in progress. A knowledge of the movement or tilting of the land now in progress in the region of the Great Lakes is important not only to the engineer who has charge of harbor improvement, but of great assistance to the geologist who endeavors to account for the many changes in water-levels that have taken place and are recorded by abandoned beaches which are no longer horizontal.

The several reports and papers mentioned above, and still others, referred to later, have been of great assistance while writing the present report. In this connection mention should also be made of the splendid charts of the Great Lakes published by the U. S. War Department.

[1]Weeks, F. B. Bibliography of North American geology, paleontology, petrology and mineralogy for the years 1892-1900, inclusive. U. S. Geological Survey, Bulletin No. 188, Washington, 1902.

[2]Recent earth movements in the Great Lakes region, U. S. Geological Survey 18th Annual Report, pt. II, pp. 595-647; republished in part in National Geographic Magazine, Vol. VIII. pp. 233-247; and also in Annual Report of the Board of Regents of the Smithsonian Institution for 1898, Washington, 1899, pp. 349-361.

OUTLINE OF GEOLOGICAL HISTORY.

The portion of the earth's history recorded in the rocks and in the topography of the part of Michigan adjacent to lakes Huron and Michigan on the north, has two distinct divisions; one dealing with the solid rocks of ancient date, the other with the superficial layer of clays; sand, soils, etc., of comparatively recent origin which rest on the surfaces of the hard rocks.

In the older chapter the records pertain to a time when the site of Michigan was covered by the waters of, ancient seas, over the bottoms of which deposits of sand and mud were spread out in horizontal layers. These beds have since been hardened into sandstone, limestone, dolomite (magnesian limestone) etc., but still retain fossil shells, corals, crustaceans, etc., which reveal the nature of the life inhabiting the ocean during the Paleozoic or ancient division of geological time. The younger chapter of the geological history deals principally with the great ice invasion, termed the Glacial Epoch, during which the site of Michigan, together with a vast region about it, was buried beneath glaciers in much the same manner that Greenland is sheltered with ice at the present day. Intimately connected with this ice invasion were lakes, at times of wider extent than the present Great Lakes, which occupied the same basins and left conspicuous beach lines about their border. Each of these two divisions of the geological history of Michigan, although conspicuously different in nearly exery detail, is full of interest even to the general reader, and in each case, also, has a direct and important bearing on human affairs.

It is instructive to tabulate the chief divisions of the two great chapters of geological history just referred to, and to indicate the nature of the records on which their interpretation depends. Such a summary reads as follows:

OUTLINE CHART OF GEOLOGICAL RECORDS.

Geological Time.	*Nature of the Records.*	
PRESENT EPOCH.....	Lake beaches still being formed; river silts and sands, peat, marl, etc., now being deposited or still growing; river valleys still being deepened; lake beaches formed since the Glacial Epoch and now abandoned; deposits now being made in lakes, etc.	
GLACIAL EPOCH.....	Abandoned beaches of ice-dammed lakes. Glacial striæ and other markings on rock surfaces. Glacial deposits, as till or boulder clay, occurring as a surface blanket over the hard rocks, and in places forming lenticular hills or drumlins. Gravel and sand deposited by glacial streams, such as irregular ridges or eskers and sand plains.	
A long time-interval during which Michigan was a land area and subject to erosion.		
PALEOZOIC ERA....	Monroe Period.....	Mostly marine limestone, usually magnesian, in nearly horizontal beds, and containing fossil shells, corals, crustaceans, etc.
	Niagara Period.....	
	Lorraine and Utica Period.....	
	Trenton Period.....	
	Calciferous Period...	

As this schedule suggests, a convenient plan for presenting a popular account of the geological history of the portion of Michigan under consideration, is to give: First, a brief summary of what is known concerning the older or Paleozoic formations, and a free interpretation of their history, or the hard-rock geology as it may be termed. Second, a discussion of the nature, mode of origin, etc., of the superficial blanket of rock-waste which rests on the -hard rocks, or the surface geology. Of these two divisions, chief attention is here invited to the surface blanket of rock-waste inclusive of soils and subsoils, for the reason that it is everywhere in sight, and in the region examined is of greater economic importance to man than the hard rocks beneath, as it furnishes the basis for agriculture, and forms the surface in which forests are rooted.

THE HARD-ROCK GEOLOGY.

The rock formations beneath the unconsolidated surface covering of glacial deposits, lake clays, etc., of Michigan—with the exception chiefly of the igneous rocks, granite, schists, etc., of the iron and copper regions of the Northern Peninsula—are marine deposits and all belong to the Paleozoic, or most ancient of the formations at present known which contain records of life.

Within the area represented by shading on the map forming Plate I, the formations of older date than the Glacial Epoch all belong to the Silurian (or Ordovician and Silurian of some schemes of classification) and include the following sub-divisions as recognized by the Geological Survey of Michigan, namely, in descending order, the Monroe, Niagara, Lorraine and Utica, and Trenton, formations. These names have been applied to sheets of rock, mostly limestone and dolomite (magnesian limestone) which in the region bordering lakes Huron and Michigan on the north, have an aggregate thickness of about 1,800 feet from the top of the Monroe to the base of the Trenton and are inclined downward or clip southward at low angles. The dip at most localities is so gentle that the beds of rock appear to be horizontal. Owing to the dip of the formations and the manner in which they have been eroded, they come to the surface in a series of concentric belts, concave to the south, as indicated on the geological map of Michigan forming Plate III.

The Monroe Formation: The rocks thus designated are about the equivalent in age of the Manlius and Salina[1] (and Lower Helderberg of some authors) formations of New York, which include the salt and gypsum deposits near Syracuse. Similar rocks occur in Northern Ohio and southeastern Michigan where they also contain beds of salt and gypsum. In Northern Michigan this formation occurs at the surface on the St. Ignace Peninsula, Mackinac Island, Bois Blanc and other neighboring islands, as was made known by James Hall in 1850,[1] and much information concerning it is recorded in his contribution to Foster and Whitney's report already referred to. The light colored limestone forming the upper portion of the conspicuous precipices about the border of Mackinac Island and appearing in the St. Ignace Peninsula and on Bois Blanc, were identified by Hall as about the equivalent of the Helderberg formation of New York. Beneath this somewhat massive limestone and exposed at the water's edge about Mackinac Island, and in a similar position on the margin of the St. Ignace Peninsula, are gypsum bearing beds having the stratigraphic position of the Salina formation of New York. These gypsum bearing beds form the surface on the northern portion of Mackinac Island and outcrop throughout a considerable area a few miles north of St. Ignace. When at or near the surface their presence is indicated by a multiform topography characterized by a succession of irregular hills with equally irregular hollows between, and as a rule the absence of surface streams. These peculiar surface features are due to the removal of the more soluble portions of the deposit and especially the gypsum (hydrous calcium sulphate) which they contain. This mineral occurs in irregular beds, and mingled with it is a similar mineral known as anhydrite or the anhydrous calcium sulphate. Possibly beds of salt like those present in rocks of the same age near Detroit, have also been dissolved away, but borings seem to indicate that they do not extend so far north. The peculiar roughness of surface referred to, is confined to the localities where the Salina formation is present and is not found elsewhere in the portion of Northern Michigan under consideration.

[1]The New York correlation was made by Hall. The presence of gypsum, etc., and a very fair description of the formations associated with it, however, had already been given by Bigsby in 1822.

The rock, mostly impure limestone, at the top of the gypsum bearing formation and marking the passage into the overlying formation, is peculiar, inasmuch as it consists of angular fragments of limestone inclined in all directions and cemented into a compact mass by carbonate of lime which has been deposited in the cracks and crevices between them. This *breccia* is well

exposed in the rocky ridges in the western portion of the town of St. Ignace, and at the “Sugar Loaf" and other localities on Mackinac Island. An explanation of the origin of the breccia, so far as I am aware, has not been offered, although Hall directed attention to it and judging from the statements made in his report, seemed to consider it as evidence of an unconformity,[1] that is, the occurrence of an interval during which the lower formation was exposed to the air and broken and eroded before the rocks resting on it were deposited. The fragments of limestone in the breccia, however, are sharply angular and not rounded as is nearly always the case with stones that have been weathered, or removed and re-deposited by water. The nature of the breccia and its occurrence above strata containing easily soluble beds of gypsum,—and of anhydrite which in the presence of water is prone to change to a hydrous condition, accompanied by an increase in volume—suggests that the fracturing and displacement of the rocks may be due to the removal of material in solution, and to changes in volume caused by the hydration of the anhydrite. Remembering that the present surface of the St. Ignace Peninsula, etc., has been exposed owing to the removal of very considerable depths and probably many hundreds of feet of rock, it is evident that the solution of beds of gypsum or the alteration of the anhydrite, at any time subsequent to the consolidation of the formations resting on it, would lead to movements, and particularly the settling and fracturing of the rocks above the gypsum-bearing layers, which would become broken, and displaced and if re-cemented would form a breccia. The above suggestion may perhaps lead future visitors to the region about Mackinac to examine the rocks attentively with the view of discovering evidence which will sustain or disprove the hypothesis here proposed.

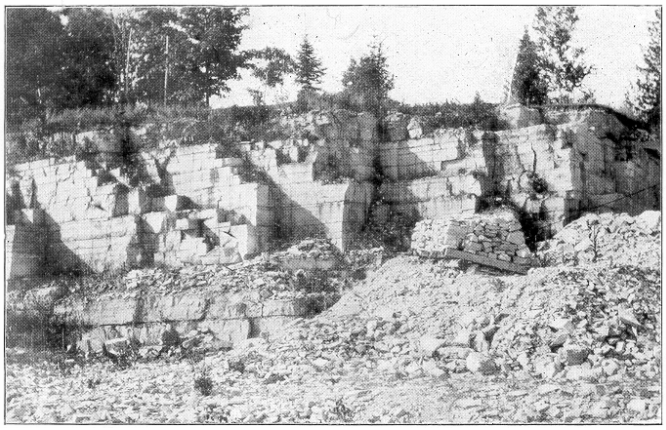

Plate IV. Quarry in joined Niagara limestone, Drummond. July 24, 1904.

As has been described by Hall, the limestone of Onondaga age in the St. Ignace region, like the limestones or dolomites of similar age in New York and Southeastern Michigan, are frequently vesicular owing to the removal from them of material more soluble than the main bulk of the rock. The cavities thus produced are frequently angular or gash-like and as has recently been shown by E. H. Kraus, have resulted in many if not all instances from the solution of crystals of celestite (strontium sulphate) with which unweathered rocks in the same formation are frequently changed.

Gypsum has been found on the St. Ignace Peninsula in considerable abundance, and is exposed at certain localities on Mackinac, St. Martin, and Goose islands, but is not known to occur at these localities in sufficient quantity and of the requisite purity to be of commercial importance.[2]

While rocks of the same age as those forming at the St. Ignace Peninsula and neighboring islands, are sometimes rich in fossils, those outcropping to the north of the straits of Mackinac are mostly barren of such remains and offer but little inducement to collectors of the relics of ancient life.

[1]Foster, J. D. and J. D. Whitney, Report on the geology of the Lake Superior Land District, Washington, 1851, p. 162.

[2]See, however, vol. 9 of the Reports of the Michigan Geological Survey.

The Niagara Limestone: The rocks corresponding in age with the Niagara and Clinton formation of New York and consisting almost entirely of light colored, white or bluish, magnesian limestone or dolomite, are the most widely distributed and in several ways the most important of the formations exposed in the region treated in the present report. They extend in a curving bed concave to the south, (see Plate III) and with an average width of about fifteen miles, from Drummond Island westward to the end of Garden Peninsula. The thickness of the sheet according to Hall, is about 350 feet,[3] and its inclination or dip is southward at a low angle, in general amounting to a descent of about thirty-five or forty feet to a mile. In a general way the dip changes from southwest in the vicinity of Detour to southeast on the Garden Peninsula, indicating as will be discussed more fully on a subsequent page, that this immense sheet of rock, in common with other and adjacent sheets both above and below has been depressed in the region occupied by Southern Michigan so as to have a saucerlike shape.

[3]Probably more rather than less. See Annual Report of the Geological Survey of Michigan for 1903, pp. 114-122.

The Niagara limestone was deposited in a shallow ocean, in which the conditions were for the most part favored the growth of corals, mollusks and other invertebrate animals which live in the open sea. The condition changed, however, from time to time, and mechanical sediment such as mud and sand were carried by currents far from shore and mingled with the organic debris of the open waters. These changes are recorded in the nature of the rocks and by the relics of life they contain. Throughout the region under consideration, the land during the Niagara period was sufficiently distant to prevent the detritus brought from it by streams from making conspicuous deposits. The material accumulated on the oceans floor was mainly supplied by the hard parts of animals and especially

corals, which lived in its waters, although clayey sediments derived from the land did at times interfere with or modify the development of the living organisms. The more purely calcareous layers of rock or the ones with no appreciable admixture of argillaceous matter, abound in corals, as remarked by Hall, and appear to have been coral reefs, which even now occupy their original positions. In many instances these ancient coral-reefs were covered by deposits composed in part of finely comminuted matter, probably derived from the remains of corals and other marine animals, but containing also appreciable quantities of land-derived mud. When those impure limestones were formed no corals lived nor as a rule are other fossils to be seen in such portions of the rocks. Again the conditions varied and corals reappeared and continued to flourish for a longer or shorter period, until another change unfavorable to their growth occurred; and in this manner several alternating bands of limestone, some crowded with fossils and others barren of the records of life, came into existence.

In some instances the Niagara limestone, as in the southern portion of the Garden Peninsula, is crowded with finely preserved fossils, consisting principally of corals and representing ancient coral reefs. Beautiful specimens of these relics are there strewn over the fields and in numerous instances have been gathered together and used in making stone fences. The reason for the abundance of these fossils at the surface is that owing to changes produced by the deposition of silica, after the rocks were consolidated and before being eroded, the original lime of the corals and other organisms was removed and replaced by silica, while the inclosing rock was not thus altered. By this process of silicification the fossils were rendered much less soluble than the rock containing them, and when exposed to the air and beaten upon by rains, were left when the more calcareous material surrounding them was removed. Resulting from this combination of conditions, we find today, strewn over the fields, wonderfully perfect and frequently exceedingly delicate and faithful representations of corals which lived many millions of years ago.

At certain localities as on Drummond Island, and in exposures of limestone in the hills about seven miles north of Hessel and Cedarville, the Niagara limestone is crowded with natural casts of the interiors of large brachiopod shells of the genus *Pentamerus*. These may be readily recognized by the five divisions into which the casts are divided in the part where the two valves of the shell were hinged together. Other fossils are also abundant at many localities where the Niagara limestone is exposed, and make an attentive study of such outcrops both interesting and instructive. The fossil corals of the Niagara limestone and of other formations in Michigan, have been faithfully described and well illustrated by Carl Rominger, in Volume 3 of the reports of the Geological Survey of Michigan.

The Niagara limestone as will be more fully considered on a subsequent page, is in general and especially in its upper portion, harder and more massive than the formations with which it is immediately associated and hence has resisted erosion more efficiently than its neighboring terranes. It is also in general a magnesian limestone and in part a typical dolomite, and for this reason is less readily soluble than if composed of pure calcium carbonate; this also favors its preservation and together with its hardness, has enabled it to stand in relief while the surfaces of the less resistant adjacent formations have been lowered so as to form valleys.

A view of an artificial exposure of the lower portion of the Niagara limestone, in a quarry at Drummond, on the north shore of Drummond Island, is presented on Plate IV, which shows the nearly horizontal position occupied by the thin sheets of rock there present. A still more prominent feature, however, to be seen in the same picture, is the presence of two series of nearly vertical dividing planes or joints which cut the strata, and together with the bedding planes divide the rock into rudely rectangular blocks, thus greatly aiding the work of the quarryman. The joints so far as now exposed are narrow, nearly smooth sided fissures, such as one may suppose would be produced by sawing the rocks along two series of parallel lines at right-angles to each other; the saw being slightly inclined instead of vertical. The two series of master joints bear respectively N. 39° E. and N. 58° W.[1] or approximately at right angles; the joint planes although nearly vertical, are inclined to a horizontal plane as may be seen in the accompanying illustration.

Joints similiar to those just noted occur in many sedimentary rocks and in fact have a world wide distribution, but their mode of origin has not as yet been satisfactorily explained. As a modest contribution to the data, on which the desired explanation must be based, the following facts are here recorded: Near the Lake Survey Signal Station at Detour, nearly flat surfaces of limestone are divided by joints, and in their at present weathered condition resemble a rude pavement of flat stones; the joints having been widened to several inches owing to the solvent action of water on their walls. The major joints are here, as is usual in two series nearly at right angles to each other; the average of several measurements, shows that one series bears N. 39° E. and the other N. 53.8° W. In a neighboring exposure the respective bearings are, N. 51° E. and N. 48° W. In each case the nearly northwest joints are stronger and more prominent than the northeast series. The joint planes are nearly vertical but owing to the effects of weathering no satisfactory measurements of their inclination were obtained. In the Niagara limestone quarries near Marblehead, two systems of joints are again conspicuous, one bearing N. 66° E. and dipping southeast at an angle varying from 85 to 88°; and the other bearing N. 44° W. and dipping northeastward at an angle of about 80°. At Whitedale, two series of joints rendered conspicuous by weathering, were observed,

one series bearing N. 24° E. and the other series N. 46° W.

[1]These and other compass readings given in this report, have been corrected for secular magnetic variation, i. e. are referred to the geographic instead of the magnetic pole.

The full significance of these and other measures of the position of joint planes is not now apparent, as they pertain to an unsolved problem, but are well worth noting. It will perhaps be found that the joints which are such a prominent feature of nearly all sedimentary rocks, have been produced by torsion generated in the earth's crust perhaps on account of variations in the rate of the earth's rotation, assisted as has been suggested, by earthquake shocks, and hence having an important bearing on profound questions concerning the relation of the earth to other planets, etc. There is yet another reason why joints should receive general recognition. They influence the manner in which rocks weather, and hence furnish a reason for many features in the shapes of cliffs and valley sides. By giving direction to streams, they also determine the major topographic features of many regions, such as hills and valleys, which have been produced by erosion.

The Lorraine and Utica Formation: The rocks to which this compound name is applied in recent publications of the Geological Survey of Michigan, are, as shown principally by their fossils, about the equivalent in age of the Hudson River shales of New York, and the Cincinnati limestone of Ohio, but in composition are intermediate between the two. They are not typical shales or representative limestones, but impure or argillaceous limestones. The significance of these differences in the rocks of the same age, deposited in the same ocean but at different localities, is that near the land in the case of the Paleozoic ocean as in the ocean at the present day, sand and mud were spread over the bottom while far from land calcareous deposits accumulated. In Northern Michigan, the rocks of the Lorraine and Utica formation were formed in a sea teeming with life, but where mud washed from land was being deposited in considerable abundance. The influence of these conditions is expressed by the organic remains still to be found in the rocks, which consist largely of brachiopod and molluscan shells and crustaceans, (trilobites) with but few and mostly small representatives of the corals. That is, the life was such as rejoiced in muddy bottoms, and did not include forms, like the corals, which thrive best in clear seas.

The rocks of the Lorraine and Utica formation occur in a belt from about two to five or six miles wide, concentric with and to the north of the similar curved belt occupied by the Niagara limestone, and extend from St. Marys River on the east to Big Bay de Noc on the west. Their distribution is shown on Plate III. The breadth of the outcrop of the formation just stated is not considered as accurate, since the region where it occurs is forested and occupied to a considerable extent by swamps, so that the nature of the underlying rocks and the precise boundaries of formations are difficult to ascertain. One of the chief features of interest concerning the Lorraine and Utica formations is its relative weakness in reference to erosion. Its softness and the thin bedding permit it to yield readily to mechanical agencies of erosion such as sand-laden streams, and glaciers in the basal portion of which stones are embedded, while at the same time the calcareous portions are subject to solution by surface or percolating waters. Mainly for these reasons the surface where these rocks are present has been eroded to a lower level as a rule, than the adjacent country where more resistant rocks occur and on account of its low relative position is now largely swampy. The Lorraine and Utica formation yields to denuding agencies more readily than the Niagara which overlies it or the Trenton which occurs beneath it, and this finds expression, as will be considered more fully later, in the relief of the hard-rock surface beneath the glacial drift, etc. and especially in the presence of Green Bay at the west and Georgian Bay at the east; where the rocks of this formation have been excavated so as to form basins.

The best exposure of the Lorraine and Utica formation in the region especially considered in this report, is in the low lake-cliff on the east side of Little Bay de Noc opposite Escanaba. At this locality the nearly horizontal bedding of the deposit, its conspicuously argillaceous character, and its richness in organic remains are well illustrated. These same cliffs also show how the waves of the lake, by cutting away soft beds which occur beneath harder and more massive layers, lead to the production of precipitous and even overhanging escarpments.

The Trenton Limestone: A series of thin, mostly bluish, impure limestone beds occurring beneath the Lorraine and Utica formation in Northern Michigan is stated by Hall to be in reality compound and to represent several formations each of which has a thickness of many score feet in New York, but is termed the Trenton limestone of which it is mainly the representative. Its thickness in Northern Michigan as computed for its dip and breadth of outcrop, as well as from the records of drilled wells, is about 200 feet. It is stratigraphically next below the Lorraine and Utica formation, and owing to the basin-like structure of the rocks beneath the greater part of Michigan, comes to the surface in a curved belt concentric with the similar belts formed by the Niagara, etc., between St. Mary River on the east and the Menominee River on the west. This outcrop is mostly to the north of the region to which attention is invited in this report, but to the west of Green Bay, underlies the surface covering of glacial drift, etc., for a distance of twelve to over twenty miles westward from the bay shore. The formation is well exposed along the lower portion of Escanaba River, where it is quarried for building stone, and also appears at the mouth of Ford River, and at a number of other neighboring localities where it has been laid bare by erosion or trenched by streams.

To the north of the Trenton limestone in Northern Michigan, other layers of rock belonging to the Ordovician or Lower Silurian, and Cambrian periods are present, including as the lower member, the Lake Superior or Potsdam sandstone, which outcrops along the southern shore of Lake Superior from near Marquette eastward to St. Mary River, but concerning this important formation little need be said at this time.[1]

Geological Structure: By this term is meant the positions or attitude occupied by the layers of rock in the earth's crust. It is a well established fact that sheets of marine sediments of the general nature of those described above, are horizontal or essentially so, unless some force has been exerted on them and cause them to become inclined or folded. In Northern Michigan as already explained, the Paleozoic formations ranging in age from the Potsdam sandstone at the bottom, to the Monroe formation at the top, are inclined southward at low angles; the dip being southwest in the eastern portion of the country beneath which they occur, and changing gradually to southeast, when traced westward to the region bordering Green Bay. The succession of the rocks together with their gentle southward inclination is indicated in the following diagram, which represents the manner in which the edges of the various formations present from Point St. Ignace northward to Lake Superior, would appear if a great railroad cut for example, should be made along such a line and extended down to sea level.

[1]See Annual Report Geological Survey of Michigan for 1903, pp. 124-142.

As an attempt has been made to show in the following section, the edges of the more resistant beds stand in relief forming hills, while the less resistant rocks underlie depressions or valleys. The entire series of beds dips southward, the inclination being in general over forty feet to a mile. Similar sections in the Georgian Bay region would show a southwest, and if made in the Green Bay region a southeast dip. Without attempting to present all the evidence in this connection, the conclusion may be stated, as the result of a long series of observations carried on by various geologists, that Southern Michigan and a large region about it including the portion of Northern Michigan to the east of the longitude of Marquette, has a basin-like structure; the rocks in the central portion occuping a horizontal position, and those about the central area, being depressed and passing under it.

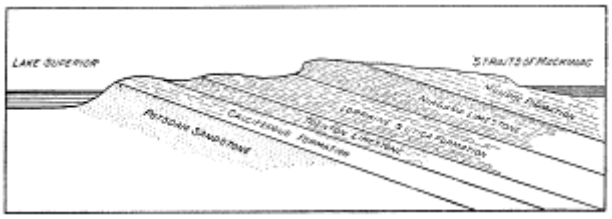

Figure 4. Ideal section showing succession of formations in Northern Michigan.

Owing to this basin-like structure the formations indicated in the above sketch section which in Northern Michigan have an inclination downward to the south, and disappear in succession as one crosses their edges in traveling from the north toward the south in the order of their age; reappear in part in Southern Michigan in reverse order and with a- downward inclination to the north. That is, the originally horizontal beds in the Michigan region have been depressed in the central part of that area, so as to resemble a pile of shallow saucerlike dishes. The upper portion of the pile has been eroded to a generally plane surface, somewhat lower than the original surface of the central and last formed member of the pile. The concentric arrangement of the surface exposures or outcrops of the formations involved in the movements just described, is shown in part on the geological map forming Plate III.

The subsidence referred to went on during the time the various layers of sediments were being deposited, and was perhaps due in part to their weight, but was mainly produced, as is believed, by a more general cause, namely, contraction of the central mass of the earth beneath its cool and rigid crust. The downward movement while extending from the earlier portion of the Paleozoic era to the close of the Carboniferous period, was not necessarily continuous throughout this immense period of time, and there is evidence showing that upward movements occurred during certain stages, as near the middle of the Carboniferous period, when a land surface existed in the central part of the Southern Peninsula of Michigan, which was eroded and had gypsum deposited in its lake basins or lagoons, before the next succeeding sheet of marine deposits was laid down.

The deformation which produces the great structural or tectonic basin of Michigan, is one of the unique features in the geology of North America, and one to which popular attention has seldom been directed. A proper understanding of its importance is necessary, however, in order to enable one to appreciate the significance of many facts concerning the geology of the hard rocks which have a direct bearing on matters of commercial importance, and in order also to learn the fundamental reason for the existence of some of the geographical features of the Great Lakes region. The Michigan tectonic basin is rudely circular and approximately 500 miles in diameter; its center being in the medial portion of the Southern Peninsula, near Midland. In this central region the amount to which the lowest rocks involved in the downward movement have been depressed below their original position, is as nearly as can now be judged, not less than five or six thousand feet. In many portions of the earth's crust, the rocks composing it have been upheaved into great domes from which mountains have been carved, but it is exceptional to find an extensive region where the opposite result or the production of a reversed dome of vast dimensions, has been reached with but little secondary disturbance, and not followed by an upward movement.

In the Michigan region the great subsidence mentioned went on during a large portion of, if not the entire, Paleozoic era; the oldest sediments known to have been involved being the Cambrian, and the youngest the Coal Measures. The subsidence permitted of the deposition of sheet after sheet of marine sediments, within generally narrower and narrower limits as the pile increased in thickness, until the coal-bearing rocks which occupy the center of the basin were deposited. This great subsidence occurred with but little secondary folding or crumpling. It is probable, however, that irregularities of the feature of up and down folds, radiating from the central portion of the depressed region towards its periphery are present, but are as yet undiscovered. This conclusion is suggested by the fact that a series of horizontal beds if depressed in its central part must be either stretched to admit of the change of shape, or be plicated in radial folds. Evidence of plication in beds that have been elevated into domes is well known, but a flow of the material of which rocks are composed so as to admit of an adjustment to a new position during such movements is much more difficult to detect. Probably each of these changes were brought about in the rocks of the Michigan region and evidence of radial folding should be looked for, since it is a matter of great economic importance in reference to the storage of gas and oil.[1]

The significance of the general structure of the Michigan tectonic or structural basin in reference to the geology of the part of the State under immediate consideration, is, that the hard rocks there present are included in the outer portion of the series of concentric belts formed by the coming to the surface of the deeper of the basin shaped formations which underly Southern Michigan. The rims of the lower members of the pile of geological saucers, so to speak, form segments of concentric belts, concave southward, which sweep in remarkably regular curves from St. Mary's River westward well into Wisconsin. On the west this series of curved belts meets a region of crystalline rocks exposed owing to the erosion of a region of upheavel, but on the east the influence of the Michigan tectonic basin is throughout the western part of Ontario.

[1]In this connection it may be suggested that wells drilled in Southern Michigan with the hope of obtaining gas or oil, would have the best chance of success if distributed about the borders of that Peninsula where radial anticlinals pitching toward the central part of the basin, may be expected to approach the surface and to afford the requisite conditions for the storage of oil and gas. Where these localities are, if they exist, has yet to be discovered. Information in this connection, however, may be found in the reports of the Geological Survey of Michigan for 1901, and 1903.

Topography of the hard-rock surface. The attention of the reader has already been directed to the fact that the geology of the region bordering lakes Huron and Michigan on the north, has two leading and conspicuously different divisions; one relating to the stratified sheets of marine sediments, now for the most part hardened into compact rock, mostly limestone; and the other dealing with the superficial covering of loose and in large part unconsolidated debris, largely sandy and stony clay, resting on the surface of the older series of formations. In the language of geologists, the younger formation rests unconformably on the older series of formations, and between the two periods of accumulation there was a vast time interval. This interval, lost so far as the geological deposits of Michigan were concerned, extends from near the close of the Carboniferous period to the Glacial epoch. During much of this interval the region occupied by Michigan was a land area, and subjected to erosion. The records of the changes that occurred are therefore, to be looked for on the surfaces of the older rocks, and as is to be expected, must be mainly of the nature of hills and valleys produced by erosion. The shapes and other characteristics imparted to the outcrops of the older rocks thus become matters of great interest, since such features take the place of the more common class of geological evidence furnished by sedimentary and other deposits. The relief of the hard rock surface is also of interest in connection with the study of the superficial deposits resting on it, for the reason that it enables one to measure the thickness and ascertain other features of the superficial accumulations.

To ascertain the characteristics of a rock surface buried beneath subsequent deposits, is in most cases a difficult task, and one that is usually accomplished principally by obtaining the records of wells, mines, etc., which pass through the material beneath which it is concealed. In Northern Michigan, this task is less difficult than in most of the formerly glacier-covered portions of the United States, for the reason that the glacial and other deposits occupying the surface are everywhere comparatively thin, but as much of the country is forest and swamp-covered, the work of assembling the necessary data is tedious. Over large areas, wells and other excavations are wanting and natural conditions such as rock outcrops, etc., are alone available.

In spite of the meagerness of the facts in hand it is evident that in the part of Michigan under consideration, the hard rock topography does not differ materially from the relief of the surface of the superficial material resting on it. This conclusion will no doubt be a surprise to persons who have studied other portions of the formerly glaciated region of the United States, where as a rule, the superficial accumulations are deep enough to effectively conceal the relief of the surfaces of hard rock on which they repose. Throughout Northern Michigan, however, the glacial drift is so thin and forms such a uniform blanket, that it has essentially the same inequalities of surface as the floor on which it rests. It is only locally that the surface deposits have a topography peculiar to themselves which thoroughly masks the relief of the hard rock surface beneath.

The major features in the present relief of the region to the north of lakes Huron and Michigan, can be correlated with the varying degree of resistance to erosion of the Paleozoic formations there present. Here as elsewhere, the resistant rocks stand in relief, forming hills and ridges, while the less resistant rocks have been eroded

so as to give origin to valleys. The basins of lakes Huron and Michigan as was first pointed out I believe, by Hall and Whittlesey, are situated where the Monroe formation (the Helderberg and Onondaga salt group of Hall) which is less resistant both to the mechanical and to the chemical agencies of erosion than the formations above and below it, would be present, if it had not to a large extent been removed. Remembering the concentric arrangement of the belts of rocks formed by the edges of the various layers in the Michigan tectonic basin, it follows that if the basins of lakes Huron and Michigan have been excavated in the Monroe formation they should have the position which would have been occupied by that formation if it had not been excavated. By referring to a geological map of the Great Lakes region (Plate III) this will be seen to be essentially true.

As stated by James Hall, the basin of "Lake Michigan has been, to a great extent, excavated from the Onondaga salt group and the upper Helderberg series" [the Monroe and Dundee formations] "while the Niagara limestone, being harder and more indestructible, forms its western border from one extremity to the other. From the breadth of the country over which we find vestiges of the Onondaga salt group and the upper Helderberg series in the northern parts of lakes Huron and Michigan we are warranted in the conclusion that at least two-thirds of the latter lake in a direction conforming to its trend, has been excavated in these limestones." A similar conclusion was also reached by Whittlesey, in reference to Lake Huron; "The Niagara limestone there forms a barrier occasionally broken through, extending along its northern shore embracing Cabot's Head, and the Grand Manitoulin islands. It dips southerly, so as to leave the Onondaga salt group and the upper Helderberg series to the south; and the area once occupied by them is now covered by the waters of this lake."

The eastern and northern shore of Lake Huron from Goderich northward, and the entire northern and western shore of Lake Michigan, are composed of Niagara limestone which dips toward the water bodies it margins. The only exception to the continuity of the Niagara in the nearly semicircular coast line, over 600 miles long, extending from Goderich to Chicago, is where the rocks of the Monroe formation appear in the St. Ignace Peninsula. This exception is significant and a reason for it is suggested on page 57.

The fact that the sheet of Niagara limestone dips toward the lakes it margins, as just mentioned, at once suggests a reason for the general lowness of these shores, and their lack of bold or picturesque scenery. At many localities the gently-sloping surface of the limestone passes beneath the water at the lake margin without noticeable change due to abrasion by the waves. At other localities and particularly at the ends of capes, the waves and currents have cut small lake-cliffs, but those features are seldom conspicuous. Bluffs are present at certain localities, however, about the portions of lake shores just referred to, but so far as I am aware, they owe their prominence to lake-cliffs cut in glacial drift and similar material belonging to the surface blanket of rock debris, or to the presence of sand that has been drifted into dunes by the wind.

From the brief outline of the conditions about the outer shores, as they may be termed, of lakes Huron and Michigan, that is, the shores farthest removed from the center of the Michigan tectonic basin, it will be seen that not only do the basins of these lakes owe their existence and position to the structures and differences in resistance to erosion of the underlying rocks, but many of the scenic features of their present borders are controlled by these same conditions.

[1]Foster, J. W, and J. D. Whitney, Report on the geology of the Lake Superior Land District, 1851, p. 176.

As the Niagara limestone dips toward the two of the Great Lakes which it borders respectively, and gives them low shores, it will be inferred no doubt, that the outer margin of the outcrop of the same bed of resistant rock should rise high in the air and form a bold ridge, or a series of prominent hills. This deduction is sustained in part by the present relief.

While the Lake Michigan shore of the Garden Peninsula is low and sandy, the opposite shore facing Big Bay de Noc, is notably bold, and presents several headlands which are prominent and mildly picturesque. The most conspicuous of these headlands known as Burnt Bluff, rises precipitously to a height of 225 feet above Big Bay de Noc, and is composed of Niagara limestone which dips gently toward the southeast. The prominence of Burnt Bluff and in general the boldness of the southeast shore of Big Bay de Noc inclusive of Middle Bluff, Garden Bluff, etc., is due directly to the structure of the rocks, and especially to the greater resistance offered to the agencies or erosion, by the Niagara limestone than by the weaker Lorraine and Utica formation on which it rests and which comes to the surface in the next concentric belt outward from the Niagara belt.

The greater prominence of the outward-facing or northern border of the Niagara limestone over its inner or southern border, is manifest also in the hills situated six to eight miles north of Manistique, and again in the hills which rise to the north of Hessel and Cederville. Whether a northward facing escarpment is present or not, between these two localities is unknown. An examination of such maps of this region as are available, fail to show that the Niagara limestone has controlled the direction of the present streams. This fact suggests that the maps are not sufficiently exact, to bring out such a relation if it exists, or that the erosion particularly by glaciers, together with the glacial deposits left on the country, have modified the topography to such an extent that the influence of the hard rocks on the direction the streams follow is no longer the controlling condition. On the northern border of Drummond Island, and generally about the southwest shore of Georgian Bay, the land is bolder and more picturesque than the neighboring shores of Lake Huron, for the same reason that the Bay

de Noc border of the Garden Peninsula is higher and more precipitous than its Lake Michigan border.

The belt of rocks next to the outer margin of the curved belt underlain by the Niagara limestone, namely the Lorraine and Utica formation it will be remembered, is composed of earthy limestone in thin layers, and is much less resistant to the agencies of erosion than the formations adjacent to it. This belt of weak rocks should therefore have been eroded away more effectually than the adjacent beds, and given origin to valleys and lake basins. In fulfillment of this prediction we have Green Bay and its connecting bays, in the northwest portion of the Michigan tectonic basin, opening to Lake Michigan through narrow channels in the Niagara limestone; and Georgian Bay and North Channel in the northeast portion of the same great basin, opening to Lake Huron by means of narrow channels through the intervening land, composed of the same sheets of limestone, namely the Niagara, which shuts in Green Bay, etc. This symmetrical arrangement of Green and Georgian bays, with reference to the structure of the underlying rocks, is of the same nature as the relation of the basins of lakes Huron and Michigan to the same series of conditions, and increases one's confidence in the conclusions reached by Hall, Whittlesey and others, in reference to the basins of the Great Lakes being due largely to erosion. Now, two chief agencies of erosion, namely streams and glaciers, have been in operation in the Great Lakes region, and the question arises, which of the two is to be held chiefly responsible for the production of the basins the Great Lakes occupy. This question has been much discussed, but is still not answered to the satisfaction of all persons interested in it. It may perhaps not be digressing too far to suggest, that the intimate relation between the basins of lakes Huron and Michigan, and of Green and Georgian bays, respectively, to the weak formations on which they are located, suggests the long continued action of streams previous to the Glacial epoch, rather than the work of ice. Strengthening this view is the fact, as will be stated more fully later, that the main direction of ice movement as recorded by striae, etc., on the Garden Peninsula, was athwart the longer axis of Big Bay de Noc and on Drummond Island was again nearly at right angles to the adjacent portion of the longer axis of Lake Huron. There were other glacial movements in each of these regions, however, and how much the flow of the ice favored the deepening of the lake or bay basins is difficult to determine. There is another series of facts of interest in this connection which needs to be discussed, that is the deposits of remarkable thickness, in places and over large areas amounting to between three and five hundred feet, which the former glaciers left in the region south of the Straits of Mackinaw and extending to central Ohio and Indiana. It thus seems probable that the glaciers did more toward the filling of the basins of lakes Huron and Michigan than they did in the way of deepening them.

Beside the basins now occupied by the waters of the Great Lakes a brief account of which has just been presented, there are other features in the hard-rock topography which have a bearing on the question as to the depth of glacial erosion. The valleys now occupied by the principal streams which enter Green Bay and the northern portion of Lake Michigan, such as the Manistee, Escanaba, Rapid and White Fish, and Manistique rivers, are older than the glacial epoch and show something of the relief of the surface before it was modified by glacial action. This conclusion is based on the size of these valleys in reference to the volume of the streams now occupying them, and the fact that above the reach of the present streams, the valley bottoms are covered with glacially deposited debris and their floor in places scored with glacial striæ. It is apparent that the valleys are not only of pre-glacial origin and were modified to only a slight degree by the glaciers which subsequently occupied them, but that the present streams have been enabled to do but little rock cutting since their present cycle of work began. The conclusion which one has forced upon him while travelling over the country drained by the river just named, and the same is true also of the region extending east from Manistique River to Drummond Island, is that the relief of the hard-rock surface beneath the superficial blanket of glacial and other debris, controls the present topography. That is, the depth of the glacial deposits, etc. is usually only locally sufficient to mask the relief of the underlying hard-rocks and give a new topography to the land. More than this, as seems to be generally true, the changes produced in the hard-rock topography by the glaciers which have passed over it, are of minor importance. The present relief, is therefore, with the exception of details, such as the long period of subaerial erosion which preceded the Glacial epoch impressed upon the surface of the land. This broad conclusion will no doubt be controverted by some students of the changes glaciers produce and is admittedly based on less evidence than I desire, but I think will sustain the test of future and more extended investigation.

Additional and conspicuously obvious facts bearing on the above mentioned conclusion, are furnished by Mackinac Island and Burnt Bluff. Mackinac Island rises 317 feet above Lake Huron, and the surrounding water is in general from 100 to 200 feet deep. Burnt Bluff has a height of 225 feet above Lake Michigan, and the adjacent water is from ten to fifty feet deep. Each of these bold eminences stood in the paths of the glaciers which successively covered the region where they are situated but were not removed. Mackinac is precipitous on its southern border and declines less abruptly but still with steep slopes toward the north, and may perhaps be claimed to exhibit in its general contour the effects of ice abrasion on its northern side, and of "ice-plucking" on its steeper southern face. In the case of Burnt Bluff, however, the topographic relations are reversed in reference to ice movement as the precipitous side of the bluff faces the northwest, which as shown by striæ on neighboring rock-surfaces, is the direction from which came the last of the former ice sheets which covered the region. Both Mackinac Island and Burnt Bluff have till on

their summits, showing that they have been completely buried beneath glaciers. Burnt Bluff reveals no evidence of ice abrasion in its general shape, or in the contour of its summit. It might perhaps be surmised that its present cliffs which face the direction from which came the glaciers that passed over and around it, are due to wave action since the last ice sheet melted. This is not true however, since the shore marks of lakes Algonquin and Nipissing are present on the face of the cliff and show that but little undermining has been done by the present lake. The effect of glaciers in rounding rock escarpments against which they flow, is here as conspicuous by its absence as in other localities it is rendered evident by the topographic forms produced. Both Mackinac Island and Burnt Bluff stand as conspicuous monuments to the fact that great glaciers even when their attacks are several times repeated, are under certain but as not yet well understood conditions, unable to seriously abrade, much less remove rock bosses and prominent peaks which stand in their paths.

Mackinac Island: An exceptional feature not only in the topography of the part of Michigan especially considered in this report, but unique in comparison with the relief of the entire Great Lakes region, is furnished by Mackinac Island and to a less conspicuous degree by the hills about St. Ignace. Mackinac Island, as is well known, is situated in the extreme northwest portion of Lake Huron. It is about nine miles in circumference, contains 2,221 acres and is the highest land in that region, within a radius of probably more than a hundred miles. Considering the topography of the hard-rocks of the island beneath the surface covering of glacial drift, etc., its prominence becomes still more significant. The height of the summit of the island above the adjacent lake bottom as stated above, is not less than 500 feet. Its southern border is precipitous and in places forms cliffs a hundred feet or more high, near the bases of which the water is in places about 100 feet deep.

The precipitous southern border of the island and including also the similar cliffs on its eastern and western shores have been accounted for by Hall as resulting from the presence beneath the massive Helderberg limestone of weaker limestone and gypsum of the Onondaga salt group. No doubt this explanation is the true one so far as the precipitous nature of the cliffs in question is concerned, but a greater problem, namely how did it happen that the isolated mass of rock forming Mackinac Island came to be left in bold relief while nearly all other portions of the outcrop of the formation to which it belongs has been eroded so as to form deep depressions, namely, as already explained, the basins now occupied by lakes Huron and Michigan.

Limestone is as a rule a weak rock in reference to its ability to resist the attacks of the agents of either mechanical or chemical denudation. Very commonly also, limestone areas are depressed in reference to the region about them for the reason that in general limestone is more easily eroded than most other common rock. This is due principally to the readiness with which limestone—and dolomite also—is dissolved in percolating water, and the small per cent, of insoluble matter which it usually contains.

Mackinac Island, standing as it does in bold relief presents a conspicuous exception to the normal topography of regions underlain by rocks similar to those of which it is composed and its preservation must evidently be due to some exceptional condition which influenced erosion. The explanation which suggests itself in this connection is that the great sheet of rocks of the Monroe formation which comes to the surface in the region now occupied by lakes Huron and Michigan, was cavernous at the locality where Mackinac Island is situated, and that during the long period of subaerial exposure and stream erosion preceding the Glacial epoch, the drainage at that locality was subterranean and surface streams were locally absent. That is, the rain water instead of being gathered into rills and brooks at the surface and eroding, descended into the openings in the limestone, which was partially removed in solution but at a less rate than the surface was lowered when the waters formed streams in the ordinary manner. This explanation is in harmony with the fact that the rocks of Mackinac Island and of the St. Ignace Peninsula, are brecciated as already explained, and the suggestion furnished by Arch Rock, that caverns are present. Under this explanation, Mackinac Island and the less conspicuous hills about St. Ignace, are to be considered as remnants left by erosion or "monadnocks" as similar residual hills have been termed; and owe their preservation to the influence of subterranean drainage.

The instances just described do not stand alone as examples of rock masses spared by erosion because of their broken and cavernous condition, but are of special interest for the reason that the influence of subterranean drainage on topography has received but little attention.[1]

[1]A brief essay in this connection may be found in Science, Vol. XXI, 1905, p. 30-32.

SURFACE GEOLOGY.

As I have already attempted to indicate, much of the geological history of Northern Michigan is recorded in the topography of the hard-rock surface. The older portion of this record pertaining to the time previous to the Glacial epoch, is much defaced and difficult to read, and as yet has received but little attention. Inscribed on the same surface, or resting upon it, however, are much fresher records the significance of which is clear. I refer to the striæ and other markings and the deposits of debris, left by the glaciers which passed over the land in times geologically modern. As is well known, ice sheets of the type of continental glaciers, such as cover the greater part of Greenland at the present day, formerly moved southward over Michigan in common with the vast area embracing about one-half of the continent of which it forms a part, and extending as far south as the Ohio river and Kansas. As is also well known, there were several distinct advances and recessions of the

ice, or glacial and inter-glacial stages. In order to indicate at least in a general way the position in this complex history, to be assigned the glacial records of Northern Michigan, the following schedule of the subdivisions of the Glacial deposits in North America, as now known, is here introduced; the deposits made during the earliest known ice-advance being at the bottom of the list.

Glacial or Pleistocene Series. .	9. Wisconsin till-sheet. (earlier and later.)
	8. Interglacial deposits. (Peoria beds).
	7. Iowan till-sheet.
	6. Interglacial deposits (Sangamon beds.)
	5. Illinoian till-sheet.
	4. Interglacial deposits (Buchanan beds.)
	3. Kansan till-sheet.
	2. Interglacial deposits (Aftonian beds.)
	1. Pre-Kansan (Albertan) till-sheet.

These subdivisions of the glacial records have been made out principally for the deposits which the glaciers left in the region to the south of the portion of Michigan especially considered in this report, and we look with interest for similar evidence in more northern regions with the hope of discovering in particular, how far north the ice front retreated during the several interglacial stages. Some evidence in reference to a far northward extension of the deposits made during what seems to have been the Sangamon interglacial stage, has recently been obtained by Frank Leverett as will be stated later, but in general the glacial records in north Michigan are referred to the Wisconsin stage of ice advance.

The records pertaining to the Glacial epoch in the region under consideration, are principally striæ and other markings on the surfaces of the hard-rocks; deposits such as till or stony-clay in widely extended sheets or fashioned, into smooth, oval hills termed drumlins; boulders strewn over the land; ridges of sand and gravel made by streams beneath the glaciers and known as eskers; and sand and gravel plains due to the deposition of debris swept southward from the glaciers by the streams fed by their melting.

EVIDENCES OF ICE ABRASION.

Striæ: Both existing and ancient glaciers, under certain conditions, as has been abundantly proven, in moving over their beds plane away the rocks on which they rest and frequently polish and striate them as well as bring about other changes by abrasion which may be easily recognized. These results are produced especially when the ice is lightly charged with sand and stones set in its basal portion. If the supply of debris thus held becomes sufficiently abundant the movement of the ice is checked, the clearer part above passing over the more thoroughly debris-charged portion below, and the hard-rock surface beneath a glacier is protected instead of being abraded.

Smoothed and striated rock surfaces are common in North Michigan wherever the hard-rock has recently been brought to view by the removal of a protection covering such as sand and clay. On the rock surfaces that have been exposed to the air for a considerable but indefinite time, weathering has in most instances removed all evidences of ice abrasion which may formerly have been present. The most promising localities to look for glacial striæ and associated inscriptions, are where excavations have recently been made which lay bare the surface of the hard-rock beneath the deposits of clay or other protecting material. The localities where glacial striæ has been observed in the region represented on the map forming Plate XVI, are indicated on the map by arrows. Where the dircetion in which the ice moved is definitely known the arrows are barbed; when two directions of ice movement are present the weaker and in all instances as seems evident, the older series is indicated by a broken arrow. The arrows without barbs have been drawn from observations made by E. Desor, in 1850; the remainder are based on notes made by myself.

It is apparent from an examination of the map just referred to, that the directions of ice movement there recorded, are discordant in a conspicuous manner. The only general conclusion to be derived from the striæ is that the glaciers which made them flowed from a northerly to a southerly region, but the variations embrace a range from north to south and west to east. Certain of the striæ are at right angles to the directions of neighboring striæ, and in one case, namely at the mouth of Ford River, two series of glacial grooves on the same surface are at right angles one to the other.

The chief reason for the discrepancies just indicated seems to be that the ice sheets which made the striæ did not flow uniformly in one direction but in currents which took various directions during different stages in their advance or retreat, and also that the markings even in a single locality, were not all made at one time.

As has been well determined, the ancient glaciers which covered the Michigan region advanced more in certain portions of their southern margins than in other portions, and became strongly lobate, and also that the ice in each lobe spread laterally in addition to advancing toward its end. As the ice front receded northward, the lobes about its margin also receded and therefore at any specific locality, a change in the direction of the striæ made on the rocks at different times would vary in direction. As has been shown especially by T. C. Chamberlin, the ice over the Michigan region during its last retreat formed conspicuous lobes in the basins of Green Bay, Lake Michigan, etc., but so far as is apparent, the striæ platted on the accompanying map do not have a definite relation to the glacial lobes thus far recognized.

The data in hand although confessedly meager, certainly suggest that currents with diverse directions, were present in the basal portion of the glacier which made the striæ referred to; their direction being determined by local variations in the relief of the underlying rock, or due to the greater abundance of debris in the lower part of the ice at one locality than at another—the presence of debris tending to retard the motion of the ice containing it.

Observations favoring the idea that a broad ice sheet does not flow in a single uniform direction, but in currents which have different rates of motion and different courses, have been made on the Malaspina glacier, Alaska.[1] On that glacier a conspicuous compound moraine supplied by the great tributary ice stream named the Seward glacier, crosses its surface from the north and on meeting the stagnant ice near its southern margin, divides and forms a series of concentric bands, several miles in diameter, on either hand. On looking down on the glacier from neighboring mountains, the medial moraine referred to is seen to divide at its distal end in much the same manner that the broken end of a celery stalk usually divides and curls upon itself. Evidently very complex currents must be present in the glacier to produce such conspicuous changes in the direction of its surface moraines, and similar currents may be expected to be characteristic of the flow of other widely extended ice sheets.

[1]Russell, Israel C. "Second expedition to Mount St. Elias, in 1891," in U. S. Geological Survey, 13th Annual Report, Part II, Plate IV.

Another reason which may be appealed to in attempting to account for the observed diversity in direction of glacial striæ along the northern borders of lakes Huron and Michigan, is that such markings made during one ice advance might be covered by till or other deposits, and thus preserved during a subsequent stage of glaciation. Or, what is essentially the same in principle, a glacier may abrade the rocks over which it flows, during one portion of its existence, and deposit subglacial till upon them during another stage; and perhaps still later re-erode its own deposits and continue the work of rock abrasion in a different direction. I suspect that some such combination of conditions is mainly responsible for the conspicuous diversity in the direction of the ice movements referred to above.

It is instructive to note in the above connection that the region under consideration, is situated to the north of a deeply moraine and till covered region and south of a still greater region from which the former glaciers removed nearly all superficial material and abraded the rock surface thus exposed. In the belt of country between the region where glacial abrasion was in excess of deposition and the region where deposition was conspicuously great, alternate abrasion and deposition under the control of fluctuating conditions may well have been the rule.

Instances where two series of glacial striæ are present on the same rock surface, as at a quarry near the mouth of Ford River, and again about one mile north of Hessel (and many similar instances are known elsewhere) are difficult to explain on the supposition that the abrasive action of the ice was continuous at each locality, or, as has been assumed in reference to such instances, that each set of striæ is a record of a separate ice advance, without the intervention of a protecting layer. One suggestive fact in connection with rock surfaces which are inscribed with two sets of striæ is, that the abrasion which produced the second series of records, was not intense. The striæ in the instances referred to above, are only a fraction of an inch deep, and the older series would have been completely removed during the production of the younger series if more than an inch of the rock surface had been worn away at the time the ice last rested upon it. It is not correct to assume, however, from this fact taken singly, that glacial abrasion is but slight, since a deep protecting sheet of till might have been laid down on the inscribed rock surface after the first series of markings was made and efficiently sheltered it from abrasion during a part of a later stage in the advance of the ice. It thus appears that striæ and associated glacial markings while affording definite and important evidence of ice work and recording faithfully the direction of glacier motion for a given locality, do not furnish a sure basis for generalization in reference to different ice advances, or separate stages of the glacial epoch, unless similar evidence is recorded at a large number of localities, and the conclusion reached is sustained by other testimony.

Two sets of glacial striæ on the same rock surface have in some instances and perhaps truthfully, been assumed to furnish evidence of two stages of the Glacial epoch, separated by an interglacial stage of ice retreat. To permit of the making of such a double record it is self evident that the first series of records must have been well covered during the intervening stage of deglaciation, for if exposed to the air for even a few score years they would have been removed or seriously defaced by weathering; and also, that during the second ice advance, the period of abrasion must have been brief, or the intensity with which the sand-and-stone-charged ice scored and scratched the rock surface exceedingly slight. Otherwise the earlier record,—in many observed instances consisting of shallow grooves and striæ, none of them when first formed as may be reasonably inferred, being over an inch deep,—would have been completely removed. When two series of glacial striæ are present on the same rock surface, the inference seems warrantable that the second series were made during a brief period of time or else that the bottom of the passing glacier was nearly free of tools with which to work.

The best general principle to bear in mind, while seeking to interpret the meaning of glaciated surfaces, seems to be that glaciers are capable both of abrading and of making deposits on the surfaces over which they pass, and that these two processes may alternate, the one with the other at a given locality; and also that broad ice sheets do not flow uniformly in one direction but have at least basal currents which are more or less flexible, although for a considerable area following the same general course.

Knobs and Trains: On the surfaces of the limestones and dolomites crossed by grooves and striæ as noted above, there are several other kinds of markings which are significant and have their special stories to tell in reference to the manner in which glaciers abrade rock surfaces. The nature of the

markings referred to has been critically described and their meanings discussed by T. C. Chamberlin[1] and while I have nothing new to contribute to this branch of glacial geology, certain observations are at least of local interest.

An approximately level surface composed of rock of uniform texture and hardness, when worn by the passage over it of a glacier charged with fine debris, will be worn smooth and perhaps highly polished, but on the polished surface straight parallel striæ produced by individual sand grains are usually visible. Departing from this normal result as it may be termed, modifications are produced owing (1) to variations in the relief of the rock surface, (2) variations in the texture of the rock, and especially the presence of silicified fossils, chert nodules, etc., harder than the matrix holding them, and (3) variations in the size and character of the foreign bodies embedded in the moving ice which serve as abrading tools.

The influence of inequalities of surface, need not be considered at this time, since in the region about the northern shores of lakes Huron and Michigan the rocks which have been glaciated are in general nearly flat, and no conspicuous evidence of the rounding of prominences or the broadening of depressions was observed. On the other hand, what appear to be conspicuous exceptions to the rule that glaciers tend to remove prominent elevations on the surfaces over which they pass, or to impart to such eminences rounded and flowing outlines, are furnished by the rocks forming Mackinac Island, and the hills about St. Ignace; as well as by several equally conspicuous elevations on the west shore of Garden Peninsula, the most prominent of which is Burnt Bluff. The hills referred to, as already explained, stood in the paths of the former glaciers and were completely over ridden by them, but give no suggestion in their forms of having been abraded. These conspicuously exceptional features of a glaciated region will be considered more fully on a later page; the immediate subject in hand being the characteristics of ice-abraded rock surfaces.

[1]Rock-scorings of the great ice invasion, in U. S. Geological Survey, 7th Annual Report, Washington, 1888, pp. 147-248.

The influences of variations in the texture of rocks on the characteristics of ice-abraded surfaces, is well shown at several of the localities indicated on the map forming Plate XVI, where striæ are recorded, and particularly on Drummond Island, the locality north of Hessel, near Orville, and at Marblehead. At each of these localities and less conspicuously at other places where striated rock surfaces were seen, the limestone or dolomite, contains silicified fossils, which are harder than the rock about them. In numerous instances where such bodies are embedded in a glaciated surface, there are grooves about their borders on the side from which the ice came; these grooves usually a fraction of an inch in depth and in width, extend along the lateral margins of the obstructions, and becoming less deep die out at a distance of an inch or so on what may be termed their lee border in reference to the direction the ice flowed over and about them. When these grooves are present there is also a tapering ridge on the lee side of the obstruction and at its proximate end having the same height above the adjacent surface, which tapers to a point in the direction the ice moved. In many instances, however, the tapering ridge on the lee of a silicified shell, is present, but a frontal groove with its decreasing laterals is absent.

The grooves and ridges just described, are of special interest as they show the direction in which the ice moved which produced them. The grooves occur on the side of the obstructions from which the ice came and passing about them, die out in the direction in which the ice moved; while the tapering, cone-like elevations, are on the lee side of the obstructions and point in the direction the ice left them as it flowed. While the grooves and striæ that glaciers charged with debris make on rock surface, do not in themselves show in which direction the abrading tool moved which engraved them whether, for example, from north to south or south to north, the grooves and trains just described answer this question with great precision. There are other markings, also, as will be noted below, which furnish similar testimony.

The grooves and ridges just referred to, are also instructive in reference to the evidence they furnish concerning the physical condition of the ice which shaped them. The grooves show that a downward direction or eddy-like movement was given to the ice when it met an obstruction, similar to the eddy on the upstream side of a stone in a stream, which enabled the ice to scoop out a depression in the rock surface; but the tapering train on the lee side of an obstruction is equally positive evidence that the ice did not plunge over the elevation in its path as flowing water would have done, so as to scoop out a depression on its down stream side, but on the contrary, there was a relief of pressure in such situations and less abrasion than on the adjacent surface. In other words, an obstruction met by the ice formed a groove in 'its bottom which slowly collapsed. An exceedingly delicate adjustment of the ice between a condition of fluidity and a condition of rigidity is thus indicated; the ice being in such state that it could flow about the obstruction and be deflected downward so as to grind out a groove, and at the same time sufficiently rigid to be itself grooved by the obstruction over which it passed, and kept from abrading the rock under its lee. The knobs with grooves and trains, seem to show that ice under heavy pressure behaves like a viscous but almost fluid body, but variations in the results produced on abraded surfaces,—such as the absence of the frontal grooves about obstacles in many instances, and the presence of striæ and deep grooves which imply a firmly held tool,—are equally eloquent in proclaiming the rigidity of the ice which was concerned in their production. These diverse conclusions seem to show that the ice in the basal portion of glacier is at times viscous and. almost fluid-like in its mobility, and at other times behaves as a decidedly rigid solid. Two variations

in the controlling condition may reasonably be surmised to account for these contrasts in results; first, differences in pressure, and second, variation in the percentage and character of the foreign material, such as sand, gravel, etc., present in the ice.

Variations in pressure while tending to vary the degree of plasticity of ice,—if the pressure were sufficient it would cause the ice to melt at the temperature normally present, and thus become a fluid—can scarcely be claimed as the controlling condition which produced the differences in results referred to, which in one area record the passage of a highly viscous body, and on a neighboring surface, give evidence of the passage of a decidedly rigid body. Indeed, both of these contrasted conditions are frequently recorded on the same surface only a few square feet in area. At the bottom of a glacier several hundred and possibly a few thousand feet thick, variations in pressure from place to place or variations in short spaces of time at the same, locality, cannot reasonably be assumed to be such as to produce the differences in the grooved and ridged rock surfaces to which attention has been directed.

While pressure on ice tends to make it behave as a plastic body—the greater the pressure up to the limit of elasticity, if not to the point of melting, the greater the plasticity—debris added to the ice acts in the other direction and tends to reduce plasticity, and if present in sufficient amount would cause the ice to remain stagnant under conditions of pressure, which otherwise would cause appreciable flowage. Differences in adjustment, therefore, between pressure and per cent, of contained debris may be taken as the immediate control which determines whether the ice at any locality in a glacier will behave as a rigid or a plastic body. This conclusion requires to be qualified, however, as not only the per cent. of rigid (under the pressure present) material such as sand and gravel, but its degree of comminution exerts an influence as does also but to a less extent perhaps, its uniformity or heterogeneity of grain. For example, a given per cent. of fine sand enclosed in a given mass of ice would exert a different influence on its flow under pressure, than if the same per cent. of debris was in the form of gravel or large boulders.

In order to bring to a focus these ideas suggested by observing the grooves and trains of glaciated rock surfaces, I would say that at the base of a glacier several hundred or a few thousand feet in thickness, the weight of the ice would be sufficient to cause its basal portion to flow like a decidedly plastic substance as for example, pitch at a temperature of 100° F. under one atmosphere of pressure. If the ice under this condition was lightly charged with fine dust-like particles, or contained a small per cent, of fine sand, it might still retain its freedom to flow, but be capable of smoothing and polishing the surface over which it moved. It is under such conditions that the grooves at the front and along the sides of hard obstructions in limestone, and the trains on the lee sides of such elevations seem to have been produced. If the percentage of foreign material present in the ice should be increased, it would make the mixture more and more rigid, the pressure remaining the same, and may reasonably be assumed to impart to the ice such a consistency that it would hold firmly to sand grain, or larger rock fragments, and carry them along so as to striate and groove the rocks over which they were drawn. Under this latter condition the small grooves and trains, considered above would not be produced, but larger features of a similar nature might result. Observations are seemingly in harmony with these deductions, since frontal grooves and lee-trains are absent from deeply striated rock surfaces, but features of a similar character as rock bosses, with or without trains of debris on their lee, are features in the landscape of many glaciated countries. These considerations invite a discussion of the entire field of glacial abrasion, glacial flow, etc., but this would lead too far afield.

In connection with the facts concerning glaciated rock-surface referred to above, I desire to put on record one suggestive observation which may be of interest to the reader.

On a finely polished limestone surface exposed at the bottom of a well, about 25 feet deep, dug in reddish, bouldery till, near Orville, there are many well-formed frontal grooves and leeward-tapering trains, associated with fossil shells embedded in the rocks and partially exposed to view by glacial abrasion. One fragment of a shell, nearly an entire valve of a brachiopod, about the size and thickness of one's thumb nail, was emplanted vertically in the rock at right angles to the direction of the former ice movement. The ice impinged on the side of the delicate shell, but was deflected by it and caused to scoop out a well defined frontal groove which was prolonged on each side of the shell in the usual manner, while in the lee of the obstruction a typical train about an inch in length was left in relief owing to the more intense abrasion of the adjacent surface. In this case, a thin, fragile silicified shell may be said to have turned a continental glacier from its course. As is evident the lateral pressure exerted against the shell was exceedingly small, probably not in excess of a few ounces to the square inch; the abrasive power of the moving ice was also exceedingly small as it failed to wear away a layer of quartz not over a tenth of an inch in thickness.

However powerful erosive engines glaciers may be when properly supplied with tools with which to abrade, the frontal grooves and tapering trains to be seen on many glaciated rocks and especially such instances of delicate work as just cited, furnish equally clear evidence that in the absence of tools they are nearly powerless to scour the surfaces over which they flow.

Chatter marks: Persons visiting localities where glaciated rock-surfaces occur in Northern Michigan, may also find still other examples of glacial inscriptions or markings the nature of which has been admirably described by Chamberlin, in the report referred to above. Among these records are "Chatter marks" in the bottom

of strong grooves and assumed to have been produced by a vibration of the stone as it was forced along, which dug out the groove. These markings are curved cracks which cross the bottoms of glacial grooves from side to side, and as a rule present their convex sides to the direction from which the object came which led to their production. That is, if the ice moved from north to south, the chatter marks produced will present their convex sides to the north; but exceptions to this rule, or perhaps imitative markings have been noted, and chatter marks alone cannot be considered as decisive evidence of the direction a former glacier flowed.

Crescentic cracks: Crescent-shaped cracks of larger size than chatter marks, and usually occurring on flat rock-surfaces, seemingly independently of striæ and grooves, are also present at several localities in Northern Michigan. Examples of these crescentic "cross-fractures" as they have been termed by Chamberlin, occur on the south shore of Lake Duncan, and on a bare rock surface crossed by the road leading from Garden to Fayette near Garden Bluff (T. 39 N, R. 19 W.) where they are unusually abundant. The cracks are three to four or five inches long, and occur in series in the direction of ice movement, at intervals of two to perhaps four inches. Some of the series containing six to ten cracks, all curved in the same direction and presenting their convex sides to the northwest, the direction from which the ice came. Just how the cracks of this nature were produced is not known, but they are clearly glacial records, and seemingly furnish good evidence as to the direction of ice movement. The cracks penetrate the rock to the depth by estimate of two or three inches, and frequently endure when striæ and other of the more delicate records left by former glaciers have been obscured or removed by weathering. The presence of a series of parallel crescentic cracks separated by intervals of two to four or five inches, is sometimes all the evidence that remains of the former passage of a glacier over a rock outcrop.

GLACIAL DEPOSITS.

The vast continental glaciers which came from the north and advanced southward over Michigan, left records of their invasion not only in the form of inscriptions on the solid rocks over which they passed, as described in part in the last few pages, but deposited debris both directly and with the assistance of the streams formed by their melting. Two classes of superficial deposits thus originated; one glacial and the other fluvio-glacial.

Till: The material gathered by glaciers as they advance and deposited as they flow, or left when they melt, is known as till. In the region here considered the till consists very largely of a reddish, sandy clay, usually containing many angular or sub-angular stones and rounded rock masses. The larger stones whether angular or rounded, deposited by a glacier are termed boulders. The material which glaciers deposit directly without the assistance of streams, passes under the general name of moraines; but this term is applied more specifically to the irregular ridges and hills of sandy clay and boulders, accumulated about their margins, as lateral moraines, terminal moraines, etc., or concentrated on the surface of the ice as medial moraines. Such heaps and ridges are not present in the portion of Michigan described in this report, which means that the former glacier did not halt in that region and maintain a definite frontal alignment for a sufficient length of time to permit of the deposition of recognizable deposits of the nature just mentioned. If the ice lingered with a front extending cross the part of Northern Michigan referred to, it was so nearly clear of debris that no ridges or hills were formed. Glaciers under certain conditions of load, deposit material as they flow and on melting leave all of the debris previously contained in them, or present on their surfaces; in this manner a general sheet of rock-waste is deposited like a blanket over the country they occupied and mantles the hills and valleys. Such a sheet of glacially deposited debris is termed a till sheet; typical till being an unstratified sandy-clay well charged with sub-angular stones and boulders. It is material of this nature which now constitutes the surface layer over large portions of Northern Michigan and adjacent regions.

Restricting attention to the land adjacent to lakes Huron and Michigan on the north, it may be said that a sheet of till was left over its entire surface when the former glaciers finally melted. Exceptions to this rule were probably furnished by precipitous slopes, such as the cliffs on the border of Mackinac Island, the face of Burnt Bluff, etc., but localities of this nature are rare, and most likely every ledge even on the faces of such precipices formerly had some glacially deposited material upon it. Since the ice melted which deposited the nearly universal till sheet referred to, many changes have occurred; the till has been washed from steep rock declivities by the rain, and rills and streams have cut channels through it, but the most conspicuous modifications are due to the wash of the waves and the action of currents in the waters occupying the basins of lakes Huron and Michigan, when they stood higher than at present. Below the old beaches, indicated on the map forming Plate XVI, the till has to a large extent been removed, assorted and redeposited through the action of lake water.

In physical composition the till in the region under consideration is nearly always reddish in color, conspicuously sandy, and contains numerous stones and boulders. The reddish color and sandy consistency is due, as seems evident, to the fact that much of it was derived from the red sandstone which is largely developed about Lake Superior, and probably now occupies, much of the basin of that lake.

Two general classes of stones and boulders are present in the till; one class consists of limestone and dolomite fragments derived especially from the Trenton and Niagara formations which form the hard-rock surface of much of the region in question; and the other class

embraces the stones and frequently rounded boulders of all sizes up to about three feet in diameter, composed of crystalline rock, such as is only found in place in the Lake Superior region, in Canada and in Northern Michigan to the west of the longitude of Marquette. As may be most reasonably inferred the boulders of crystalline rocks occurring in the drift to the north of Lake Huron, were derived principally from the portion of Canada lying to the north and east of Lake Superior; while the similar debris in the region north of Lake Michigan, was mainly derived from areas of crystalline rock to the south and southwest of Lake Superior. In reference to the relative proportions of locally derived, mostly calcareous material, and of the crystalline rocks brought from a greater distance, the former is nearly everywhere conspicuously in excess of the latter.

The nature of the stones contained in the till furnishes a means for determining from what direction the former glacier came, and the direction the ice moved, but as yet this criterion cannot be applied except in a few instances, as the rocks represented usually occur in place at more than one locality, or are not sufficiently characteristic to be readily identified.

There are two conspicuously characteristic rock outcrops, however, the debris from which can with certainty be referred to the parent ledges from which it was derived. These are: A red jasper conglomerate which outcrops in Ontario, to the north of North Channel, and about fifty miles north of Drummond Island; and the copper-bearing rocks of Keweenaw Peninsula.

The red jasper conglomerate is easily recognized by the angular fragment of bright red jasper it contains, embedded in a usually white, somewhat vitreous quartzite base. Fragments of this rock frequently a foot or two in diameter, were observed on Drummond Island, about Hessel, on Bois Blanc, and other localities as far west as the St. Ignace Peninsula. Evidence is thus furnished that glaciers once covered the region to the north of Lake Huron, and moved southwest at least as far as the north end of Lake Michigan. This may not have been a single direct movement, but a general southwest flow of the glaciers at some time during the Glacial epoch in the region indicated is certainly shown by the distribution of jasper conglomerate just cited. Fragments of this same red jasper conglomerate are present in the glacial deposits of Southern Michigan, Northern Indiana and Ohio, and have been found in the vicinity of Cincinnati. A surprisingly wide distribution from a restricted area is thus shown to have occurred and taken in connection with other evidences indicates that the material laid down during one ice advance was removed and redeposited during one or more subsequent ice advances.

Native copper derived, as seems most probable at least, from the copper-bearing rocks of the Keweenaw Peninsula, has been found in the glacial deposits of Menominee county, on the Garden Peninsula, and as far eastward as the St. Ignace Peninsula, thus demonstrating that during some portion of the Glacial epoch there was an extensive ice movement over Northern Michigan from the northwest toward the east and southeast. Boulders of native copper have also been found in the glacial deposits of Southern Michigan and Ohio, thus showing as wide a dispersion by ice moving from the northwest, as do the boulders of red jasper conglomerate referred to above, in reference to the ice which came from the northeast. On the St. Ignace Peninsula, these two general movements overlapped as they did also over an extensive region to the south. Which was the earlier movement so far as is now known, is not definitely shown in Northern Michigan, although as will be stated later, in Menominee county the last ice invasion of that region came from the northeast and covered a till sheet containing native copper and fragments of iron ore, which had previously been deposited by a glacier moving from the northwest. In Southern Michigan, and the states adjacent on the south, much more definite information is recorded by terminal moraines, etc., than has yet been discovered in Northern Michigan, and a complex history has been deciphered by Frank Leverett and others.

The blanket of till covering the country under consideration is thin, not only in comparison with the glacial deposits of Southern Michigan, etc. but actually as measured in feet. From the east shore of Drummond Island westward to the north end of Lake Michigan, an estimate based on the records of a few wells and on the height of the present surface above observed rock outcrops, places the general depth of the superficial covering of rock-waste at from 20 to 30 feet. Practically all of this region, however, has been covered by lake waters, and the surface material has to a considerable extent been reasserted and concentrated especially just below the abandoned shore lines of the former lakes. Where the till has not been disturbed, as on the hills about six miles north of Hessel, on the summit of Mackinac Island, and about Allenville, etc., its thickness on an average is approximately from 15 to 20 feet. To the west of the St. Ignace Peninsula, numerous measures were obtained of the depth of the till sheet there generally present, and an estimate of from 10 to 20 feet may be taken as a general average of its thickness. To the south of the Minneapolis, St. Paul and Sault Ste. Marie railroad, on the triangular area terminating at the south in Point Patterson, many surface exposures of the underlying limestone are present, and the greatest thickness of till obtained from the records of well, is 20 to 25 feet; the average for the area indicated is thought to be not over 10 to 15 feet. On Garden Peninsula to the south of the surface sand which occupies much of its northern portion, the covering of till is noticeably thin, many rock outcrops being present, and numerous well records available, and its average depth is certainly not over 10 feet. On the Bay de Noc Peninsula, a large amount of testimony gathered in part from farmers, shows that the thickness of the till which is spread quite uniformly over the level surface of the underlying limestones is on an average not over five feet. Throughout the greater portion of Menominee county,

situated to the west of Green Bay, numerous hills composed of drift, termed drumlins, are present, and much more glacial debris was left on the underlying hard-rock surface than elsewhere in the region here considered. The hills referred to are in many instances about 40 feet high, and composed of till throughout, while in the intervening valleys the underlying rock although bare in places is usually from five to ten feet below the surface. The depressions or valleys occupy more space than the hills and for the entire country the average depth of till is probably not over 20 feet. Observation made on the hills about Metropolitan and Iron Mountain, show that in that region the true till sheet is from 10 to perhaps 15 feet in thickness, although in the low lands, considerably thicker deposits of the same material together with water laid sand and gravel are present.

The thinness of the sheet of morainal material left by glaciers over the portion of Northern Michigan described in this report, is in conspicuous contrast to the deep accumulations of similar material over all of the Southern Peninsula, and in fact of nearly the entire glaciated area of the United States from the Atlantic to the Dakotas. To the north of Lake Superior, however, ,as is known at least in a general way, glacial deposits are wanting over extensive areas, and bare and for the most part glacially abraded rocks are exposed. Northern Michigan thus appears to be situated between a region of glacial abrasion on the north and a region of glacial deposition on the south, but is more nearly related to the northern area. The facts presented above in reference to the small thickness of till in the part of the Northern Peninsula referred to, and the absence in that region of moraines, such as are formed about the margins of glaciers, together with the notable depth of glacial deposits, inclusive of surface-formed moraines, over the whole of the Southern Peninsula of Michigan, show that the change from abrasion to deposition in the case of the former glacier which covered Michigan, occurred in the region bordering Lake Superior on the south. It should be remembered, however, that glaciers may both erode and deposit at the same locality, at different times, and that deep glacial deposits may formerly have been present in North Michigan and later removed through the same agency which laid them down. In fact, as will be shown later, there is evidence of a conspicuous amount of ice erosion of previously deposited till in the region here considered.

DRUMLINS.

Among the characteristic changes in topography produced by the broad ice sheets of the Glacial epoch, both in Europe and North America, are smooth-surfaced, oval hills and ridges composed of till, the longer axes of which are parallel to the direction of flow of the ice which shaped them. These symmetric "lenticular hills," as they were at first termed in this country, are now designated as *drumlins*, a name first applied to them in Ireland and signifying a back or a ridge. Two types of drumlins have been recognized; one comprising short, broad forms, elliptical in ground plan, the longer axis only two or three times the length of the shorter axis, and measuring from a few hundred to perhaps two or three thousand feet in length; and the other consisting of long narrow ridges, in which the length is perhaps ten or twenty times the width, which attain lengths of from perhaps a mile to two or three or more miles. Between these two most common types, however, intermediate gradations may be found; and in many regions, more or less oval hills and ridges composed of till, approach in shape the true drumlin, but are less regular and less systematically arranged and may be termed *drumloids*. By this term is meant that the hills and ridges to which it is applied, approach or simulate typical drumlins in many ways, and are probably to be considered as incomplete or immature topographic forms of the same mode of origin.

In Northern Michigan two drumlin areas are known; one including Les Cheneaux Islands, and a portion of the adjacent mainland; and the other situated principally in Menominee county to the west of Green Bay. These two regions in each of which the dominant topographic forms are drumlins, are from 125 to 150 miles apart in essentially the same latitude, and are conspicuously different in the trend of the longer axes of the oval hills and smooth crested ridges which give them character. In Les Cheneaux area the direction of the last ice movement was from the northwest toward the southeast; and in the Menominee region from the northeast toward the southwest. The drumlins in each area were fashioned and given their characteristic shapes by the last ice sheet that moved over it, but the direction of ice movement in one of the areas, as just stated, was at right angles to the similar movement in the other area. This contrast in the direction: of glacial flow is suggestive when taken in connection with the records of ice movement furnished by striæ, etc. on the solid rocks of the same general region and by the character of the boulders in the till, which can be traced to their parent ledges. That is, the details in the history of the Glacial epoch are far more varied and complex than is perhaps generally appreciated.

LES CHENEAUX DRUMLIN AREA.

An examination of the shore line about the Great Lakes as platted on the charts of the Northern and North western lakes issued by the Corps of Engineers, U. S. army, shows that the outline of the land among Les Cheneaux islands; and along the neighboring coast of the mainland, is conspicuously different from that of any other portion of the borders of the Great Lakes. The exceptional feature is the conspicuous parallelism in trend of the islands and of the capes on the adjacent mainland. Six measurements of the trend of the longer axes of the islands and capes made on the charts referred to (reproduced in part on Plate V), give an average bearing of S. 52° 30' E., with an extreme variation of less than one degree. Long narrow, stony ridges on the adjacent main land have the same trend as

the similar ridges which form the islands and capes. In brief, the leading characteristic in the relief of the land and in the trend of the shore line, is furnished by a series of long, narrow parallel hills, part of which stand on the land and a part in the water. These hills are composed of till and have other characteristics of drumlins. As the reader will infer from these statements, Les Cheneaux Islands, owe their peculiar and conspicuous alignment to the fact that a group of drumlins is there partially submerged by the water of Lake Huron. This conclusion is rendered still more evident when the relief of the islands is also considered, as their surfaces present ridges and troughs, similar to the corresponding features about the neighboring villages of Hessel and Cedarville. The larger islands bear on their surfaces groups of parallel ridges trending northwest and southeast, the troughs between the ridges being above water except at their ends where narrow bays extend into the land. A number of the smaller islands as Richard, Isadore, etc., which consist of a single straight ridge with rounded cross-profile are individual drumlins. In a few instances as shown on the Lake Survey charts, the ends of islands and of capes are hooked or barbed, as for example the northwest end of Boot Island, and the extremity of the cape where Hammers fishery is located. A visit to these localities showed that the exceptional outlines they present are due to wave action along the shore, such as the building of spits, or connecting bars between islands, etc.

The trend of the longer axes of a group of drumlins as already stated, is as a rule parallel to the direction of flow of the glacier which shaped them. This test can be applied to the long narrow hills in the Les Cheneaux region. On a flat limestone surface about one mile north of Hessel and crossed by the road leading north from that village, glacial striæ and associated markings are well exposed. The general direction of ice movement thus recorded, is from northwest to southeast, and indicated on the map forming Plate XVI. Two series of striae, etc. are present; the stronger, and as the evidence seems to show, the earlier series, trends N. 70° W. (an average of six measurements with a range of 10 degrees); crossing this series is a series of more delicate striae, bearing N. 57° W. (three readings being the same). The trend of Les Cheneaux Island as stated above is S. 52° 30' E. This as nearly as can be determined is also the trend of the longer axes of the ridges, as measured along their summits; the trend of the hills thus corresponds approximately with the direction of the lighter series of striæ on the adjacent rock surface; the difference being four and one-half degrees. In this instance the ice at the time the hills were given their present symmetrical shapes, crossed a previously scored rock surface but left only a delicate inscription upon it.

The drumlins at Les Cheneaux, are of the elongate type, being in several instances from one to two miles in length, with a maximum width of from about five hundred to eight hundred feet in the largest examples and with a height above the intervening troughs of forty to about fifty feet. How many drumlins there are in the group is not definitely known, but there are certainly fifty and perhaps twice that number may be present. They are composed of compact clayey till of a reddish color and contain many large boulders. The boulders are in part composed of limestone and are of local origin, and in part of crystalline rocks such as occur in places in the neighboring portion of Canada. At one excellent section across a drumlin at Cedarville, where a cut for a road has recently been made, the stiff clay is, laminated, the laminæ being distinct in the upper five or six feet of the exposure; but less evident and seemingly wanting at a greater depth. The laminæ are curved and parallel with the convex surface of the ridge as exposed in cross sections.

One of the most conspicuous features of the drumlins forming Les Cheneaux Islands, etc., is that their surfaces are strewn with a multitude of boulders. This feature is well shown by the photograph forming Plate VI, A, taken at Hessel. This roughness of surface and abundance of loose boulders is exceptional to the normal condition of the surfaces of drumlins, which as a rule are conspicuously smooth and even. Its explanation lies in the fact that the waters occupying the Lake Huron basin were formerly higher than at present, and the waves and currents working on the drumlins removed much of the fine material from their surfaces and thus concentrated the stones and boulders. In their present condition they may be termed washed drumlins. At one stage in the history of the basins of the Great Lakes the water was about 200 feet deep at Les Cheneaux Islands the shore line being then about six miles to the north, where islands were present in Lake Algonquin as the former water body has been named. The washing, however, which removed the finer material from the surface of the drumlin, as just mentioned, occurred when the lake waters were at a lower level and principally when they stood about forty feet above their present horizon and what is known as the Nipissing beach was produced. The position of this old lake margin is shown by gravel terraces on the sides of some of the drumlins about Hessel and is particularly well marked at Cedarville.

MENOMINEE DRUMLIN AREA.

Distribution: Well defined and characteristic drumlins occur over the greater portion of Menominee county, with the exception of the sandy region five to six miles wide adjacent to Green Bay, and perhaps extend northward into Marquette county and westward into Dickinson county. The drumlin area is more extensive than the one at Les Cheneaux Islands, and is thought to embrace about 750 square miles. The number of drumlins is certainly many hundred, and possibly several thousand, but no reliable estimate in this connection can as yet be made. The most characteristic portion of the area so far as now known, lies between Wallace on the south, and Northland on the north, and in an east and west direction, between Ford River station and Hermansville. The drumlins are numerous along each of

the railroads radiating westward from Escanaba within the region just indicated, and are especially abundant along the line of the Chicago and Northwestern railroad between Bark River and Powers. Perhaps the best localities for observing them is in the .vicinity of Wilson, Spalding, Powers, Hermansville and thence southward to Stephenson.

Absence of solid-rock cores: The region just designated is underlain by Trenton limestone which is approximately horizontal, and has a nearly even surface. No suggestion of rocky knobs or other elevations that might have served as nuclei for the accumulation of glacial debris are present.

Shape: The drumlins are largely of the elongate or ridge like type, many of them being from half a mile to two miles long, while some are yet more extended. Their widths are in numerous instances, from 300 to 800 feet in the widest part. A typical example, the first one cut by the Chicago and Northwestern railroad to the west of Indian Town, measured by pacing, is 9,000 feet in length, and 750 feet wide in the central part; and has a maximum height of 30 to 35 feet above the adjacent marshy troughs. It tapers gradually in both width and height from the center toward each end and terminates in each direction in a well defined obtuse point. Several neighboring examples have similar dimensions. The ratio of width to length in these instances is in general about as one to twelve or fourteen. In some of the smaller examples near Spalding, this ratio is approximately one to two or three.

Trend: The general trend of the longer axes of the drumlins is northeast and southwest, but considering the entire area there are conspicuous variations in this particular. While neighboring drumlins as for example throughout a distance of a mile measured at right angles to their general trend, are in some instances strictly parallel, in other instances a divergence of trend of their larger axes amounting to fully fifteen degrees as observed. Throughout the portion of the area which was traversed the extreme variation in trend is between N. 12° E. and N. 55° E. These variations seem to have an orderly sequence and the drumlins over a large area to swing symmetrically, but not enough observations are in hand to make this conclusion definite.

Uniformity in elevation: A more conspicuous feature than the general parallelism of the drumlins is their nearly uniform height. An observer standing on the highest portion of the crest of any one of the larger examples and examining the neighboring drumlins with the aid of a hand level will find that all of the larger ones in view rise to the same level with a variation of less than five feet. Some of the smaller examples fail to reach the summit level of their larger companions, but no drumlins rise above that level. In other words, if the depressions and valleys between the drumlins were filled to the level of the summit of the majority of them, a horizontal or essentially horizontal plain would be produced.

Height: The height of the drumlins above the bottoms of the intervening valleys is in general from thirty-five to forty feet; the variation being due to the depth to which the valley has been excavated, and the amount of stream deposited sand and gravel or peaty material present in them.

Rock striæ: Exposures of rock surfaces between the drumlins are somewhat common, and at one locality about one mile east of Spalding, on the line of the Chicago and Northwestern railroad, a glaciated limestone surface bears glacial striæ and related markings, which record an ice movement from the northeast toward the southwest. The striæ bear N. 38° E. That is the direction of glacial flow as recorded by striae, etc., is substantially the same as the trend of the longer axes of the drumlins; it is worthy of note, however, that the drumlins nearest to the locality where the striæ were observed, trend N. 55° E.

Composition: The drumlins with the exception of a thin surface layer, are composed of reddish, sandy till charged quite uniformly with stones and boulders. Their appearance in section is well shown on Plate VI B. Many of the stones are angular fragments of Trenton limestone, derived from near at hand, but the larger and more conspicuous boulders are of hard crystalline rock and usually well rounded. In certain of the drumlins near Powers, the limestone fragments amount to fully eighty-five or ninety per cent of the rock-masses present which are a foot or more in diameter. Of the finer material between the stones and boulders quartz sand constitutes a conspicuously large proportion. The limestone fragments are mostly flat masses broken from strata from two to six inches thick and are without orderly arrangement; that is, the flat blocks are packed in the enclosing sandy-till with their longer axes pointing in all directions.

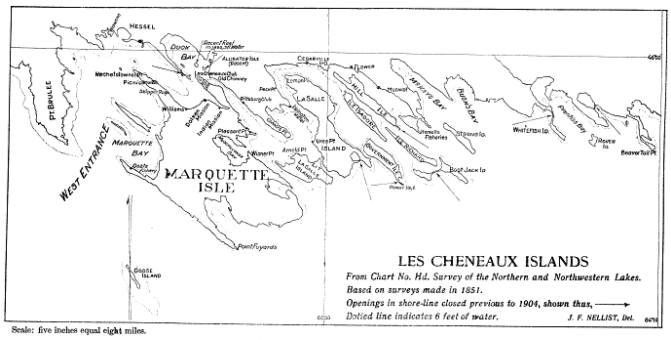

Plate V. Map of Les Cheneaux Islands; from chart No. Hd. U. S. Lake Survey

Absence of lamination: In no instance was the lamination observed, which is sometimes stated to be peculiar to drumlins. This feature as cited on a previous page, is present in the clayey till of the drumlins at Cedarville, and its absence in the drumlins under consideration, suggests that it is dependent on the physical condition of the till of which drumlins are composed, and is to be expected in those consisting

largely of clay but not in those composed of decidedly sandy till.

Copper and Iron boulders: In certain of the drumlins near Powers, Nadeau and Daggett, several battered and scratched masses of copper have been found, and also large fragments of specular iron ore. These boulders as already stated, were no doubt derived from the copper and iron-bearing formations which come to the surface in Northwestern Michigan and show that the glacier which transported and deposited them moved from the northwest toward the southeast. The trend of the striæ on a rock surface near Spalding, and the general alignment of the drumlins as already stated, point conclusively to an ice movement from the northeast toward the southwest. The bearing of the evidence thus furnished, of two ice movements,—the later being at right angles to the earlier—on the theory of the origin of drumlins will be considered later.

Surface material: The surface portions of the drumlins as stated above, differ from the material beneath. As observed in a large number of instances their surfaces to a depth of about a foot or eighteen inches, are uniformly covered with a layer of fine dustlike loamy sand. This material when examined under a microscope is seen to consist principally of angular grains of quartz, but mingled with the determinate grains are fine, brownish, amorphous particles. It is so fine that 66.35 per cent of it will pass through a sieve having one hundred meshes to the linear inch.[1] This fine surface soil is exceedingly favorable to agriculture and for this reason the drumlins throughout the Menominee area, have to a great extent, been cleared of forests, and are now under cultivation. Mingled with the fine dust-like material of the surface layer are numerous stones of all sizes up to boulders fully three feet in diameter. These surface stones are to a great extent limestone fragments, but a few and including the larger ones, are of crystalline rock. In many of the fields on the drumlins, the surface stones have been removed and piled in large heaps, leaving a surface of conspicuous evenness composed of fine rich loam. Where the stones have not been removed they form a pronounced feature of the surface.

[1]An average sample of the soil freed from pebbles, and subjected to mechanical analysis in the presence of water, gave the following results:

Retained on a sieve having 10 meshes to linear inch	6.73 per cent.
Retained on a sieve having 50 meshes to linear inch	11.21
Retained on a sieve having 100 meshes to linear inch	15.71
Passed through sieve having 100 meshes to linear inch	66.35
Total	100.00

Of the portion of the sample which passed through a 10 mesh sieve, 20.05 per cent was soluble in hydrochloric acid, and may be termed a dolomite rock-flour.

Irregularities: Normal drumlins, as is well known, are smooth oval hills without irregularities; while the majority of the drumlins in the Menominee region fulfill these conditions, there are certain notable and suggestive exceptions. It is difficult to classifiy the irregularities referred to, but they may at least provisionally be termed transverse trenches, side trenches, surface pits, and asymmetry in ground plan and marginal slopes.

Transverse trenches are trench-like depressions through a drumlin at right angles or nearly so, to its longer axis and in the case of the deeper examples resembling railroad cuts. Their bottoms are frequently on about the same level as the adjacent troughs or valleys but in some cases are less deep. In no instance were deposits observed in the marginal troughs at the ends of the trenches, of the nature of alluvial cones, such as would suggest that the trenches are due to the action of streams since present conditions obtained; although in certain cases a small amount of gravel has thus been washed out of them and deposited at their ends. Good examples of the kind of irregularity here considered and in fact of several of the irregularities mentioned above, may be seen in the first drumlin cut by the Chicago and Northwestern railroad to the west of Indian Town. Another typical instance is present about one mile southwest of Wilson and to the south of Cedar River. The most instructive example thus far seen, however, occurs near the southwest end of a drumlin about half a mile northwest of Spalding (in the N. E. quarter of section 9, T. 38 N. R. 26 W.) In this instance an esker, as will be described more fully later, which follows an irregular east and west course, approaches the transverse cut in the drumlin from the east, and at the west end of the cut continues its course westward. The conditions are such as to show that the esker was deposited by a sub-glacial stream which excavated the trench across the drumlin.

Side trenches are cuts in drumlins which begin near their crests and extend down one side, becoming deeper and broader as the adjacent valley is approached. In a number of instances the depressions referred to head well to one side of the crest of a drumlin, cut through its axis and open out into the trough on the opposite side, thus showing most of the features of the transverse trenches, but having a distinct proximal end. For example, in the first drumlin west of Indian Town and near its northeast end, an excavation begins on the southeast side of the drumlin and only a few feet above the level of the marginal trough on that side, and extends toward the northwest through the drumlin and opens out on a level with the inter-drumlin trough on that side. These trenches are usually nearly straight, but in some instances their courses are conspicuously curved.

Each of the types of trenches just noticed, is favorable for the passage of roadways and in several instances they have been utilized for this purpose.

Surface pits are irregular depressions in the surfaces of drumlins, which have no draining channel and in at least one instance, at the south end of the Indian Town drumlin, retain sufficient rain water to form a small swampy pool. The pits are from perhaps ten to thirty or fifty feet across, and in many instances five to seven feet deep. These occur principally on the summits of the drumlins both in their central and terminal portion. Numerous examples of these irregular pits were observed but many drumlins are free from them.

By asymmetry in ground plan, is meant an irregularity such as would be produced if a portion of the side of drumlin should be eroded away, as by a stream for example, leaving a steep bluff. Irregularities of this nature are rendered conspicuous by reason of the exceptional steepness and boldness of the slopes they present, which are in striking contrast to the smooth undulations of the lines characteristic of a drumlin landscape. Two examples of the asymmetry referred to, were observed; one on the northwest side of a large drumlin situated partially in section 3 and partially in section 10, about one mile northward of Spalding; and the other on the southeast side of a large and otherwise characteristic drumlin, crossed by the road leading south from the same village and three miles distant. The former has a steep bluff on its northwest margin, and the latter a similar bluff on its southeast margin. In each case the regularity of the elliptical ground plan of the drumlin is rendered irregular by a flattening or straightening of its curvature where a steep bluff occurs.

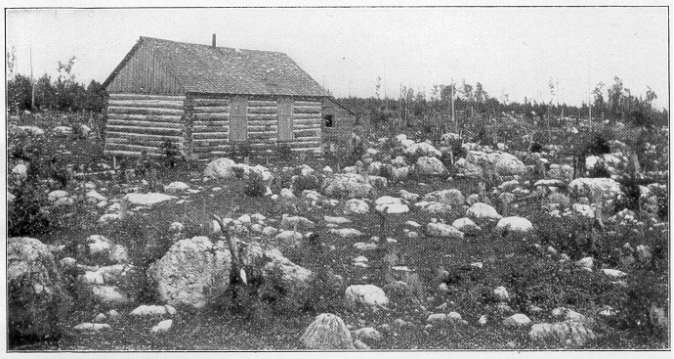

Plate VI. A. Surface of washed drumlin near Hessel.
July 10, 1904.

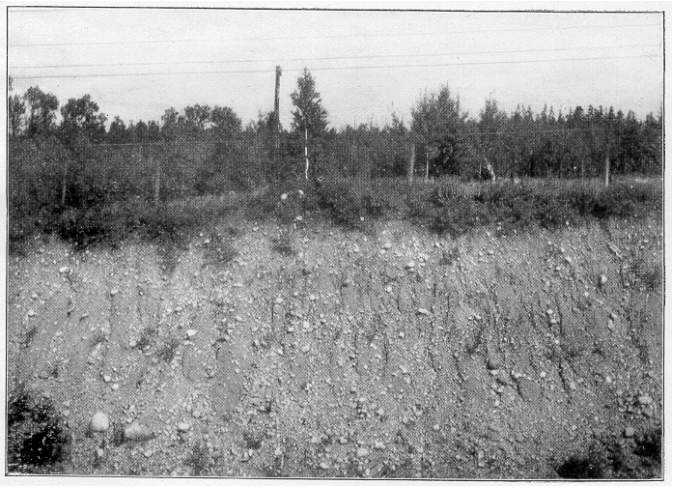

Plate VI. B. Section of a drumlin near Powers.
September 1, 1904.

The grooves and valleys between drumlins: The drumlins in certain instances as about Spalding, and Powers, and thence southward to the vicinity of Daggett, may be said to occupy as much ground space as do the intervening depressions. In many portions of the region referred to, the depressions between the drumlins form the exceptional feature in the landscape, and call for an explanation rather than the smooth oval hills they surround and separate one from another. The depressions are normally broad, shallow concave troughs (Plate VIII, B) which widen adjacent to the ends of the drumlins and become narrow where the drumlins broaden in their central portion. The troughs like the hills they separate, have smooth, flowing outlines, and even surfaces, except where gravel and sand in the form of eskers and kames have been heaped up within them. If accurately mapped they would be found to have a current-like arrangement, analogous to the shallow channels between the numerous sand bars and islands of an overloaded or "braided stream," such for example as the Platte River at low water.

A characteristic example of the grooves to which attention is here directed, is associated with a small drumlin, about one mile northwest of Spalding, (it is crossed by the road between sections 4 and 9, T. 38 N. R. 26 W. and lies principally in the N. E. ¼ of the N. W. ¼ of section 9.) It is one of a cluster of four or five closely united drumlins and is situated on the southern side of the general mass and on a southward descending slope. Its length is about one thousand feet, width in central part approximately two hundred feet, height about twenty-five feet, and trend N. 48-49° E. About the northeast end of the drumlin and extending all the way along its eastern side, and for about half the length of its western side, there is a distinct, round-bottomed groove about twenty-five or thirty feet wide and ten to twelve feet deep. This groove is evidently a result of erosion by flowing ice and has been excavated in till. The absence of the groove as a distinct feature on the southwest side of the drumlin, is owing to the fact that the slope there descends into the valley of Cedar River and other topographic conditions prevail. Some of the features just described are shown on Plate VIII. The groove just described, recalls to mind the frontal grooves with side extensions, to be observed on many glaciated rock-surfaces where hard bodies are embedded in softer material, but while such grooves are usually less than an inch across and a fraction of an inch deep, the one in question is measurable in feet as just stated. The similarity in form in these two instances is conspicuous, however, and tends to strengthen the conclusion that the groove about the drumlin is due to ice erosion.

The groove about the proximal end and along the sides of the drumlin near Spalding is similar to many other grooves and shallow depressions between neighboring drumlins in the Menominee region and leads to the suggestion that the drumlins throughout that region have been given their prominence principally by the erosion of the grooves and valleys separating them.

Terrace on the side of a drumlin: The drumlin here considered is situated about one and one-quarter miles northwest of Powers, on the branch of the Chicago and Northwestern railroad which connects Powers with Iron Mountain. The railroad crosses the drumlin by means of a cut about eight hundred feet long and thirty to forty feet deep in the central part; in the sides of the cut, good

exposures of the normal reddish, sandy and bouldery till of the region may be seen. The trend of the drumlin is N. 53° E. or about at right angles to the railroad track, and its length by estimate in the neighborhood of one mile.

The drumlin is normal in every way so far as seen, except that on its southeast side there is a terrace-like flattening of the slope about midway between its base and summit. In cross profile the surface of the terrace is about thirty feet wide and slightly concave. It can be traced nearly the entire length of the drumlin and in longitudinal profile is convex upward, being parallel with the crest line of the drumlin on the side of which it occurs.

Hypotheses as to the origin of the drumlins of the Menominee region and explanations of the irregularities they present will be considered later. As the drumlins are intimately associated with another class of topographical forms, namely eskers, it is convenient to insert here a brief record of such observations as were made concerning them.

Eskers.

Under this name have been grouped certain irregular, winding ridges composed of crossbedded or current-bedded gravel and sand, which occur in regions formerly occupied by ice sheets. Their lengths are from a few hundred yards to many miles, the shorter ones in numerous instances being clearly disconnected portions of what would otherwise be conspicuously elongated examples. In width they measure from a few score feet to several rods, and their heights are equally variable, being at times only a few feet and in other instances one or two hundred feet. One of the chief peculiarities of these irregular ridges, is that they cross the regions where they occur with but slight if any reference to other features of the relief. The name *esker* has been applied by Irish geologists to the class of ridges here considered; in Scandinavia they are known as *osar*, but the former term seems preferable.

As to mode of origin, the eskers are considered perhaps by most students of glacial phenomena, to have been formed by streams flowing in tunnels at or near the bottoms of glaciers, but hypotheses assigning them to the work of streams flowing in open cuts in ice sheets have been advanced, as well as other explanations.

In the Menominee region eskers are numerous and have a significant distribution in reference to the drumlins with which they are intimately associated. Most commonly they occur in the troughs or valleys between drumlins, and in a general way trend with the longer axes of the drumlins with which they are most nearly associated. In certain instances, however, they cross the trend of the drumlins approximately at right angles and in a few cases are superimposed upon them.

Eskers in the valleys, which follow the general trend of the associated drumlins, occur in the immediate vicinity of the several branches of Cedar River, particularly to the northward of Spalding, but are also frequently present in valleys that have only insignificant draining streams, or none at all. In this connection it is suggestive to note in reference to the mode of origin of eskers, that the streams of the region under consideration, flow between or about the numerous drumlins, and, do not cut through them. That is, the streams are consequent to the relief of the surface as produced by glacial agencies, and have modified that surface to only a slight degree. The streams wind about the bases of the drumlins, but so far as observed have not cut into them so as to break their normally even and flowing outlines. The greater number of the eskers follow similar courses and occur in the immediate vicinity of streams which they parallel in a general way. In many instances the streams have cut trenches through the eskers.

Plate VII. A. Drumlin half a mile northeast of Spalding; looking east.
September 5, 1904.

Plate VII. B. Drumlin topography near Nadeau, looking south, showing groove between drumlins.
September 7, 1904.

But one conspicuous example of an esker extending in a direction approximately at right angles to the longer axes of the associated drumlins has been observed. The one referred to, was mentioned on page 23 in connection with a description of a transverse cut in a drumlin about half a mile northwest of Spalding, and is crossed by the road leading north from that village. It has an irregular east and west-course across open fields and from the road is in sight for a distance of about half a mile. At the west it approaches the east end of a trench in a conspicuous drumlin situated in the N. E. ¼ of Sec. 9, T. 38, R. 26. The same esker is again crossed by a road leading northwest from Spalding near the center of section 9, and to the south of a cemetery. To the east of

the cemetery the esker follows an irregular course across a field to the west end of the trench which cuts the drumlin. This association of the eskers with a trench across a drumlin is good evidence that both the esker and the trench owe their origin to the same cause; namely a sub-glacial stream which deposited the gravel and sand of the esker and excavated the trench across the drumlin with which it is intimately associated.

An example of an esker perched upon the summit of a drumlin, is furnished by a prominent ridge immediately south of Wilson, which is about a mile long, seventy to eighty feet high in the central portion, and trends N. 32° E. The extreme northeast end of the ridge is crossed by the Chicago and Northwestern railroad by means of a shallow cut in the sides of which coarse gravel is exposed. The main portion of the surface of the ridge is also composed of gravel and sand but its southwest end consists of till and. has the smooth flowing contours characteristic of drumlins. The compound ridge in its summit portion is conspicuously higher than any of the numerous drumlins in sight from its summit. This exceptional height, together with the facts just noted, indicates that an unusually large esker for the region where it occurs, was deposited on the summit of a drumlin, the longer axes of the two coinciding, but at the southwest the till of the drumlin extends farther than its covering of water-laid material.

The conditions pertaining to the prominent ridge near Wilson are repeated on a smaller scale at a locality about one mile east of Nadeau, or more precisely at the corner common to sections 8, 9, 16 and 17, T. 37 N. R. 26 W. At this locality there is an irregular hill trending about N. 43° E. which by estimate is fifty to sixty feet above the adjacent swampy valleys, and as is evident to a person standing on its summit, is higher than any other of the numerous hills in sight. The summit portion of the hill is composed of sand and well rounded gravel but to the southeast this material terminates in a steep slope about fifteen feet high and the continuation of the ridge is composed of till and has the contours and other features normal to drumlin. In this instance, however, the deposit of gravel and sand on the summit of the drumlin, lacks the characteristic ridge form, conspicuous at the esker near Wilson, and the deposit may perhaps be of the nature of the gravel and sand hills described below.

KAMES.

This name has been given to irregular heaps of gravel and sand, made by streams in association with glaciers, but without the extended ridge-like form peculiar to eskers. Kames, as a rule, occur as more or less isolated groups of irregular knolls and hills, with underdrained depressions among them; their general arrangement being parallel with the margin of the ice sheets about, or perhaps in part beneath, which the material composing them was deposited.

Kames are present in the Menominee region but they are less common and less conspicuous features of the relief than are the eskers, and as it seems, one form grades into the other. A characteristic group of kames occurs about a mile and a half south of Wilson, south of Cedar River, in section 18, T. 38 N. R. 26 W.

Comparisons: The drumlins, eskers and kames, of the Menominee region, present certain characteristic differences, which make them easy to distinguish one from another and are also of economic significance.

The drumlins are conspicuously smooth, and at the surface are composed of exceedingly fine sandy loam which makes them highly valuable for agricultual purposes. The soil is porous and absorbs all the water that comes to it as rain, or from melting snow, and even on steep slopes in plowed fields, is not scored by rill channels. Owing to the excellence of the soil on the drumlins they are to a great extent, cleared of native vegetation and under cultivation. For farming purposes they furnish the best conditions found in any considerable portion of northern Michigan.

The eskers are composed of coarse material, are unfavorable in most instances for agriculture, have conspicuously uneven surfaces and although partially cleared in many instances, are usually left bristling with stumps and the dead trunks of trees and serve best for pasture lands. The absence of fine soil over the eskers is apparently due to its having been washed down into the open spaces in the coarse, loose material beneath, for as will be stated later, it seems that the eskers like the drumlins must at one time have had a thin surface sheet of fine silt-like material on their surfaces.

The kames, judging principally from the nature of the group of hills a mile and a half south of Wilson, are composed of finer material than the eskers, and in reference to agriculture are nearly as favorable as are the drumlins. Both eskers and kames, like the drumlins are unscored by rill channels. Throughout the entire Menominee region, in fact, with the exception of the bottom of certain of the larger valleys, the topography is still in almost precisely the same condition that it was when the region was abandoned by the ice sheet and associated streams, which gave it shape and character. That is, post-glacial changes are trifling and over large areas are practically absent.

The entire Menominee region was until recently entirely forest covered, and probably more than half its area is still occupied by trees and shrubs. A conspicuous difference between the drumlins and eskers, in reference to their relation to the trees which once grew upon them, is that the fine soil and till sub-soil of the drumlins, gave a good anchorage for large trees, while the trees growing on the loose-textured gravel-ridges were less securely rooted. On the drumlins there is but little evidence that trees have been uprooted by storms, but on the eskers the characteristic mounds with accompanying depressions which overturned trees produce, are a common and characteristic feature.

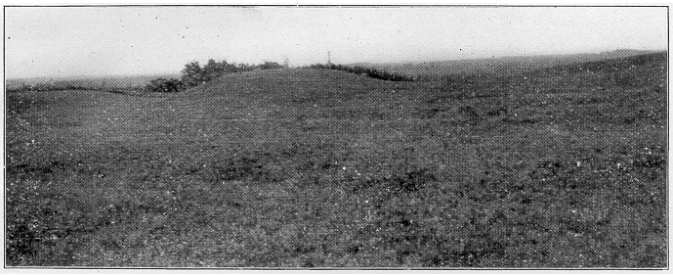

Plate VIII. A. Drumlin with frontal and side grove, one mile northwest of Spalding; looking southwest.
September 5, 1904.

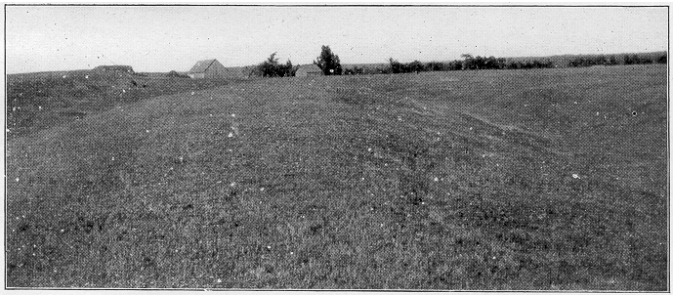

Plate VIII. B. Drumlin with frontal and side groove, one mile northwest of Spalding; looking northeast from top of the drumlin.
September 5, 1904.

ORIGIN OF DRUMLINS AND ESKERS.

On the preceding pages considerable evidence has been presented concerning the nature of drumlins, eskers and kames. It now remains to sum up this evidence and learn to what conclusion in reference to the mode of origin of the topographic forms referred to, it lends support.

The drumlins of the Menominee region share certain characteristics in common, while a few of them present individual peculiarities. Any hypothesis to account for their origin should, therefore, explain each of "these two classes of conditions in order to be worthy of acceptance:—

Their like features are: the till of which they are composed is of the same general nature in all instances, there is an absence of lamination, the flat stones present have no orderly arrangement or orientation, a thin surface layer of fine silt-like material associated with many stones and boulders is seemingly always present, they have the same general shape and the same general alignment.

Their unlike features are: transverse trenches, lateral trenches, surface pits, frontal and side grooves, asymmetric ground plan, et cetera, as described above, which are present in certain and relatively few examples but usually wanting.

The till of the drumlins, as has already been stated, contains boulders of native copper and of iron ore, showing that it was deposited by an ice sheet which flowed from the northwest toward the southeast: while the trend of the longer axes of the drumlins and the striæ observed in one instance on a rock surface exposed in their midst, record an ice movement from the northeast toward the southwest.

The best translation of the records just summarized with the aid of current knowledge in reference to the nature of glaciers and the various discussions as to the origin of drumlins that have been publishd, is as it appears, the following:

A till sheet about fifty feet thick was spread with a conspicuous degree of uniformity over the Menominee region by an ice sheet which came from the northwest; afterward, this ice sheet melted, or a change occurred in the direction of its flow and a movement from the northeast became general. During the later stage of glaciation the ice eroded the till over which it flowed, and excavated grooves and valleys and pressed and moulded the intervening ridges into the smooth oval hills and ridges which are now present. As the nearly clear ice melted, which eroded the previously deposited till, it left a thin sheet of fine material (as is presumed composed largely of dust which accumulated on the ice) together with loose stones and boulders, over the surface of the land it vacated. On the drumlins this surface sheet or dustlike material still remains, but on the coarser textured eskers it has been carried down into the interstices in the gravel beneath by percolating rain water. In the shallower grooves between the drumlins the fine material is also still present but in the broader and deeper valleys it has not been observed and presumably is concealed beneath subsequently formed peaty soils.[1]

The last glacier which covered the region, as has been stated, excavated the till over which it passed, but did not remove it uniformly in all places. The ice, as seems to be well shown by the grooves and channels it left, flowed in currents which were somewhat flexible and curved about and among the masses of till which remained. Over certain areas ice erosion was more intense than at other localities, and all the till was removed and the hard rocks beneath striated. The hypothesis of ice erosion thus seems to account for all the normal characteristics the drumlins present.

[1]The surface covering of fine silt-like material, may in part have been deposited as dust during the post-Glacial time, but as the region was formerly forested, the contributions from this source were probably not great.

As shown especially by the frontal groove in connection with a drumlin near Spalding, the current in the basal portion of the eroding ice-sheet was deflected, as it seems by some apparently moderate irregularity in the resistance of the till it rested upon. Similar deflections when they caused an ice current to impinge on the side of a previously well shaped drumlin, eroded it and if the process was checked by the melting of the ice, before the drumlin was completely removed, an unsymmetrical drumlin with a portion of one side removed and a steep bluff produced, would result. Examples of such irregularities as already described, are furnished by a

drumlin one mile northeast of Spalding which has been eroded on its northwest border, and by a drumlin three miles south of Spalding, which has been eroded on its southeast border.

The pits in the surfaces of the drumlins can be accounted for on the assumption that depressions were present in the surface of the till sheet before it became eroded, the depressions being occupied by stagnant ice over which the moving ice passed by shearing; or else the material of the drumlin has settled unequally since it was formed. I am strongly inclined to accept the first of these two alternatives, but other explanations may be forthcoming.

The transverse and side trenches present in certain of the drumlins, all though in part perhaps, like the surface pits, to be ascribed to depressions in the till before ice erosion began, are evidently in most instances due to corrasion by running water. The material removed however, is not present in the condition of alluvial fans etc. in the adjacent, and in certain instances streamless valleys,—the exceptional case when an esker is in line with a transverse trench will be referred to below—and from this it is safe to conclude that the water corrasion did not occur since the melting of the last ice sheet which occupied the region. The uniformly smooth surfaces of the drumlins and the entire absence of rill channels upon them, is strong collateral evidence in favor of this same conclusion. If the transverse and lateral trenches were not excavated since the melting of the ice sheet which gave shape to the drumlins, they must have been formed while the ice was still present. This conclusion is in harmony with the accepted explanation of the origin of eskers, and is a warrant for the farther conclusion that streams of water flowing in ice tunnels or in ice channels were present.

The intimate association of an esker with a transverse trench in a drumlin, referred to between dashes above, is highly instructive, as it shows in what portion of the glacier the streams were situated which cut the trench and deposited the associated esker. That is, the stream was sub-glacial, or nearly so, since the crest of the drumlin across which it excavated a channel is only about twenty feet above the bottoms of the adjacent troughs. The only remaining irregularity of the drumlins under consideration to be re-considered at this time, is the terrace-like shelf on the side of a drumlin, one and a quarter mile northwest of Powers, described on pages 24-25. This terrace it will be remembered, is on the side of the drumlin, has a convex curvature in the direction of its length, and is parallel or nearly so with the curvature of the longitudinal crest-line of the drumlin with which it is associated. Now, at several localities in the same general region, drumlins are present in close juxtaposition, but separated by a round bottomed groove. They have a relation one to another, to use a familiar comparison, similar to that of loaves of bread baked in the same pan; that is, the groove between two adjacent drumlins is all that serves to differentiate them. If two loaves of bread which have become united along their sides while in the oven are broken apart, a scar remains on each one; so in the case of two drumlins which are united along their sides, if one is eroded away an irregularity or scar showing where it was formerly united with its neighbor may remain. The terrace on the side of the drumlin referred to above, is of the nature of such a scar; the companion drumlin having been removed by ice erosion, but leaving a portion of the bottom of the groove which formerly separated the two. It thus appears that both the normal and the abnormal features of the drumlins of the Menominee region can be consistently accounted for on the hypothesis of ice erosion of a .previously formed till sheet, and that this as it seems must be the true explanation of the origin of the drumlin of that region. This explanation is not new, but is essentially in harmony with an hypothesis of the origin of drumlins proposed by N. S. Shaler[1] several years since, but as it seems, not generally accepted by geologists.

Other explanations of the origin of drumlins as is well known, have been advanced[2] but a general discussion of them cannot be undertaken in this report. I need scarcely warn the reader that the conclusion reached above, in reference to drumlins having resulted from-the ice erosion of a previously deposited till sheet, relates to the Menominee region simply, and is not at present advanced as a general explanation applicable to all drumlins.

[1]Boston Society of Natural History Proceedings, vol. 13, 1870, pp. 196-204; see also, U. S. Geological Survey, 7th Annual Report, p. 321.

[2]The nature and origin of drumlins has been well discussed by Warren Upham, and many references to the literature of the subject given, in Boston Society of Natural History Proceedings, Vol. XXIV, 1889, pp. 228-242, and Vol. XXVI, 1892, pp. 2-25.

FLUVIO-GLACIAL DEPOSITS.

Under this title students of glacial phenomena group a considerable number of deposits with various topographic forms, which are due to the work of streams in intimate association with ice sheets. Examples of two classes of such deposits in the Menominee region, namely eskers and kames, are described above. A third class, termed valley trains and outwash plains, have a wide development in Northern Michigan and the adjacent portion of Wisconsin, but to only a minor extent enter the strip of country adjacent to lakes Huron and Michigan which is especially considered in this report.

Valley trains and outwash plains consist of cross-bedded sand and gravel, which has been washed out of a glacier and deposited about its margin and in depressions in the land leading away from it. Such deposits as a rule have even, gently sloping surfaces, but are sometimes conspicuously pitted or contain large irregular depressions, owing to the melting of ice which was contained in or surrounded by the sand and gravel at the time of its deposition. When these features are prominent in an outwash plain it becomes a "pitted plain," and the depressions frequently contain lakes.

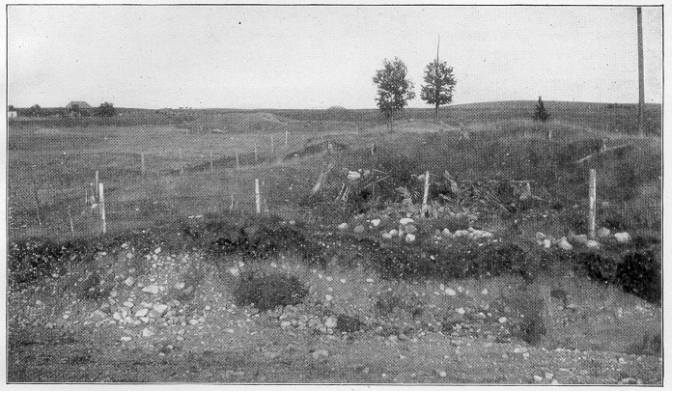

Plate IX. A. Esker near cemetery, half mile west of Spalding, looking northeast.
September 5, 1904.

Plate IX. B. Esker half a mile north of Spalding, looking northeast.
September 5, 1904.

Sand and gravel plains of the nature just noted, are a common feature in North Michigan, particularly to the north of Little Bay de Noc, and as is judged from the reports of persons familiar with the region mid-way between Lake Michigan and Lake Superior are there extensively developed. The plains referred to are commonly designated as "jack-pine plains" but other sandy areas have similar characteristics of forest growth. Pitted plains occupy an extensive area to the west of Iron Mountain, and extend into Wisconsin, but this area, like the greater part of the jack-pine plains referred to lies outside the region here especially considered.

The only localities where sand plains of fluvio-giacial origin form a conspicuous feature of the region described in this report, are on the west border of Little Bay de Noc, as at Gladstone, and thence northward along the west side of the valley occupied by Rapid and White Fish rivers, and on the east border of the same valley from near Ensign northward. This valley now in part submerged, is a little over two miles wide near Rapid River village and has a nearly flat floor. Two streams flow down it, but without a noticeable height of land between, and each river has a solid rock bottom, (limestone) throughout much of its course. Resting on the rock of the valley floor is an irregular sheet of the ordinary reddish sandy till of the region, usually as it seems from the records of wells, from five to fifteen feet deep, the solid rock beneath being glaciated. There is also a minor quantity of stream deposit of sand and gravel in the valley, but its amount is seemingly insignificant. These features show that the valley is either pre-glacial or was excavated by the ice which occupied it. Without discussing this question I may state that the first of these hypotheses is probably true. That the valley is not due to post-glacial stream erosion, even to the extent of removing the incoherent deposits left by the ice which last occupied it, is shown by the parallel but independent courses which Rapid and White Fish rivers follow for a distance of about twelve miles, each of them being in a channel from a few inches to three or four feet deep cut in solid rock. This conclusion is apparent from the consideration that if the valley had been cleared of debris by stream erosion, only one main stream would have resulted from the process of stream development that must have obtained.

The most striking features of the valley occupied by Rapid and White Fish rivers, however, is the boldness and the composition of its borders. The escarpment overlooking it both on the east and west is made by slopes of sand which border extensive plateaus. A southward continuation of the bluff on the west forms the conspicuous escarpment of sand which extends from near Rapid River station past Gladstone, to the mouth of Escanaba River, and is present in a modified form, in the western part of Escanaba. The bluff at Gladstone is about 160 feet high, but so far as can be judged from the facts in hand decreases in height when traced northward. The corresponding bluff, on the east side of White Fish River is about 75 feet high. In other words there are two conspicuous escarpments of sand facing each other, with a rock-floored valley between, each sand bluff being the margining escarpment of an extensive sand plain. The sand plains referred to are in each case at least five miles wide in the row of townships (T. 41 N.) crossing the head of Little Bay de Noc, and widen in a conspicuous manner when followed northward. These plains are occupied by open growth of pine and juniper, and are typical "jack-pine plains."

The conditions just described call for an explanation, but as the plains referred to have their chief development to the north of the region examined by me, and pertain more particularly to that section of the state, only a tentative suggestion as to the manner in which they were formed will here be indulged in.

The hypothesis that presents itself in the above connection, is that during the final melting of the former ice sheet which rested on Northern Michigan, a tongue of ice or a narrow ice lobe, lingered in the valley now occupied by Rapid and White Fish rivers and that outwashed sand from the general ice field at the north, accumulated as sand plains along its sides. When the ice tongue finally melted, the sand on its borders was left with steep escarpments facing the depression it left. Stated more briefly, the extensive sand plains bordering the valley of Rapid and White Fish rivers are of the nature of Kame-terraces, as described by R. D. Salisbury[1] and others.

[1] Geological Survey of New Jersey, Vol. V of the final report of the State Geologist, 1902, p. 121.

BEACHES OF FORMER LAKES.

Predecessors of the present Great Lakes:

One of the most interesting and instructive episodes in the later geological history of North America, for the reason in part that it has an immediate and tangible influence on the commercial and other industries of to-day, relates to the development of the present Great Lakes. As has been shown by the long continued and painstaking investigations of a considerable body of geologists, the Great Lakes have had a varied history and important changes are still in progress.[2]

Previous to the Glacial Epoch, as is judged but not as yet specifically demonstrated, the region occupied by the Great Lakes was well drained and had a maturely developed topography. With each advance of an ice sheet from the north pre-existing conditions were greatly altered, but during each of the several intervals between the ice advances, as has been in part determined, large lakes were probably present. With the final melting back of the ice of the last or Wisconsin stage of glacial occupation, there came a time when the southern margin of the retreating glacier withdrew to the north of the divide separating the streams flowing to the Ohio and Mississippi from the watershed now tributary to the St. Lawrence. The water-parting referred to, is an irregular line, and the southern margin of the retreating ice was also irregular. For these reasons, as the ice melted back, certain portions of the northward sloping land adjacent to the ice became flooded and several small lakes were formed, as for example, at the west end of the Lake Erie basin, the south end of the Lake Michigan basin and the west end of the Lake Superior basin. As the ice withdrew still more to the northward and northeastward, these first formed lakes expanded, and in time united one with another. As successively lower and lower outlets became available, the water of the lakes fell and many changes in their outlines occurred. These changes were controlled mainly by variations in the dam of ice which retained the waters, but movements in the land, of the nature of upheaval and subsidences, also exerted an influence. These earth movements as a whole, tended to tilt the surface of the region in which the basins of the Great Lakes are located; the net result being an elevation of the northeastern portion with reference to the southwest portion.

[2] A popular account of this chapter of geology with the title; "A short history of the Great Lakes," by F, B. Taylor, may be found in Charles R. Dryer's "Studies in Indiana Geography," 1897. Published at Terre Haute, Indiana. The chief first-hand contribution to the literature of the subject may be found in indices to American geology, under the names of E. Desor. Charles Whittlesey, J. W. Spencer, G. K. Gilbert, F. B. Taylor, Frank Leverett, and H. L. Fairchild.

When the ice had withdrawn sufficiently toward the northeast to leave the entire region now occupied by the Great Lakes to the west of the Ontario basin, free of glaciers, but still lingered in the valley of the St. Lawrence, the Ontario basin discharged its surplus waters by way of the Mohawk valley into the Hudson. At this time a vast lake named Lake Algonquin, larger than the combined areas of all of the present Great Lakes, flooded the basins of lakes Huron, Michigan and Superior, and overflowed into the Ontario basin by way of the valley of Trent River. Lake Algonquin existed sufficiently long to permit its waves and currents to form well defined gravel terraces and accompanying lake-cliffs about many portions of its border.

A farther withdrawal of the ice which lay on the surface of the present province of Ontario, coupled with movements in the earth's crust, made the Nipissing-Ottawa valley available for the drainage of Lake Algonquin. Its surface was then lowered and it gave place to another lake at a lower level, known as Lake Nipissing. This lake also formed gravel terraces and cliffs about its shores which are stronger and better defined than the similar records left by Lake Algonquin. Lake Nipissing was somewhat smaller than its predecessor, but occupied nearly the entire area now included in lakes Superior, Huron and Michigan, and was larger than the present area of these lakes combined, since its waters were maintained at an horizon about 40 feet above the present elevation of the water in the straits of Mackinac.

The existence of Lake Nipissing was brought to a close by a tilting of the land, which raised its outlet above the level of the channel occupied by St. Clair river, and the present distribution of the Great Lakes was initiated.

Such contributions to the history of the basins of the Great Lakes, as I was able to secure along the northern borders of lakes Huron and Michigan, relate principally to the Algonquin and Nipissing shore-lines and their accompanying gravel and sand deposits.

Topographic Features of Lake Shores:

At many localities on lake and ocean shores there is a well defined terrace due to the action of waves and currents in eroding the land. A characteristic cross profile of such a topographic feature is here presented:

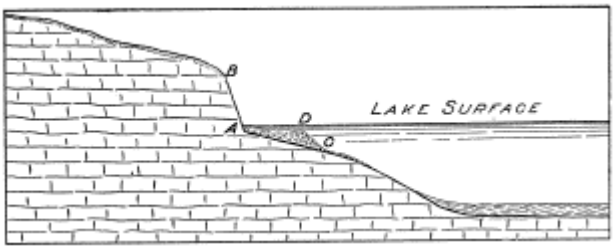

Figure 5. Cross profile of a lake-cliff and accompanying terrace.

The notch at *a* is due principally to the beating of waves charged with sand and gravel against the land; by this process the cliff *a b* and the cut terrace *a c*, are produced. The deposition of sand and gravel on the cut terrace and extending lakeward, forms a built terrace with a surface inclined downward toward the eroding

water-body. When the land bordering a lake slopes gently upward from its margin, and the water deepens gradually lakeward, the destructive action of the waves is less than under the conditions referred to above, and a lake cliff and its accompanying cut terrace may be obscure or wanting. Under these conditions the pricipal topographic change produced by waves and currents is usually a sand and gravel ridge built in shallow water, parallel with the shore line.

It is by means of these and other similar topographic changes made by the waves and currents of lakes that their former outline can be traced when their waters subside.[1]

[1]The changes which lakes make in the topography of the land margining them, has been clearly described by G. K. Gilbert, in an essay entitled "Topographic Features of Lake Shores," in U. S. Geological Survey, 5th Annual Report, 1885, pp. 69-123, see also, "Lakes of North America," by Israel C. Russell published by Ginn & Co., 1895.

The Algonquin Beach: As is indicated on the map forming Plate XVI shore lines made by the waters of Lake Algonquin occur at several localities in the area represented. These are: on the hills about six miles north of Cedarville and Hessel; about the summit portion of Mackinac Island; in the vicinity of Cook's Mills, and again near Ensign, each of these localities being a few miles northward of Big Bay de Noc; about the higher portions of Garden Bluff and Burnt Bluff, on the west side of Garden Peninsula; and a few miles inland from the west shore of Little Bay de Noc and of Green Bay, from the vicinity of Gladstone and Escanaba, southwest to Birch Creek station, about six miles north of Menominee.

At the locality to the north of Cedarville and Hessel there is a group of hills formed principally of Niagara limestone which rise about 300 feet above the present level of Lake Huron. These hills formed two and perhaps three Islands in Lake Algonquin, which have been named by F. B. Taylor, the Munuscong Islands.[2] The waves of the old lake beat on the border of these islands until a well defined beach of coarse gravel was formed about them. A good example of this deposit now excavated for gravel with which to make roads, occurs six miles north of Hessel, where two roads cross at the northwest corner of section 36 T. 43 N., R. 1 W. A fine example of the same ancient lake margin is present about six miles northwest of Hessel near the northwest corner of the township in which that village is located. At the last named locality an extensive view may be obtained of the region to the south and west, which includes the neighboring land and broadly expanded waters of Lake Huron as far as Mackinac Island. With this far reaching landscape in sight, it is easy to fancy the waters of Lake Algonquin restored, and to picture the scene the region formerly presented. At the time referred to, the only land in sight from the Munuscong Islands, in all the vast expanse of water to the south, west and north, was a tiny island formed by the summit portion of the present Mackinac Island. To the northeast, the nearest land was in what is now Ontario to the north of the site of Mud Lake and St. Mary's River. In all other directions the ancient lake extended somewhat farther than do the waters of lakes Superior, Huron and Michigan at the present time.

The elevation of the Algonquin beach about the borders of the former Munuscong Islands is 860 feet above tide and 280 feet above Lake Huron, (The level of Lake Huron being taken as 580 feet.)

The waves as stated above, beat on the margins of the islands for a sufficient length of time to make a well defined gravel beach and the sand washed out from the shore was deposited on the bottom of Lake Algonquin near at hand, and where the water deepened rapidly and especially to the south and west, made extensive accumulations. This apron-like extension of sand below the old shore still remains and is a conspicuous feature of the low land adjacent to the former islands. Near the northwest corner of the township in which Hessel is located, a well has been dug in this sand to a depth of about ninety feet. The sand about the Munuscong hills becomes gradually thinner, when traced southward but meets the similar deposit made at a lower level by the water of Lake Nipissing, and for these reasons, nearly all the soil of the lowlands to the north of Les Cheneaux Island are sandy.

[2]American Geologist, Vol. XV. 1895, pp. 24-33.

While the waves were breaking on the borders of the Munuscong Islands and also after the waters of Lake Algonquin subsided, sand was blown over their surfaces from the encircling beach and in places, quite conspicuous sand dunes were produced.

Mackinac Island was much smaller during the existence of Lake Algonquin than at present; the water then stood about 205 feet higher than now on its sides, or 785 feet above tide, according to measurements made by F. B. Taylor and Frank Leverett, and cut a well defined shelf which in places is margined on the landward side by a lake-cliff. At most localities the terrace is covered with water-worn gravel; but in places characteristic gravel beaches are present, without the usual accompaniment of a cut terrace and lake-cliff.

"With the exception of the rocky faces of the great limestone cliffs," as has been well described by Taylor,[1] "which rise on its eastern and western sides, all the lower levels of Mackinac Island show plain evidence of postglacial submergence. The modern beach is composed almost entirely of limestone pebbles which are generally well rounded. The proportion of crystalline drift material from the north is not great and is confined mainly to bowlders of considerable size. The narrow strip of land upon which the village is built, and which rises to an altitude of 40 to 50 feet at the base of the cliff, is composed entirely of the same characteristic beach material; as may be seen in any of the little gardens of the villagers and in the deep cut back of the Astor house and the old court house. But on ascending to the higher levels of the island the evidence of post-glacial

submergence are even more marked. At an altitude of about 170 feet there is a heavy, well developed beach ridge. This ridge is the lowest of a series of four or five like ridges which rise by successive steps to an altitude of about 205 feet above the strait or about 787 feet above sea level. These old beaches may be seen to best advantage on the short target range back of Fort Mackinac. The ground is there cleared of trees and is covered with a short, thick turf, so that the whole series of beach ridges, with their intervening troughs and minor ridges, is admirably exposed to view. At this place the ridges are parallel and comparatively narrow, though strongly developed, and they are also more compactly arranged and more convenient of access than in any other part of the island.

[1]B. F. Taylor, "The highest old shore line on Mackinac Island," in American Journal of Science, Vol. XLIII, 1892, pp. 210-218. In this article the statement is made that the water body termed above Lake Algonquin was an arm of the sea. This view is now held by few if any students of the history of the Great Lakes, and was long since proven to be untenable by Taylor's own investigations.

"The short target range crosses the beaches nearly at right angles and the width of the series here is a little less than a quarter of a mile. But on the southwestern side of the island it is three times this width. In some places two or more ridges run together and form one, as is often observed elsewhere. On the short range four heavy ridges are clearly seen with possibly a fifth less distinctly formed. In two of the wider troughs, which are five to six feet deep between the main ridges, there are apparently several other little ridges, one or two feet in height. A road which runs parallel to the range and close to its west side cuts the top of each ridge and shows its composition to be a characteristic beach formation. The 205 foot beach is not only the highest one of the series here described, but also the highest on the island. If this ridge be followed through its full extent around the higher ground, it will be found to surround a small tract on three sides. On the remaining side, which is a long, straight line of limestone cliffs facing towards the northeast, all the beach ridges, except the lowest or 170 foot ridge, are wanting. This beach is situated at a considerable distance from the cliff, and the ground between is a broad, level plain with an altitude of 170 to 175 feet. On this plain a heavy talus of fragments and angular limestone bowlders lies against the base of the cliff. While the waves were forming the 205 foot beach around the other sides of the circumscribed tract, they were beating against this northeast cliff and the water on the plain at its base was 30 to 35 feet deep.

"The little island of ancient times, thus defined, was about three-fourths of a mile long and less than half as wide, with its longer axis running about northwest and southeast. Its north end was a sharp promontory formed by the long cliff facing northeast, as just described, and another shorter one facing almost directly west. At the base of the latter the 205 foot beach is well developed, but it is very narrow and the ground drops off rapidly westward to the 170 foot plain. The highest point of the ancient island is at its southern end which forms a rounded promontory and rises to a little less than 100 feet above the 205 foot beach. This point is now crowned by the earthworks of old Fort Holmes, built in 1812, and the descent to the 170 foot plain on the east, and to the 205 foot beach on the south is a steep slope of drift. On its west side, and about a quarter of a mile south of its north point, the surface of the island descends gradually to the 205 foot level. The upper beach is here wide and flat and encloses a considerable tract of low ground behind it."

On the lower portion of the slopes of Mackinac Island, there are other beaches, the Nipissing beach being especially conspicuous, as will be .described later.

The hills on the St. Ignace Peninsula rise to a height of about 160 feet above the level of the lakes Huron and Michigan and were completely submerged during the existence of Lake Algonquin, but as the water was drawn off, several islands appeared and at two stages, above the Nipissing horizon, strong well defined beaches were produced.

To the west of St. Ignace in the belt of land adjacent to the north shore of Lake Michigan, the next elevation sufficiently high to stand above the water of Lake Algonquin, is at Cook's Mills on the line of the Minneapolis, St. Paul and Sault Ste. Marie railroad, and near the landward end of the Garden Peninsula. At this locality as determined by Taylor,[1] the Algonquin beach has an elevation of 750 feet above tide, or 168 feet above Lake Michigan. An island or group of small islands existed at this locality during the highest stage of the water in the basins of the Great Lakes and was the first land to the west of Mackinac Island.

The Algonquin beach appears again near Ensign, about 15 miles west of Cook's Mills at an elevation of approximately 700 feet, but this, however, is an indefinite measurement.

[1]F. B. Taylor, "A reconnaissance of the abandoned shore lines of Green Bay," in The American Geologist, Vol. XIII, 1894, pp. 316-327.

On the west side of Garden Peninsula, the coast bordering Big Bay de Noc is bold and rendered picturesque by prominent headlands. From Garden Bay toward the southwest there are several bluffs, the most conspicuous being known in their order from north to south as Garden Bluff, Middle Bluff, and Burnt Bluff, each of which has beach lines about its higher portion. The summit portion of each of these elevations stood as an island in the water of Lake Algonquin. The highest beach on Burnt Bluff, which from its position is identified as a portion of the shore of Lake Algonquin, is 705 feet above tide, or 125 feet above Lake Michigan. The measurements of this elevation by Taylor and myself, by means of aneroid barometers, are identical. Burnt Bluff (Plate XI) is not only the highest elevation in the region about Big Bay de Noc, but is one of the most picturesque localities on the border of the Great Lakes. It resembles Mackinac Island, but presents a steep slope to the northwest instead of southward, and faced the direction from which came the chief ice movement that

left striæ on neighboring rock-surfaces. Its summit is covered with glacial drift, proving that like Mackinac Island, it was completely buried beneath ice during at least one and probably during each ice advance of the Glacial epoch. On the bold face of the bluff overlooking Big Bay de Noc, as may be seen from Fayette and other neighboring localities, there are two horizontal lines, due to the presence of cliffs with more or less definite terraces at their bases, which mark the position of the Algonquin and Nipissing shore lines.

As has been recorded by Taylor in the essay referred to above, the Algonquin beach is present on Washington Island, to the south of the southern point of Garden Peninsula and forming a part of the territory of Wisconsin. Other similar islands existed in Lake Algonquin to the southward of Washington Island and were formed by the highest hills on the peninsula and islands of Wisconsin bordering Green Bay on the southeast, thus showing that the present embayment on the northwest shore of Lake Michigan was outlined in part by a belt of small islands in Lake Algonquin.

The shore line of Lake Algonquin has also been identified by Taylor and myself near Gladstone and Escanaba, and thence southwest near the west border of Green Bay, to Birch Creek, about six miles north of Menominee. Its elevation near Escanaba is about 720 feet above tide, or 140 feet above Lake Michigan, but declines when traced southwest to 630 feet above tide or 50 feet above Lake Michigan as determined by Taylor, at Birch Creek. Throughout the portion of the old beach just indicated its position is recorded in part by a gravel ridge, associated in places with a cut terrace and accompanying lake cliff, but principally by the occurrence on its landward side of drumlins and other topographic features due to the action of glaciers, and on the lakeward side by the prevalence of sand which was deposited in the waters of former lakes.

As shown by the measurements of the elevation of the Algonquin beach given above, it is not now horizontal. As the beaches were at least essentially level at the time they were formed, since they record the surface level of a lake, the present departure of their plane from horizontality is evidence of a movement in the portion of the earth's crust beneath. Tabulating the measurements in hand pertaining to the present position of the Algonquin beach, at localities north of and adjacent to the shores of lakes Huron and Michigan, we have:

Locality.	Elevation above tide determined by aneroid barometer.	Measured by.
Munuscong Islands, to the north of Hessel and Cedarville.	860 feet.	Taylor.
Munuscong Islands, to the north of Hessel and Cedarville.	859 feet.	Russell.
Mackinac Island	785 feet.	Taylor and Leverett.
Mackinac Island	780 feet.	Russell.
Cook's Mills	750 feet.	Taylor.
Ensign	700 feet.	Russell.
Garden Bluff	700 feet.	Russell.
Fayette	710 feet.	Russell.
Burnt Bluff	705 feet.	Taylor.
Burnt Bluff	705 feet.	Russell.
Escanaba River, two miles west of West Gladstone	720 feet.	Russell.
Gladstone	700 feet.	Russell.
Ford River	680 feet.	Russell.
Pine Ridge	690 feet.	Taylor.
Birch Creek	630 feet.	Taylor.

These measurements show an upward inclination of the plane marked out by the waves of Lake Algonquin, from the southwest toward the northeast, at an average rate of approximately two feet to a mile; to the northeast of Mackinac Island, however, the rate increases to about five feet to a mile. Additional observations in this connection made by Taylor, Leverett and others, show that the movement that has occurred since the time of Lake Algonquin, was not of the nature of a regular tilting of the land, but that an irregular upward movement occurred to the northeast of the central part of the former lake. As will be described more fully later, the plane of the Algonquin beach and the plane of a lower, and equally well defined beach in the same region, namely the Nipissing beach, are not parallel and neither of them is now horizontal. That is, earth movements were in progress between the time of Lake Algonquin and of Lake Nipissing and also after the existence of Lake Nipissing.

OLD SHORE-LINES BETWEEN THE ALGONQUIN AND NIPISSING BEACHES.

The outlet of Lake Algonquin as has already been stated, was across the Province of Ontario, by way of the Trent River, and into Lake Iroquois which occupied the basin of the present Lake Ontario. The vast Laurentide ice sheet during the existence of Lake Algonquin, still covered the northeastern part of Ontario, including the valleys of Nipissing and Ottawa rivers. When the margin of the ice melted back so as to leave those valleys uncovered, a lower channel of discharge for Lake Algonquin was rendered available, and its waters were drawn down about 230 feet below their former level. This great change is warrant for giving the lake with a new outlet, an independent name, and it has been christened Lake Nipissing in reference to the river now occupying in part its channel of discharge.

The subsidence of the water from the Algonquin beach to the Nipissing beach was not a continuous process, as beaches strongly defined in certain localities, occur on the sides of the basin these two lakes occupied but intermediate between the beaches they left. On the north side of Mackinac Island, as has been recorded by Taylor, there is a strong well defined gravel beach at the old battlefield now the site of the Wauashkamo Golf Club, known as the Battlefield beach. Its elevation by aneroid is 75 feet above Lake Huron.

A few rods north of the cemetery near the extremity of St. Ignace Peninsula, there is a well defined beach at an elevation of 84 feet, measured by hand level, above the present level of the water in the Straits of Mackinac. On the hill to the west of St. Ignace near the public school building as recorded by Taylor, there is a strong gravel beach with an elevation of about 75 feet above Lake Huron, or at the same horizon as the Battle Field beach on Mackinac Island.

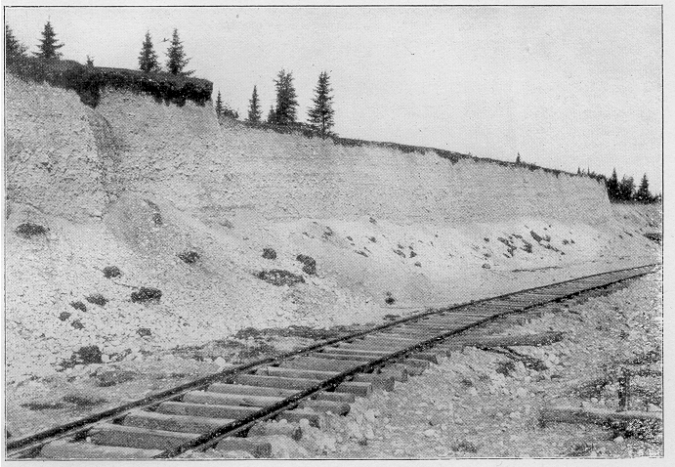

Plate X. A. An excavation in the Nipissing beach at St. Ignace.
July 6, 1904.

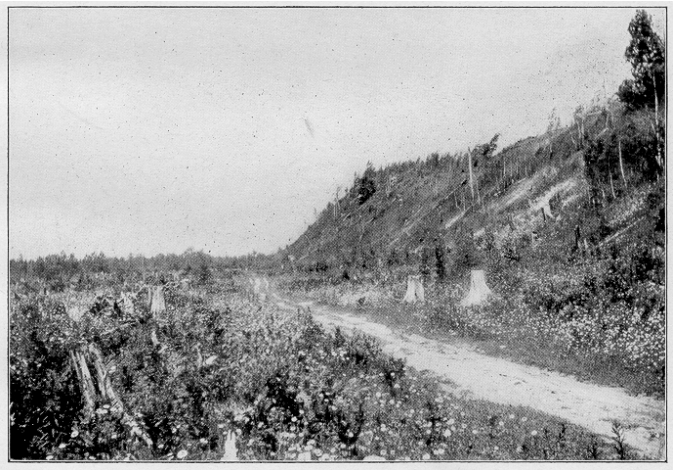

Plate X. B. The Nipissing beach, a cut terrace and lake cliff near St. Ignace.
July 20, 1904.

At Escanaba there is a broad lake terrace between the Algonquin and Nipissing beaches, its elevation being about 50 feet above Lake Michigan.

These and other, but less well defined terraces show that the water lingered at perhaps several horizons during the interval between the formation of the Algonquin beach and the Nipissing beach.

THE NIPISSING BEACH.

The waters of Lake Nipissing lingered longer at one horizon than did the waters of Lake Algonquin and formed much more strongly pronounced shore features. The beaches it left are not only conspicuous in the topography about the north shores of lakes Michigan and Huron, but have an important influence on the drainage of the land and hence on its agricultural and other economic uses.

The Nipissing shore line is in most instances marked by a gravel ridge, but in places where the shores of the lake were steep, cut-terraces and lake-cliffs are present. An important accompaniment of this shore line, as is the case of the Algonquin beach, is the presence on its lakeward side of extensive tracts of lake deposited sand. Nearly everywhere between the beach in question and the margins of the present lakes, the land is sandy, and sand dunes are sometimes present. Above the beach and retained by it are several lakes, and numerous swamps, particularly on Bois Blanc Island and about the borders of St. Ignace Peninsula.

Beginning at the east end of the tract of country considered in this report, (see map forming Plate XVI.), and proceeding westward, the chief localities at which the Nipissing beach is well developed are as follows:

The beach is recognizable at many localities about the borders of Drummond Island and also on the mainland at Detour, at which place its elevation as measured with a hand level, is 51 feet above Lake Huron.

On the south side of a drumlin at Cedarville, (the hill conspicuously marked by the presence on its summit of an old church) there is a strongly defined terrace of coarse well worn gravel, about 40 feet above Lake Huron, which judging from its strength and elevation, is no doubt a part of the Nipissing shore line.

About the heads of several of the deep bays adjacent to Les Cheneaux Islands there are stony gravel ridges at about the height at which the beach under consideration should occur. Owing to the density of the vegetation and in part the swampy character of the land, however, these ridges are somewhat difficult to follow. Les Cheneaux Islands have a general elevation of less than 40 feet and seem to have been shoals during the existence of Lake Nipissing. Their surfaces as already stated, have been washed by waves and currents, and the finer portion of the till of which they are composed, removed, and the stones and boulders it contained concentrated at the surface.

Goose Island and the St. Martin Islands are low, and the Nipissing beach is not present on them, unless, perhaps, about the highest portion of the larger St. Martin Island.

About Mackinac Island the Nipissing beach is strongly drawn, except when precipitous cliffs occur. As has been recorded by Taylor,[1] its elevation is 45 feet above Lake Huron. It forms the terrace on which the higher portion of Mackinac village is built, and on which the Grand Hotel stands. The lake-cliff above this portion of the beach is occupied by the block houses of Fort Mackinac. It is present also near British Landing and is continued as a well defined cut-terrace from there eastward across the north end of the island.

On Round Island this same beach again occurs and a part of the lake-cliff rising above it is noticeable in the forest clothing its eastern side.

All about Bois Blanc Island, the Nipissing beach is well developed. Usually it is a broad gravel ridge, with a surface elevation of about 45 feet above the present lake, but in places, as near Bois Blanc village on the north side of the island and again on the east shore, a stony lake-cliff excavated in limestone is present. The

small lake near the east end of the island was not visited by the writer, but judging from the reports of persons familiar with it, seems to be on the landward side of Nipissing beach and to owe its existence to this cause. Duncan or Twin Lakes and its neighboring lake to the east, have a surface elevation of about 35 feet above Lake Huron and are on the lakeward side of the Nipissing beach which is well developed in their vicinity. Between these lakes and the present water margin of Lake Huron, there are sand dunes and beach ridges, pertaining to the time since Lake Nipissing existed. The lakes just mentioned are shallow, the general depth being only five or six feet, their bottoms are dark with peaty accumulations and their waters of an amber color on account of vegetable matter in solution.

All about the borders of the St. Ignace Peninsula, the Nipissing beach forms a conspicuous feature. At the entrances of several embayments on the border of the old lake, stony gravel bars were formed which closed their outlets and transformed them into lagoons. Now that the water in the Huron-Michigan basins has fallen below the level of Lake Nipissing, several of the former lagoons have been transformed into lakes. A fine section of a gravel beach at the Nipissing horizon has been exposed in the excavations recently made for railroad ballast, in the northern part of St. Ignace, an illustration of which is presented in Plate X, A. The appearance of the beach near St. Ignace where it is accompanied by a cut terrace, is shown in Plate X, B.

Lake cliffs due to the undercutting of the borders of Lake Nipissing where the land rose precipitously, occur at St. Louis rock, about three miles north of St. Ignace, and again at Gros Point on the west side of the peninsula where for a distance of several miles a broad cut-terrace with bold bluffs on its landward side, overlooks Lake Michigan. Isolated rocks rising from this terrace show where skerries existed at the time the waters of Lake Nipissing beat upon the shore. Much of the beauty of the scenery in the region about Gros Cap, is due to the shore topography of the old lake. At the cemetery near the south end of Point St. Ignace, the Nipissing beach is represented by a well defined gravel terrace at the foot of a steep slope or lake-cliff, and has an elevation above the level of Lake Michigan, of 45 feet, as determined by means of a hand level.

[1]F. B. Taylor, "The Second Lake Algonquin." in the American Geologist, Vol. XV, 1895, pp. 100-120, 162-179. (By "Second Lake Algonquin" is meant Lake Nipissing.)

Brevoort Lake is 20 to 25 feet below the level of the Nipissing beach which skirts its southeast border. The lake is separated from Lake Michigan by a broad tract of sand dunes, and probably owes its existence to the cutting off of an embayment of the waters in the Michigan basin at a time subsequent to the existence of Lake Nipissing. Its waters adjacent to its south and west shores are shallow, but in its northern portion are reported to have a depth of 180 feet.

From Brevoort Lake westward for a distance of twenty or more miles, the shores of Lake Michigan are bold and the Nipissing beach was not recognized by me while traversing that region, until reaching the vicinity of Point Patterson where it appears at a distance of from three to five miles inland. From near Point Patterson westward nearly to Manistique the beach is represented by a gravel ridge connected at certain localities with a terrace and low lake-cliffs. At White Dale (Sec. 35, T. 41 N., R. 14 W.) the beach is about 40 feet above Lake Michigan. To the south of the beach the country is usually sandy and in part occupied by dunes, while the lower portions are swampy. Several small lakes below the level of the Nipissing beach owe their existence to beach ridges formed at a later date, or to the accumulation of sand dunes. About the borders of Garden Peninsula the beach is present, and at Burnt Bluff and other localities on the bold shore overlooking Big Bay de Noc, is usually a cut-terrace; but in the valleys leading inland from the heads of the present coves and bays and generally (as is reported) on the low eastern border of the peninsula, it is a sand and gravel ridge. Its elevation at Garden Bay and Burnt Bluff as determined by means of a hand level, is 30 feet above Lake Michigan. As has been recorded by Taylor,[1] "the Nipissing beach has been identified around the northern shore of Green Bay, but was not found to the south of Escanaba. It is the wide flat upon which the higher parts of the towns of Gladstone and Escanaba are built. Back of the former place its upper mark is strong and plain against the foot of a high bluff."

At the mouth of Escanaba River there is a well defined gravel terrace with an elevation of 24 feet above the level of Lake Michigan, and at Farmer's Dock on the east side of Little Bay de Noc, opposite Escanaba, there is a cut-terrace in limestone which records a water level 23 to 24 feet above the same datum.[2]

These old shore features are associated with similar records at both higher and lower horizon and their assignment to the Nipissing stage in the history of the Great Lakes basin is based on their relative strength in comparison with the beaches most nearly related to them, and on the conclusion derived from additional evidence by Taylor and others, as to the position the Nipissing beach should occupy in the Escanaba region.

The measurement of the present height of the Nipissing beach given on the past few pages, shows that it declines from 51 feet above the level of lakes Huron and Michigan at Detour, to 45 feet at Mackinac Island and St. Ignace, 30 feet at Garden and Burnt Bluff and 24 feet at Escanaba. The rate of this inclination as determined by Taylor, from a wider range of observation than is indicated above, is 6½ inches per mile.

[1]F. B. Taylor, "The Second Lake Algonquin," in The American Geologist Vol. XV, 1895, pp. 106-107.

[2]The height of the Nipissing beach at Gladstone and Fayette is given by Taylor as 20 feet. American Geologist, Vol. XV, 1895, p. 118.

The planes of both the Algonquin and the Nipissing beaches, in the region about the north shore of Lake Michigan, as stated above, are inclined downward from the northeast toward the southwest, the former at the

rate of about two feet per mile and the latter 6½ inches per mile. At these rates of inclination the two beaches should coincide in the region about Menominee. The country on the west side of Green Bay between Escanaba and Menominee, for a distance of five or six miles inland, is low, sandy and swamps and covered with dense vegetation. It has not been examined in detail and only the position of the highest beach present and that at only a few localities, has been well determined. Precisely at what locality the two beaches referred to came together is not known.

To the south of Menominee, the Nipissing beach as represented on a map published by Taylor, passes below the level of Lake Michigan, but observations made by Frank Leverett, as yet only in part recorded, seem to indicate that more tilting has occurred to the northward of a northwest and southeast line drawn through Lake St. Clair and the vicinity of Menominee, than to the south of such a line, and that the Algonquin and Nipissing beaches coincide in the southern half of the Lake Michigan basin, their combined records being a well defined beach about 15 feet above the present water level.

The portion of the glacial and post-glacial history of the basins of the Great Lakes outlined in these pages, although serving to explain many phases of the relief of the region here described, pertains to the changes a very much larger region has experienced, the complete records and full significance of which cannot be discussed at this time. A good summary of the changes referred to may be found in a chapter by Taylor, in Dryer's "Studies in Indiana Geography," to which the reader is referred for additional information.[1]

[1]C. R. Dryer, "Studies in Indiana Geography," Inland Publishing Co., Terre Haute, Indiana, 1897, pp. 90-100.

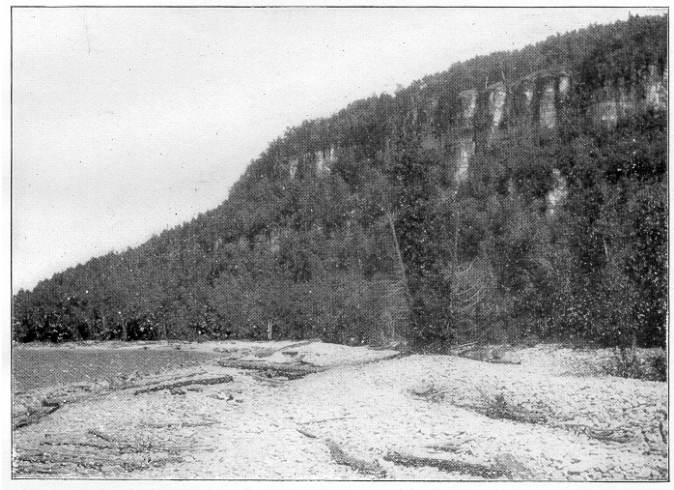

Plate XI. Burnt Bluff-Garden Peninsula, looking southeast. August 13, 1904.

LAKE CLAYS.

At two localities in the portion of Michigan embraced in this report, one near Hessel, and the other in the region about Isabella, to the north of Big Bay de Noc, there are deposits of fine, pink, thinly laminated, highly plastic clay which as shown by its fineness and evenness of bedding was laid down in a large water body. Similar clay is perhaps present at other localities in the same general region, concealed beneath later deposits of sand and possibly of till, but evidence in this connection is at present wanting.

The clay deposit referred to near Hessel, is located about one mile north of the village in a depression between two drumlins. Its known area is only a few acres, and its depth not ascertained. At Isabella and in the region to the north of that village for a distance as reported by residents, of five or six miles, pink clay is well exposed in the sides of stream and rill channels, and evidently has a thickness as indicated by wells, of at least 50 to 75 feet, but probably exceeds these measures. All about the border of this clay area there is sand in part in the form of dunes, as about Moss Lake, but the clay extends under the sand at least to the westward, as may be seen at many localities in the banks of Sturgeon River.

The clay deposit at Isabella is favorably situated for commercial purposes and as indicated by its fineness, plasticity, general freedom from coarse sand, concretions, etc. is well worth experimenting with for the purpose of ascertaining if it will serve for brick making. An analysis of the clay is as follows:

ANALYSIS OF CLAY FROM ISABELLA.

Analyzed by F. K. Ovitz.

	Per cent.
Silica, SiO_2	52.61
Aluminium oxide, Al_2O_3	15.66
Ferric oxide, Fe_2O_3	4.91
Calcium oxide, CaO	8.54
Magnesium oxide, MgO	3.16
Phosphoric anhydride, P_2O_5	.12
Sulphuric anhydride, SO_3	.11
Manganous oxide, MnO	.28
Sodium oxide, Na_2O	1.34
Potassium oxide, K_2O	3.72
Loss on ignition	10.18
	100.63

The deposits of clay briefly described above, are of the same character as much larger deposits exposed near Sault Ste. Marie and occurring widely on the Lake Superior shore of Michigan. Judging from the pronounced physical characteristics of the clay at these several localities and its known relation to other and associated deposits, it seems evident that it was laid down in a single widely extended water body. No fossils have been found in it to show whether it is of marine or lacustrine origin, but the presumption is that it was deposited in a lake. As to the date at which this lake existed no good evidence has as yet been obtained in Northern Michigan, but during the past summer similar clay previously known to exist in the northern portion of southern Michigan, has been shown by Frank Leverett to be several hundred feet thick and of older date than the surface morainal deposits of the region and to rest upon older glacial deposits. It is thus shown to have been deposited previous to the southward advance of the Wisconsin ice sheet. This is a highly instructive discovery, and if as now seems probable, the pink clays of Northern Michigan were deposited in the same lake as the similar clays in Southern Michigan, the existence

of an inter-glacial lake in the Great Lakes basin of comparable size with Lake Algonquin is made manifest.

SAND DUNES.

General characteristics: Sand blown by the wind is frequently deposited in piles, forming conspicuous hills, in much the same manner that snow is blown into drifts. Sand, however, is sometimes piled up at the same locality during a succession of years and the hills formed are in many instances far larger and more conspicuous than the snow drifts that are formed on the lowlands of temperate regions.

One source of supply of sand available for wind transportation, is along lake shores where it is left on the land by waves generated during storms. When sand thus left becomes dry it is blown about by the wind, and on-shore winds frequently drift it inland and pile it in conspicuous heaps. The localities of annual accumulation are usually determined by the presence of vegetation, and to induce conspicuous deposition the plants which assist in the progress of accumulation must be capable of growing from year to year, with comparatively little moisture. Drifts started in this manner are usually elongated in the direction the prevailing winds travel, but when a considerable elevation is produced it causes an eddy in the winds passing over it, and thus leads to additional sand accumulation, which take the form of a snow drift, and an elongated ridge or drift is produced at right angles to the direction of the carrying winds. Such drifts of sand or *dunes*, have a gentle slope facing the wind which brings the sand and a steep slope in the opposite direction. Sand swept up the gentle slope to the crest of the drift is precipitated over it and the dunes progress as one side is eroded and the other side added to. In this stage the sand drifts are known as *traveling dunes*.

The sand can only be moved by the wind however, when it is dry, and when but little vegetation is growing upon it. In a humid climate like that of Michigan, the prevailing moisture of the sand and the favorable conditions thus produced for the germination of seeds and the growth of vegetation, are factors tending to arrest the advance of sand drifts. When these conditions become dominant the drifts are soon clothed with vegetation, and their progress is arrested. In this condition they are termed *established dunes*.

The drifting of sand inland from a lake shore, is favored to a higher degree on shores facing the prevailing winds of the region where a lake is located, than when these conditions are reversed. The supply of sand is also regulated by currents in lake waters, which tend to carry sand from one part of a lake shore and to deposit it on another part; such localities being determined respectively by the direction of the wind and the nature of the outline of a lake's margin and the topography of its bottom adjacent to the land. Of these and other less conspicuous conditions, which control the movement of sand by lake water, prevailing direction of wind is usually the most important. For example, the winds blowing over Lake Michigan, are prevailingly from the westward and sand dunes are a common and conspicuous feature of its eastern shore, but are practically absent from its western shore. A more complete analysis of the condition favoring the formation of sand dunes about the margins of lakes would include the breadth of the water bodies, and hence the strength of their waves and currents, a broad water body being more favorable in this connection than a narrow one, but perhaps enough has already been said to enable the general reader to appreciate the significance of the facts concerning the sand dunes of Northern Michigan to which attention is invited below:

Dunes on the north shore of Lake Michigan: Nearly the entire area adjacent to lakes Huron and Michigan on the north, is conspicuously sandy. The sand is composed essentially of fragments of quartz, but the solid rocks of the regions are limestone and dolomite, in which sand grains seldom occur, and none of which would yield a conspicuous amount of sand on weathering. The immediate source of the vast quantities of sand mantling the surface and forming the greater part of the soils, as long since pointed out by Desor, is the glacial drift. All of the larger streams of the region especially during their flood stage, bring quantities of sand to the localities where they enter lakes Huron and Michigan, but many of the smaller streams, and even the larger ones during the low-water stages, are clear but of a brownish-yellow color owing to vegetable matter in solution. The clearness of the streams when not in flood, is due to the fact that they are fed at such times by water which filters through sandy deposits, or percolates through the vegetation of swamps.

The waves of the Great Lakes on reaching their shores, as a rule meet deposits of glacial drift, which is eroded, the finer particles being carried lake ward by currents, and the stones and sand dropped near shore in shallow water. This process of washing and assorting the drift has been in operation from the highest level reached by former water bodies in the basins of lakes Huron and Michigan down to the beaches of the present lakes and throughout this interval sand is abundant. At the various localities where the Algonquin beach is present, sand dunes are more or less prevalent, but as a rule are not conspicuous. Along the Nipissing beach drifted sand is more plentiful than at higher stations, and below that beach and down to the present margins of lakes Huron and Michigan the influence of the wind in forming dunes is frequently well illustrated. The principal dune and the broadest area of wind deposited sand, however, are adjacent to the borders of the present lakes.

Dunes are not a conspicuous feature of the region examined to the east of St. Ignace, although some drifting of the sand which is so abundant in the vicinity of the Nipissing beach, between Hessel and Detour, seems to have occurred. Adjacent to the north shore of Lake Michigan sand is more abundant than about the north

shore of Lake Huron, and at several localities has been shaped into characteristic dunes. From near Gros Cap to Brevoort, on the west side of the St. Ignace Peninsula, there is a belt of country adjacent to Lake Michigan and from one to four or five miles wide, which is conspicuous on account of its dune topography. Over much of this region the sand is still drifting, but in large part the hills that have been formed are completely clothed with vegetation, or in other words are established dunes. Many of the dunes are so old that dense forests grow upon them, and before the region was devastated by lumbermen they supported a fine growth of pines.

A characteristic portion of the sand-buried area in question, occurs between Lake Brevoort and Lake Michigan, where there is an extensive tract of undulating and hilly country with marshes and ponds, scantily clothed with vegetation. In this region extensive areas are rendered blue by huckleberries in late summer. Conspicuous dunes rising to a height of 60 to 80 feet, border Brevoort Lake on the west and form the highest land in the vicinity. These hills with deep depressions between, something of the picturesque-ness of which is revealed by the photograph forming Plate XII, A, were formerly clothed with pines, and owing to the difficulties of lumbering in such a rough region, some of the aged trees still remain. The dunes are in part washed along their eastern bases by the waters of Lake Brevoort and precipitous slopes imparted to them. The sand removed has in large part been spread out in the lake, shoaling its waters, and along its shore when dry, is again being blown into drifts. Certain portions of the clean washed sand, when dry, gives forth a musical or barking sound when trodden upon, not unlike the sounds emitted by snow beneath one's feet during unusually cold weather.[1]

Sand dunes are also abundant on the blunt peninsula which terminates in Point Patterson, and from there westward to Manistique forming a belt, in general from two to three or four miles wide adjacent to the shore of Lake Michigan. In this region as in the case of the dunes near Brevoort Lake referred to above, the dunes are on the lakeward side of the Nipissing beach. The topography has the usual irregularities of regions of drifted sand and in the hollows swamps are frequent. Owing to the piling up of the sand certain low areas have been isolated and basins produced which hold lakes. The region was formerly almost completely forest covered, but the pines have now been cut and fires following the destruction wrought by lumbermen have greatly altered the character of the primitive vegetation. A narrow belt of dunes from 30 to 50 feet high, extends along the shore of Lake Michigan for about two miles, eastward of Manistique. Deforesting has there been complete and the smooth curved surfaces of the sand hills have been converted into pasture land. Near the tops of some of the hills the thin sod has been broken, owing to the trampling of stock, the wind has gained access to the sand beneath the shelter of the grass roots, and has begun to scoop it out. Conspicuous changes from this cause are likely to result. Near Manistique the sand of a dune has been excavated for industrial purposes, and a good section exposed in which the irregular cross bedding, characteristic of wind-deposited material, is well shown. A photograph of this section is presented on Plate XII, B.

[1]Such "barking sand," "singing sands," "musical sand," or "sonorous sand," as it has been termed, occur abundantly in various parts of the world, but the reason for its sound-emitting quality when disturbed has not been explained. At Brevoort Lake the sonorous sand is rather coarse, uniform in grain, and free from fine particles. It is dune sand which has been washed and assorted by the waters of the lake and thrown on the shore, where some drifting has taken place. An abstract of an interesting paper on musical sand, by H. C. Boulton and A. A. Julien may be found in Proceedings, American Association for the Advancement of Science, Vol. XXXIII, 1885, pp. 408-413.

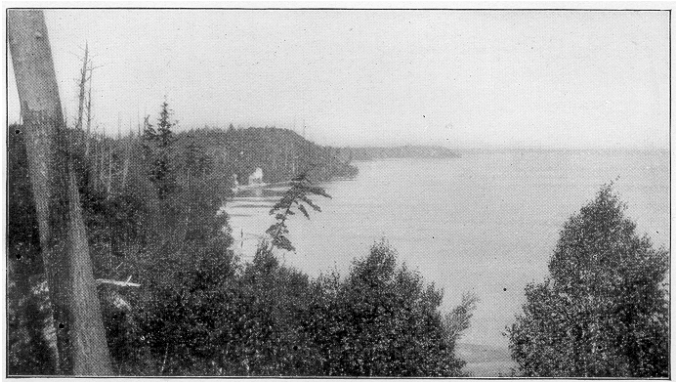

Plate XII. A. Established dunes on west shore of Brevoort Lake.
August 3, 1904.

Plate XII. B. Excavation in a dune near Manistique.
August 10, 1904.

A conspicuous feature observed in sections of the dunes near Manistique, and common in many of the sand and till deposits of various kinds throughout the part of Michigan under consideration, is the whiteness of the deposits to a depth of from a few inches to a foot or two below the surface, in comparison with the yellowish or reddish color of the same material at a greater depth. This bleaching of the surface portions of previous deeply colored deposits is due to the removal from them of the iron they previously contained, owing to the solvent power of the downward percolation water charged with acids derived from the decay of vegetation.

Drifted sand covers the surface of the northern portion of the Garden Peninsula, as far south as Portage Bay, and is reported to occur all along its eastern shore. In this region and adjacent to the railroad from Manistique to near the crossing of White Fish River sand dune topography is the prevailing feature of the landscape. Conspicuous dunes occur in the neighborhood of Ensign and also to the north of that village over the jack-pine plains bordering White Fish River on the east.

As previously mentioned, the country from Gladstone to Menominee throughout a belt in general about five miles wide, adjacent to the shore of Green Bay, is deeply sand covered, but conspicuous sand dunes are not known to occur except in the immediate vicinity of Manistique where small examples are conspicuous on account of their barrenness, and also because of the flatness of the country about them. The general lack of dunes in the sandy belt just mentioned, is as it appears, due principally to the fact that the prevailing winds are from the westward and tend to blow the sand that is thrown ashore by waves, lakeward instead of landward.

The dunes to which attention has been directed are instructive chiefly as examples of "established dunes." The regions where sand is now being drifted are restricted in area and confined for the most part to the west side of the St. Ignace Peninsula. At this locality the prevailing westerly winds have the broadest sweep across a lake surface, of any part of the country here considered, but the natural conditions have been greatly modified, owing especially to forest fires. Throughout the whole extent of the north shore of Lake Michigan, the conditions were formerly more favorable than at present for the drifting of sand, and indicates that the dunes preceded the forests. This consideration coupled with what is known of the history of the Great Lakes after the subsidence of the waters of Lake Nipissing, seems to show that when the waters fell from the Nipissing beach to their present horizon, a sandy region was left exposed and before vegetation became abundant upon it the sand was drifted into dunes. It thus appears as if the now "established dunes" were formed soon after Lake Nipissing subsided, and that the accumulation of drifting sand has gone on at a less rate since that event to the present time.

LAKE AND SWAMP DEPOSITS.

Wet basins: Of later date than the glacial drift and also, in part, subsequent to the formation of the beaches of Lakes Algonquin and Nipissing, and subsequent, also, in many instances to the formation of the established dunes about the northern border of Lake Michigan, are certain deposits made in the many lakes and innumerable marshes and swamps of the region under consideration.

In localities covered with glacial drift at higher elevation than the Algonquin beach, depressions are frequently occupied by lakelets, or swamps. In a similar way, below the Algonquin beach where sand is not abundant, the topography of the drift controls the relief of the surface, and wet depressions are not uncommon; areas of this character are frequent at localities at a distance from the beach, which were deeply submerged during the existence of Lake Algonquin. Illustrations in point are furnished by the numerous lakes and undrained basins on Drummond Island. By far the greater number of the lakes and swamps on the land adjacent to lakes Huron and Michigan on the north, however, occur in association with the Nipissing beach or in the usually sandy tract of country below that beach and extending to the margins of the present Great Lakes.

Deposits: In the wet basins to which attention has just been directed, two classes of deposits have accumulated; one class consists of material brought in suspension by inflowing streams, i. e. mechanically formed; and the other class has been produced by vegetable growths, i. e. organically formed.

Of the mechanical deposits referred to, no more need be said at this time, than that they consist principally of sand.

The organic deposits in the wet basins consist principally of (a) peaty accumulations, due to the growth and decay of many generations of water-loving plants together with leaves etc., blown from the adjacent land, and (b) so-called marl, formed principally by the concentration of lime (calcium carbonate) from lake waters by certain species of algæ.

Peat: The peat deposits are widely distributed throughout the portion of Northern Michigan examined, and occur not only in definite basins but quite generally over the surface of nearly flat and poorly drained land. They seldom reach a great thickness, although in some swampy areas, as about four miles north of Hessel and at certain localities on Drummond Island, they are reported to be 20 to 30 feet deep. In general, however, their depth is measurable in inches rather than feet. In a few instances the peat may perhaps be sufficiently deep and of the requisite physical character to be of economic importance as fuel in the distant future when wood shall have become scarce, but in general it has rather the character of muck or a mucky soil, and is of chief value on account of the fertility it imparts to the sand with which it is usually intimately associated. It is an economically important fact that much of the present swampy condition of Northern Michigan is due to the mat of partially decayed vegetation that rests on the surface and clogs the drainage channel. The removal of this material from the channels of rills and brooks, and the excavations of shallow ditches would result in rendering sufficiently dry for agricultural purposes, pasturage etc., many extensive tracts which are now dense tamarack and cedar swamps.

Marl: White pulverulent, calcium carbonate resulting from the decay of *Chara* and other fresh water algæ, is present in some of the lakes on Drummond Island and on St. Ignace Peninsula, but so far as has been learned,

the amount of such material of sufficient purity to be of value in the manufacture of Portland cement, is not great. More careful exploration in this connection is desirable[1] however, before the absence of commercial quantities of marl can be asserted with entire confidence.

[1]See Reports of the Geological Survey of Michigan, Vol. VIII, Part III, p. 340.

SOILS.

The leading characteristic of the soil of the portion of Northern Michigan considered in this report, is its sandiness, the only conspicuous exceptions being the region occupied by pink clay about Isabella, the surfaces of the washed drumlins in or near Les Cheneaux Island, and the presence over many extensive areas and irrespective of the character of the sub-soil, of muck arid other forms of decaying vegetable matter.

The soils of the region indicated on the map forming Plate XVI. with the exception of those composed largely of partially decayed vegetable matter, may be classified so as to indicate this economic importance, in the same manner as the superficial deposits to which they owe their principal characteristics are subdivided. The map just referred to thus becomes a soil map from which in a general way the agricultural possibilities of various areas can be judged. In this connection, it is understood of course, that in addition to the general nature of the soil of a region, other conditions such as its topography, drainage, etc. must be considered as affecting and frequently as exerting the leading control in reference to its agricultural possibilities.

The soil in the portions of the region here considered where till forms the surface are in general reddish, sandy loams.[2] From St. Ignace Peninsula eastward to and including Drummond Island, the till soils which are prevailingly sandy, contain. in general a higher percentage of clay-like material than do the similar soils to the north and northwest of Lake Michigan. Examples of till soils without the modifications due to submergence beneath lake waters, in the region lying east of the St. Ignace Peninsula, occur only on the summit portion of Mackinac Island and on the hills to the north of Hessel and Cedarville above the horizon of the Algonquin beach. The former of these localities is only a few score acres in area and is not under cultivation; the latter embraces several square miles, and is favorable for agriculture as is shown by the many fine meadows and grain fields it contains. The soil is a rather stiff loam, except where sand has been blown over it from the Algonquin beach, or muck is in excess as is the case in the poorly drained portions. In general the entire area above the Algonquin beach excepting the wet basins, is favorable for agriculture.

[2]A loam is a mixture of sand and clay in various proportions, together with more or less but in general a small per cent, of organic matter; should any one of these three ingredients be present in excess, and form the leading characteristic of a soil, it may conveniently be termed respectively, a clayey loam which may grade into a clay soil, a sandy loam which may grade into a sandy soil, or mucky or black loam, which may grade into a muck soil. These terms are in common use among farmers and others and are here employed instead of certain more technical classifications of soils that have been proposed.

Below the Algonquin beach on the St. Ignace Peninsula and thence eastward to and including Drummond Island, the till soil, when not concealed beneath subsequently deposited sand, is a reddish loam, but in general contains a notable percentage of sand and grades into decidedly sandy tracts where lake waters have deposited material. Drummond Island, owing to the fact that its site was many miles distant from the nearest land during the existence of Lake Algonquin, is mostly free from lake deposited sand and is covered with a reddish sandy loam of glacial origin. The topography of the central part of the island above the Nipissing beach has an uneven surface and owes its hills and hollows to the irregularities of the till sheet which covers it. The soil is in general fertile and is judged to be suitable for the growing of hay and use for pasture, but only comparatively small portions have been cleared.

Till soils are present in the region about Detour, but a mile or two west of the village sand predominates and extends throughout much of the region adjacent to the north shore of Lake Huron, as far as the low tract of densely forested country about the shores of St. Martin's Bay.

On Les Cheneaux Islands and the hills of the mainland adjacent the soil is till, but as previously explained, much of it has been washed by the waters of lakes and the finer surface material removed leaving the stones and large boulders. The surface is excessively stony (Plate VI, A.) and unsuitable for agriculture, although room for fruit trees might be found among the countless boulders that occupy the surface.

Bois Blanc Island is excessively sandy throughout although the presence of boulders indicates that the surface layer is in part at least a glacial deposit. The sand is usually dark at the surface owing to decaying vegetable matter and when newly cleared and cultivated is said to yield favorable returns, but the vegetable matter soon disappears from cultivated areas, being in part blown away when dry, leaving nearly white sand.

On the St. Ignace Peninsula above the Nipissing beach (45 feet above the surface level of lakes Huron and Michigan) the soil is principally a sandy till. Where the land is sufficiently well drained it is favorable for agriculture as is demonstrated by the prosperous appearance of the farms near Allenville etc. In this region the fertility of the soil is probably enhanced by the presence of gypsum derived from the underlying formations. In the main, however, the soil consists of till brought from the northward by glaciers and not subsequently buried beneath lake deposited sand.

Reddish sandy till soil predominates in the various areas above the Algonquin beach to the west of the St. Ignace Peninsula and especially in Menominee county. The comparatively small area at Cook's Mills and Ensign,

which are about the horizon just mentioned, are to a large extent covered with wind deposited sand and are not favorable for agriculture. At Ensign, however, a thin layer of reddish sandy till is present, barely enough to conceal the solid rock beneath, and agriculture has been attempted and more favorable results obtained than the thinness of the soil seems to warrant.

The most favorable agricultural region of considerable extent, throughout the portion of Northern Michigan represented on the map forming Plate XVI., is situated in the drumlin area to the west of Green Bay. This region is higher than the Algonquin beach and the soils on the hills and in some of the valley is a reddish, exceedingly fine sand-loam of glacial origin. As has already been explained the hills throughout Menominee County and extending into adjacent counties on the north and west, were given their characteristic slopes by ice-erosion during the last advance of glaciers over the region, when the ice melted the fine silt and dust it contained together with a notable but not excessive quantity of stones and boulders was left as a surface sheet over the hills and valleys. To this glacial deposit some æolian dust has probably been added since the melting of the last of the former ice sheets.

The fine surface layer thus superimposed on the land furnishes an excellent soil. In the valleys between the smooth, oval hills, gravel and sand was deposited in many localities by sub-glacial streams, and since the Glacial epoch, peaty soils have been formed in the wet depressions. The drumlins on account of the fine rich soil covering them and also because of the rapid absorption and retention of rain water, and favorable exposures to the sun, offered conditions highly favorable for agriculture. The valleys are more difficult to clear of forest growth and to drain, than are the hills, but yet are by no means beyond redemption.

From an agricultural point of view as well as in reference to mode of origin, the hills and ridges of the Menominee region present two very different types of land forms. The smooth surfaced drumlins with silt-like soils and reddish stony sub-soils, are well suited for agricultural purposes and will no doubt all be cleared and cultivated at an early date; while the eskers or winding ridges of gravel and sand, on account of the extreme porosity of the sub-soil and in general the frequently complete absence of a true soil, other than decaying vegetable matter, are unfavorable for cultivation. While economic interests demand that the drumlins should all be cleared and cultivated, the best use that can be made of the eskers, is, seemingly, to reserve them for wood land, or utilize them for growing fruit. The eskers also furnish an abundant supply of gravel for road-making and other uses.

Below the Algonquin beach and above the Nipissing beach, in the portion of the field lying between the St. Ignace Peninsula and Manistique River, reddish till soils consisting mostly of sandy loam, are present over areas which were sufficiently remote from the shores of the lake which formerly covered them to escape receiving a deposit of lake sand. The areas referred to occur principally between Bovee and Manistique, adjacent to the Minneapolis, St. Paul and Sault Ste. Marie railroad, and on the southern portions of Garden and Bay de Noc Peninsulas. In the region adjacent to the railroad, the till soil over large areas is concealed beneath swamp accumulations, but considerable portions of the region in the neighborhood of Point Patterson, have a favorable slope for drainage, and in fact are drained in part by underground streams flowing through limestone caves and have been cleared for farming purposes. On the Garden Peninsula to the south of the deep sand which covers its northern half, the soil is a reddish sandy loam, with many stones and boulders and in numerous localities when drainage conditions are favorable, is susceptible of a high degree of cultivation. This is a favorable fruit region, and in many ways gives evidence of agricultural prosperity.

On Bay de Noc Peninsula the last ice advance seems to have completely removed all previous surface accumulations, that may have been present, and spread out as it melted, a thin sheet of fine sandy loam, containing loose stones and boulders, in composition much like the surface covering of the drumlins in the Menominee region. The soil layer thus formed is seldom over three feet thick, and its average depth is in the neighborhood of two feet. It rests on a remarkably even surface of limestone and in spite of its flatness is mostly well drained owing to the presence of fissures in the rock beneath. The soil although thin is of good quality, and a fair advance in agriculture has been made. Below the Nipissing beach as roughly indicated on the map forming Plate XVI., sand is almost invariably found, and these areas together with their associated sand dunes and the jack-pine sand plains to the north of Bay de Noc Peninsula, cannot be claimed as favorable for cultivation. Their chief value, as it now seems is for the growing of trees.

The most exceptional soils of the region under consideration are those formed from lake clays, as in the region about Isabella (See analysis p. 94.) These are stiff clay soils which in most situations require ditching or other methods of draining, but are productive and give promise of favorable returns when methods of agriculture adapted to their peculiarities are employed. This soil is closely similar to the soil of the large clayey area to the south of Sault Ste. Marie, which is a prosperous agricultural region, and should be equally productive.

In the above brief review of the characteristics of the lands bordering lakes Huron and Michigan on the north, several references have been made to the muck and peat deposits of swamps. On the whole, the soils which owe their leading characteristics to the presence in them of a predominating percentage of decaying vegetable matter are the most common and widely distributed of any of the soil types of the region. The peaty or mucky soils occur not only in wet depressions but in many instances on surfaces which would have a free drainage

if the mat of vegetable litter and roots of living plants which occupies the surface were removed. The dense and all but impassable tamarack and cedar swamps for example, which cover extensive areas in Northern Michigan, frequently have a subsoil of sand, and could be drained at comparatively small expense if the land thus rendered available was of sufficient value for farming, but in general these sandy lands, although perhaps productive in hay and grain for a few years after being reclaimed, deteriorate rapidly as the vegetable matter contained in them decays, on account of exposure to the air, and their ultimate value is probably small.

In brief, the two leading types of soil in the region here considered, are sand which grades into sandy loam, and muck which also grades into sand and when drained and exposed to the air is apt to be removed leaving sand or sandy loam. Considering all conditions the region cannot be justly claimed as being even moderately favorable for agriculture, although there are certain conspicuous exceptions as for example, in the drumlin area to the west of Green Bay, on portions of the St. Ignace Peninsula, etc.

RECENT CHANGES OF LAKE SHORES.

In traversing the borders of lakes Huron and Michigan with the charts of the Lake Survey in hand, it becomes apparent that at certain localities conspicuous changes have taken place in the shore lines of the lakes since the surveys on which the charts are based were made. Evidence in this connection has also been obtained from fishermen and others, which shows still more definitely at what time the changes referred to were produced.

The principal changes that have been observed pertain to the formation of gravel bars between islands, or uniting a former island with the mainland, the building of gravel spits, and the origin of new shoals and islands.

Included in the Lake Survey chart of the Straits of Mackinac, (No. Hd.), based on surveys made—so far as the shore-lines here considered are concerned—in 1851, there are several localities where the present conditions differ from those represented on the chart. The principal instances noted are among Les Cheneaux Islands, (See Plate V.).

White Fish Island as designated on the chart, is now connected with the mainland by a gravel bar, a view of which looking north from the north end of the former island, is presented on Plate XIII, A. The bar has been produced by the junction of two spits; one starting from the island and the other from the end of a cape on the mainland. Fishermen and others familiar with the locality, state that boats with a draught of four feet, passed through the former opening as late as 1889. The pass was closed between 1890 and 1900[1].

Since the surveys referred to above were made, a gravel spit some five hundred feet long, has been formed at the north end of Rover Island. Owing to the unusual height of the water of Lake Huron during the summer of 1904, the spit was submerged at that time with the exception of a few square yards near its lakeward end.

On the chart referred to above, Boot Island is represented as being separated from another and smaller island to the southwest by a narrow strait. This strait is now closed by a gravel bar the surface of which is four or five feet above the present level of Lake Huron.

At the southeast end of La Salle Island a bay is shown on the chart, with a narrow point of land, i. e. a gravel spit, projecting from its southwest shore and nearly dividing it. The spit has been prolonged during recent years, through the action of waves and currents coming principally from the south, and now completely closes the entrance to the inner portion of the former bay, thus transforming it into a lake, from which a small stream outflows to Lake Huron.

The most conspicuous change in the lake shore among Les Cheneaux Islands, is the tying of a small islet known as Penny Isle, to Isle William. The strait between the two formerly independent islands is now crossed by a gravel bar, a portion of which is shown in the photograph forming Plate XIII, B. The bar is in general from ten to twenty feet wide, and rose about two feet above the adjacent water-surface in the summer of 1904. At one locality, however, near its middle, the waves broke across it during storms from the south. The bar consists of two spits which have been extended until they united. One of the spits was built out from Penny Isle towards the northwest and nearly reached Isle William; the other spit was formed by waves and currents coming from the south, which moved gravel and sand along the shore of Isle William, and at present meets the spit projecting from Penny Isle, near its growing end. The sand and gravel swept northwest from Penny Isle, was, as it seems, supplied by material pushed up by ice floes from the surface of the shoal on which the isle is located. The islet itself although indicated on Lake Survey chart No. Hd.; and therefore in existence in 1851, is certainly of recent origin, and probably owes its beginning to the concentration of stones and boulders on the surface of a shoal through the action of ice.

[1]For much of the information here presented concerning recent changes of the shore topography among Les Cheneaux Islands, I am indebted to Prof. John R. Allen, of the University of Michigan, who has made several visits to that region.

The process just mentioned, of moving loose stones which rest on the bottom in shallow water and shoving them into piles, is accountable for the appearance from time to time of boulder reefs at various localities about the shores of the Great Lakes. The stones and particularly large boulders, become frozen into the ice which when it breaks and forms floes is moved by the wind and waves; the tendency seems to be to force the greater part of the material thus held, landward, for the reason that in general the onshore are stronger than the

off-shore winds, and also because when open water is present the waves assist in the on-shore movement but not in the reverse movement. The best example of land formed as seems most probable, by this process, is Goose Island, situated about two miles southwest from Marquette Island the largest of "The Snows."

Goose Island is about a mile long, a few rods wide and from 15 to 20 feet high. So far as can be judged it is composed entirely of well worn limestone gravel together with large boulders derived from the glacial drift, and occupies the central part of a shoal. The action of waves and currents in moving the loose material is conspicuous all about its margin, and especially at its north end where the gravel spit shown on Plate XIV, A, has been produced by the meeting of streams of shore drift which travel northward along its sides.

A similar spit with a recurved end, on the south shore of Round Island, is shown in Plate XIV, B.

The most pronounced of the recent changes in shore topography to be recorded at the present time, is at the northwest end of Round Island, a mile south of Mackinac Island, where a gravel spit about a thousand feet long has been formed during the past decade. Two photographs of this locality from nearly the same point of view, one taken in 1885 and the other in 1904, are presented on Plate XV., which indicate quite satisfactorily the nature of the changes that have occurred.

The recent changes in elevation of the surfaces of the Great Lakes have been critically studied by G. K Gilbert,[1] and the conclusion reached that a movement is taking in the portion of the earth's crust on which the lakes are situated, of the nature of a rise to the northeast or a depression to the southwest. The rate of tilting is about 0.42 foot per hundred miles per century. That is, in the case of a line one hundred miles long, extending in a northeast and southwest direction, and situated in the region of the Great Lakes, the differential movements of its extremities would be 0.42 foot in one hundred years. This change tends to cause a rise of the water on the southwest shores of lakes which have no outlet in that direction, and a shoaling of the water on their northeast shores. From the nature of this change, it is to be expected that the water on the northeast shore of Lake Huron has been falling during the past century, but certain observed conditions appear to furnish an exception to this conclusion.

[1]U. S. Geological Survey, 18th Annual Report, Part II, pp. 601-647. See also p. 36 of the Report on Huron County, Vol. VIII, Mich. Geol. Survey.

At Fort Drumrnond, situated on the southwest shore of Drummond Island, docks supported by cribs filled with stones, were constructed before 1822, and two groups of cribs are still in place. At the more westerly of these two groups, on July 22, 1904, the water was thirty inches above the tops of the upright posts at the corners of the cribs. At the eastern group of cribs on the same date, the water was forty inches deep over the tops of the-corner posts. The posts are square at the top, and not abraded as if cut off by moving ice, but have the appearance of having been sawed to a uniform level. The relation of the summits of the posts to water level at the time they were put in place, is not known, but a reasonable supposition is that they were above water at that time. Adjacent to the cribs referred to and south of them, i. e. at the lakeward end of the former dock, the water is now seven feet deep. The bases of the chimneys of a former building now designated by the residents of the locality as the Barracks, are now three feet above the water as measured by a hand level.

The facts just recorded indicate that there has been a rise of water of about three feet since the docks at Fort Drummond were built, but the qualifications mentioned, render this conclusion of doubtful value. Possibly a search of the records pertaining to Fort Drummond, would reveal data for determining more accurately than is now practicable to what extent the level of the water has changed since the old fort was built.

The limited time available for the reconnaissance on which the present report is based, did not permit of my making a detailed study of the changes in shore-line topography to which attention has been directed, but it is hoped that the meager data presented, will lead persons who visit Les Cheneaux Islands, Mackinac Island etc., to photograph the localities where the changes are progressing most rapidly and thus secure a record of the alterations in progress.

DESCRIPTION OF PLATE XIII.

This plate is referred to in the text on page 42 and shows some of the changes which have taken place in a very few years.

A. This photograph was taken looking north from the north end of White Fish Island, July 29, 1904.

B. Is a recent gravel bar connecting Penny Island with Isle William and the photograph was taken July 31, 1904.

The characteristic shape of such bars and the advance of vegetation out upon them is also shown.

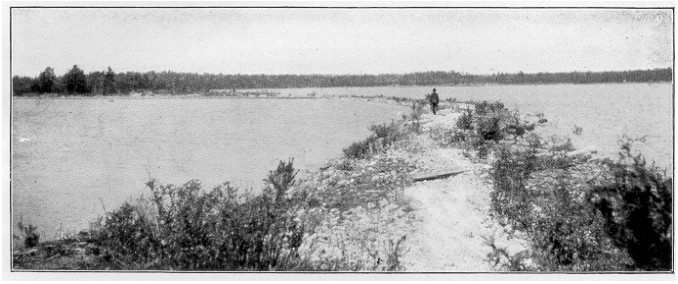

Plate XIII. A. Recent gravel bar connecting White Fish Island with the mainland.

Plate XIII. B. Recent gravel bar connecting Penny Island with Isle William.

DESCRIPTION OF PLATE XIV.

This plate is referred to on page 43 of the text and also illustrates recent changes of shore line. Similar spits have been quite elaborately studied by Gulliver and others.

A. Is a photograph, taken July 16, 1904, of a recent gravel spit at the north end of Goose Island.

B. Is a photograph, taken August 2, 1904, of a recent gravel spit on the southeast shore of Round Island.

Plate XIV. A. Recent gravel spit at north end of Goose Island.

Plate XIV. B. Recent gravel spit on southeast shore of Round Island.
August 2, 1904.

DESCRIPTION OF PLATE XV.

This plate is referred to on page 43. The two photographs were taken from almost the same point and in almost the same direction, at the northwest end of Round Island looking toward Mackinac Island, the bluffs of which appear in the background. The growth of a thousand feet of spit upon which a lighthouse is now located is shown.

There are also some indications of the beach levels on Mackinac Island.

Photograph A was taken July, 1885.

Photograph B was taken July 17, 1904.

Plate XV. A. Northwest end of Round Island.
July, 1885.

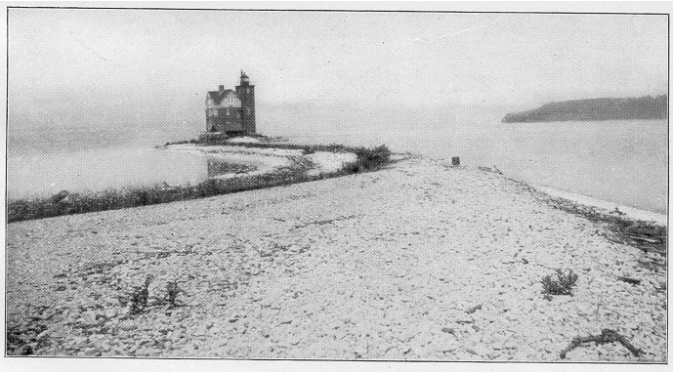

Plate XV. B. Recent gravel spit on northwest end of Round Island.
July 17, 1904.

DESCRIPTION OF PLATE XVI.

This plate is referred to in the text on pages 52, 62, 66, 85, 90, 99, 100, 102, and the features of it more fully explained.

While it shows primarily the glacial deposits, the glacial scratches, and the two most important shore lines left by former extensions of the Great Lakes system, yet on these in a broad way the character of the soil depends, as is more fully explained in the text from page 99 on, so that it may also be taken as a soil map, except that no attempt is made to indicate the smaller areas and peaty deposits. The originally swampy areas are shown on old maps issued by the Silas Farmer Company of Detroit.

Plate XVI. Map showing the surface geology of the region described in this report.

ERRATUM

[original document]

Plate II was omitted as unnecessary, although it is mentioned in the table of contents on p 36.