REPORT

OF THE

STATE BOARD OF GEOLOGICAL SURVEY

OF MICHIGAN

FOR THE YEAR 1906

ALFRED C. LANE
STATE GEOLOGIST

BY AUTHORITY

LANSING, MICHIGAN
WYNKOOP HALLENBECK CRAWFORD CO., STATE PRINTERS
1907

SEPTEMBER 10, 1907.

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1906

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Papers included.

THE SURFACE GEOLOGY

OF PORTIONS OF

MENOMINEE, DICKINSON AND IRON COUNTIES,

MICHIGAN.

BY

ISRAEL C. RUSSELL.

PUBLISHED BY THE STATE BOARD OF GEOLOGICAL SURVEY AS A PART OF THE REPORT FOR 1906.

LANSING, MICHIGAN
WYNKOOP HALLENBECK CRAWFORD CO., STATE PRINTERS
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LETTER OF TRANSMITTAL.

OFFICE OF THE STATE GEOLOGIST,
LANSING, MICHIGAN, Nov. 20, 1906.

To the Honorable the Board of Geological Survey of Michigan:

Hon. Fred M. Warner, President.
Hon. W. J. McKone.
Hon. Patrick H. Kelley, Secretary.

Gentlemen: I herewith transmit and recommend for publication as a part of your report for 1906, the following report by Prof. I. C. Russell, whom Ann Arbor has recently lost.

This may be the last work to appear from this gifted writer and eminent geologist, and certainly represents the fruits of his last field season in the summer of 1905.

The manuscript was put in my hands toward the end of the following winter, and returned to him with some slight suggestions which we talked over. It was found on his table after his untimely decease, with all the matters we had talked over adjusted, so that it is ready for the printer.

Your report for 1905 was already as large as a report should be, and it seemed wise to let it with the report of his co-worker, Prof. C. A. Davis, begin the report of 1906. Prof. Russell was more than a scientist. He was an artist. This shows not merely in the many beautiful descriptions of scenic effects which he gives, in his account of his trip up Mount St. Elias, but in his choice of words and attention to style, and lends to his writings an enduring charm.

Very respectfully,
ALFRED C. LANE,
State Geologist.

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THE SURFACE GEOLOGY

OF PORTIONS OF

MENOMINEE, DICKINSON AND IRON COUNTIES, MICHIGAN.

BY ISRAEL C. RUSSELL.

INTRODUCTION.

During the summer of 1905, I visited Menominee, Dickinson and Iron counties, in the southwest portion of the Northern Peninsula of Michigan, at the suggestion of Dr. A. C. Lane, State Geologist, for the purpose of studying the surface geology of the region. The examination was in continuance of similar work done the year previous, an account of which has been published.[1] The region visited is indicated on the map forming Plate III, and includes, essentially, the western half of Menominee County and the southern portions of Dickinson and Iron counties; in all about 1,000 square miles.

Field work was begun at Menominee on July 6th and terminated at Iron River on August 29, 1905. During this time I received much assistance and advice from Professor C. A. Davis, of the Department of Forestry of the University of Michigan, who traveled with me for the purpose of continuing investigations previously made in the Southern Peninsula of Michigan, concerning the nature, mode of origin, etc., of peat, together with other problems of a combined geological and botanical nature. Throughout the journey, I was also accompanied by Mr. A. P. Frapwell, who rendered efficient service as a field assistant.

Method of Work: The portion of Michigan visited was formerly almost completely covered by a dense forest, but as settlement progressed, and important iron mines were exploited in Dickinson and Iron counties and an extensive lumber industry developed, a portion of the land was cleared, wagon roads constructed, and several lines of railroad built. Aside from the railroads, intercommunication is almost wholly over wagon roads, and in carrying on geological work, the only practicable means of travel and transportation was found to be with horses and wagons. The main roads, and particularly the state and county roads, are good, but the secondary roads, many of them formerly used in connection with lumbering and now abandoned for that purpose, are in

[1] Report of the State Board of Geological Survey of Michigan for the year 1904. Lansing, Mich., 1905, pp. 30-150.

general in a bad condition and difficult to traverse. While considerable portions of the counties named above have been cleared for farming purposes, extensive tracts are still clothed with primitive forest, consisting on the uplands principally of hardwood trees, such as the maple, birch, elm, together with basswood, hemlock, etc., and in the low-lands, particularly when swampy, of spruce, tamarack and cedar. The hardwood forests are frequently sufficiently open to permit one to walk through them with ease, but the swamps are almost as difficult to traverse as a tropical jungle. The formerly extensive pine forests have almost entirely disappeared, owing to the invasions of lumbermen, and fires have swept the regions they occupied and completed the desolation. On the burnt areas, young trees and shrubs have taken root and grown vigorously, forming dense tangles nearly as difficult to traverse as are the cedar and tamarack swamps.

Mention has just been made of the means used for transportation and of the difficulties in the way of exploration, for the purpose of indicating that the work I was enabled to do was not of the nature of a detailed survey, but should be considered simply as a rapid reconnaissance. This statement will, perhaps, be better appreciated when it is remembered that the region studied is approximately 1,000 square miles in area, and the time devoted to its examination but fifty-four days.

Object of the Reconnaissance: The immediate object of the field work which furnished the data for the present report, was the furtherance of the preparation of a soil map of Michigan soon to be published by the State Geological Survey. This map, drawn to a scale of six miles to an inch, will show the distribution of various classes of soils, with considerable detail, and the localities where the rocks older than the glacial drift come to the surface. The purposes of the map fall mainly in two groups, which may be designated as commercial and educational.

The commercial uses of a soil map are suggested by the fact that from it can be readily ascertained much in reference to the agricultural possibilities of the region it represents, the location and nature of such superficial deposits as clay, sand, gravel, marl, peat, etc., as well as the places where the solid rocks come to the surface and may be utilized for building-stone, road metal and other purposes. Intimately associated with the agricultural interests of a state, are its possibilities in reference to forestry. From a soil map can be readily determined the location and extent as well as the facilities for transportation, of tracts of land like the so-called jack-pine regions of Michigan, which, in many instances, are of little or no value for agriculture, but may, in the near future, be in demand for tree-culture. The reforesting of the now desolate pine-lands of Michigan, has just begun, and as there are many reasons for believing, will develop into an extensive and important industry. As a basis for this and other occupations dependent directly on the soil, such as sugar-beet raising, fruit culture, etc., a knowledge of the soil, in order to make the best use of it possible, is of primary importance. It is with the view of encouraging future developments in the directions just indicated, that the Board of Geological Survey has wisely concluded to furnish all the information practicable in reference to the soils of Michigan.

The educational importance of a knowledge of the superficial deposits of a state is perhaps not exceeded by the direct money value of such information. Only a suggestion, however, can be given in this connection at present. To a large extent, and in fact almost wholly, the superficial deposits which form nearly the entire surface of Michigan, were either directly or indirectly placed where they now occur, by glaciers. One of the most astonishing facts in the geological history of the earth, is that vast areas in various continents, now highly fruitful and containing populous cities, were formerly deeply buried beneath ice sheets. A well-established part of the chapter of geological history referred to, is the fact that an ice sheet, similar to the one now covering Greenland, formerly occupied the region of which Michigan is a part. Not only was there one advance of the ice from the north over this region, but several such invasions, with intervals of mild climate intervening, during which forests flourished. This series of stupendous physical events and their attendant influences on plant and animal life, as well as the direct bearing of the conditions they produced on human history, when once understood and thoroughly appreciated, produce a profound impression on an enquiring mind and awaken an earnest desire to know more concerning the earth on which we live. Such an awakening of interest is one of the main factors of education.

It is for the purpose of systematically and accurately recording the data pertaining to the glacial and other of the later chapters of the geological history of Michigan, that the publication of a soil map of the State has been undertaken.

The present report is a minor contribution to the preparation of the map referred to, the larger part of which will be based on detailed work continued through several years, by Mr. Frank Leverett, under the auspices of the U. S. Geological Survey.

This report is addressed to the people living in the region to which it relates, and is an attempt to translate the records of nature into the language of every-day life. It is my hope that the reader will find in the following pages suggestive facts which will aid in the development of industry, particularly in the direction of agriculture, forestry and the use of water power, and also derive from them some knowledge of the interesting geological history of the region described.

TOPOGRAPHY.

The region represented on the map forming Plate III, is nowhere mountainous, and at only a few localities can it be truthfully claimed to be even moderately impressive on account of the height or boldness of its hills. Considering simply the present relief, the land forms may be classified in the three groups, plains, valleys and hills, but a more critical study will show that each of these divisions contains several members, with diverse characteristics and widely different histories.

Plains: On the west side of Green Bay there is a plain which extends some fifty miles westward, and is bordered on its inland margin by a more elevated region with a moderately rough surface. The plain, however, is separated into several portions, and in various parts is mildly diversified by low hills.

Bordering Green Bay on the west is a sandy strip of country, mostly in the condition of a cedar swamp, from five to six miles wide, which was formerly submerged beneath the waters of a lake, known as Lake

Algonquin, that occupied the basin of Lake Michigan, and may be termed a lake plain. To the west of the high water line of the former lake, the land is, in general, nearly flat and largely in the condition of a swamp, but has numerous well-drained uplands which, in places, rise sufficiently above the general level to form low hills. The depressions and hills alike are for the most part underlain or composed of sandy and stony clay or *till* as it is technically termed by geologists. The flat or nearly flat portions are frequently several square miles in area, as may be seen along the State road leading north from Menominee, and have a surface covering of till. Although the till is frequently concealed beneath peaty soils that have accumulated in the depressions, the fact that it forms a nearly continuous covering on the hard rocks beneath, may be readily determined, and gives warrant for the term *till-plain* as the best descriptive name to apply to the region. Rising from the plain to a height, in general, of thirty or forty feet, there are three classes of hills which will be described later under the titles *drumlins, eskers and kames.* Of these the drumlins are the most numerous and most characteristic, and appear as smooth, oval hills and ridges which, on account of the fine texture of their soils, favorable exposure, etc., have, to a great extent, been cleared of their primitive tree-growth, and are under cultivation. Examples of the hills referred to, are abundant in the central and northern portions of Menominee County, where they occur in large numbers and are the dominant features of the relief. The eskers and kames are ridges and knolls composed of sand and gravel, situated for the most part in the midst of swampy tracts, and rising, in general, to a height of twenty to thirty feet, but in a few instances as much as sixty feet above the till plain which occupies nearly the whole of Menominee County.

Beginning in the vicinity of Sturgeon Falls, there is a series of sand and gravel plains which extends far westward, along the general course of Menominee River and into the lower portions of the depressions or valleys drained by its larger tributaries. These plains, in some instances fifty or more square miles in area, are known in part to the residents of the region, as jack-pine plains, in reference to the most characteristic of the trees growing on them. They are underlain by thick sheets of sand and gravel, and in numerous instances have conspicuously pitted surfaces. The sand and gravel of which they are composed was deposited by streams that flowed from former glaciers, and they may, with propriety, be termed fluvial plains. Examples of plains of this character occur in the vicinity of Menominee River near Iron Mountain, Crystal Falls, etc., and extensions from them occupy many of the tributary valleys.

Valleys: The valley-like depressions bordered by uplands, less extensive than the till and alluvial plains, may be divided into two groups. These are the usually narrow and irregular low-lands separating rocky hills, and the channels excavated by streams during modern times, in alluvial deposits.

The rock-bordered valleys are represented by the numerous irregular depressions in Dickinson and Iron counties, which extend in an irregular manner among the numerous rocky hills, and are of ancient date. For the most part they are partially filled with alluvium and thus shown to antedate the period when the alluvial plains and connecting valley gravels were laid down. Examples are furnished by the irregular depressions occupied by the several principal tributaries of Menominee River, and their secondary branches.

The alluvial-bordered valleys represented by the immediate or inner valleys of Menominee River in the vicinity of Norway, Iron Mountain, etc., are margined by terraced escarpments, simulating great stairways, which connect the present flood-plain of the river with the higher and widening sand and gravel plains. The broad alluvial plains referred to, are simply ancient flood-plains, in which the present streams have excavated modern valleys. It is only at localities, however, where the ancient stream-laid deposits have a conspicuous thickness that the modern trench-like valleys have been excavated.

Associated with the alluvium-bordered valleys and, in several instances, connecting one section of such a valley with another section in the same drainage channel, there are short, narrow, steep-sided, rock-bordered gorges or canyons. In the same manner that the alluvium-bordered valleys record the work of streams in modern times in deepening and broadening their channels in loose material, the gorges in resistant rock represent the changes produced by streams where their tasks were more difficult. Examples of the rock-walled channels referred to, are furnished at each of the localities along Menominee River and its tributaries, where cataracts and rapids break the generally even descent of the streams. Of these short canyons, the most picturesque is the narrow gorge above Big Quinnesec falls, known as the Horse Race, a photograph of which is presented on Plate IB.

Hills: In the western portion of the Menominee region, hills are as characteristic features of the relief, as plains are of the topography of the eastern portion of the same region. The line of demarcation between these two sharply contrasted provinces, trends north and south and passes near the town of Waucedah, and is located at the junction of nearly horizontal sedimentary beds on the east and highly inclined and largely crystalline rocks on the west. The sedimentary beds consist principally of limestone, which are weak in reference to their degree of resistance to the agencies of erosion, while the crystalline rocks and their associated terranes are not easily dissolved and not readily removed by the friction of débris laden streams. The line of junction between these two provinces is irregular and cape-like projections and island-like areas of the nearly horizontal beds, characteristic of the province of the east, occur to the west of the general boundary and form conspicuous hills, of which the bold uplands in the vicinity of Norway and Iron Mountain are examples.

Throughout Dickinson County, and extending west from its western border into Iron County, the most conspicuous features in the topography are hills and ridges composed of crystalline rocks, such as gneiss, schist, and granite, or of various dark, basic, igneous rocks. The more prominent hills have a height of four or five hundred feet, but in general the differential elevation between the depressions and elevations is less than two hundred feet. The hills are seemingly lacking in systematic arrangement, but exceptions to this generalization are furnished by certain ridges of white quartzite and of dolomite in the iron-bearing formations, and ridges or ranges of hills due to the presence of dikes. Systems such as pertain to stream-sculptured topography, or the characteristic profiles of ice-eroded eminences, are not at all conspicuous. The reason for the lack of plan, as will be explained more fully later, is due principally to the fact that glacial and glacio-fluvial deposits have been superimposed on a surface which had previously been sculptured both by streams and glaciers, and to a considerable extent mask the features of the underlying hard-rock topography.

Examples of the hills referred to, occur in the vicinity of Vulcan, Norway, Iron Mountain, Metropolitan, Crystal Falls, etc., and furnish illustrations of the general character of the elevations that are present throughout the western portion of the Northern Peninsula of Michigan. Something of the general appearance of the hills may be seen in the photograph reproduced on Plate V, of a rounded and glaciated ridge of white quartzite near Loretto.

The rocky hills impart to the land a moderately rough surface, but there are no conspicuously prominent elevations. A striking feature in the relief is that the higher hills throughout areas of many square miles, rise approximately to the same height, although the rocks of which they are composed are of various degrees of resistance to the agents of erosion. This feature becomes especially significant when it is noted that certain hills and ridges are composed of rocks which occur in nearly vertical layers, and as is known are remnants of truncated folds. Evidently the land has been eroded to a generally uniform horizon, and the plane surface thus produced roughened by subsequent erosion and this process supplemented and the relief to a considerable extent subdued by the subsequent deposition of material by glaciers and streams.

In addition to the numerous hills and ridges composed of hard rock and in part superimposed upon them, there are numerous and for the most part minor elevations of the same character as the drumlins, eskers, and kames, which vary the monotony of the till-plain in Menominee County. With these constructional topographic forms are also included the irregular heaps and piles of till left by glaciers, and known as *moraines*. Examples of these several glacial and glacio-fluvial deposits, with the exception of drumlins, are present as minor features of the topography, in the province underlain by crystalline rocks and the iron-bearing formations, to the west of Waucedah, and extending westward to beyond Crystal Falls. Still further west, and especially in Iron County, moraines become conspicuously prominent and cover extensive areas, so as to almost completely mask the topography of the underlying rocks. About Iron River, for example, bold rounded hills, composed to a depth of two hundred feet or more of stony clay, dominate the landscape, and impart to the country a characteristic relief, which is conspicuously different from the topography of the country to the eastward where rocky hills, fluvial plains, till plains, etc., form the prevailing features of the surface of the land.

Streams.

Menominee River: The region described in this report is drained almost entirely by Menominee River which forms a portion of the boundary between Michigan and Wisconsin.

A.—LOWER TWIN FALLS, MENOMINEE RIVER.

B.—HORSE RACE RAPIDS, MENOMINEE RIVER.

The Menominee and its tributaries constitute the largest and longest river system which discharges into the Great Lakes, in the Northern Michigan-Wisconsin region. The trunk stream is formed by the junction of the Bois Brulé and the Michigamme, and has a length of approximately 104 miles. It is a fine stream of usually clear but brownish water, the color being due to the vegetable matter held in suspension or in solution, which is contributed by the numerous swamps along its course. The extent of the area drained by the river, or its hydrographic basin, is not accurately known, but is approximately of 4,000 square miles of which 2,240 square miles is situated in Michigan and the remainder in Wisconsin. The principal tributaries to the trunk stream in Michigan are the Bois Brulé, which forms a part of the Michigan-Wisconsin boundary, Iron River, a tributary of the Bois Brulé, Michigamme River, Sturgeon River and Little Cedar River. Of these the Michigamme is the longest and has the largest volume; its source is in Michigamme Lake, in Marquette County, which is supplied by several streams, the sources of which are within some ten miles of Lake Superior. The tributary second in importance, is Sturgeon River, the hydrographic basin of which lies to the east of the country drained by the Michigamme. This stream, after following a tortuous course through a comparatively wide and densely forested valley, passes through a water-gap in a prominent quartzite ridge near Loretto in Dickinson County, where it forms a short but picturesque rapid, and joins the Menominee about half a mile above Sturgeon falls.

The Menominee and its several tributaries are characteristically clear-water streams and furnish an illustration of the manner in which a thick covering of vegetation and porous soils lead to the filtration of surface waters. Another result of these same conditions is that the streams have but small seasonal variations; a feature which has an important bearing on their utilization for water power.

The Menominee is of special interest to the geologist, owing to the fact that its course is in a conspicuous manner independent of the composition and structure of the hard rocks underlying the region it drains, and has been determined, to a great extent, by the glacial deposits left on the surface of the land at the time of the melting of the last ice sheet which covered it. Interest centers in this fine river, however, principally because of its commercial importance. It is nowhere navigable, but its strong current and numerous rapids and falls afford important sources of power. Accurate surveys of the river are not available and no comprehensive study of its water-power has been made, but suggestive estimates in this connection are contained in the reports of the Tenth Census of the United States,[1] from which the following table has been compiled, showing approximately the available water power in the trunk portion of the river.

[1] Vol. 10, Part 2, Washington, 1887, pp. 57-67.

Principal Rapids on Menominee River and their Estimated Theoretical Power.

Name.	Fall in feet.	Horse-power.
Bad Water rapids	5	455
First Twin Fall	12	1,130
Second or Lower Twin Fall	12	1,130
Pine River rapids	6	566
Big Quinnesec falls	120	14,950
Little Quinnesec falls	80	9,936
Sand Portage rapids	40	5,078
Sturgeon falls	12	1,831
Nose Peak rapids	4	605
Pemena falls and rapids	70	11,115
Chalk Hill rapids	8	1,302
White rapids	20	3,275
Grand rapids	25	4,954
Twin Island rapids	10	1,995
Schappee rifts	7	2,024
Rapids at Marinette	19	3,930
Total	450	64,231

As stated in the report from which the above table has been compiled, the figures given are largely estimates, but such tests as I have been able to make, indicate that they do not vary greatly from the truth. The table refers to natural conditions and it is to be remembered that the available power could, in most instances, be materially increased by constructing dams.

Since the estimates quoted above were made, the U. S. Geological Survey has begun a critical study of the water power of the Menominee and its tributaries. The reports thus far issued,[1] contain a large amount of valuable data, from which the following data have been compiled:

The volume of Menominee River, as shown by a number of measurements made near Iron Mountain, in 1903 and 1904, varies from 1,558 to 9,490 cubic feet per second; the mean of 12 gaugings made between May and November, during the years mentioned, was 4,666 cubic feet per second. (U. S. Geological Survey, Water-Supply and Irrigation Paper No. 97, p. 475, and ibid No. 129, p. 21.)

Again, estimates based on a large number of gauge readings at the same locality as just mentioned, in 1902, '03 and '04, but not including the months of January, February and March, during which the presence of ice interfered with the correct reading of the gauge, the minimum flow was 1,032 and the maximum flow 11,770 cubic feet per second; the mean being 3,925 cubic feet per second. The highest stage of the water during 1903 and 1904, so far as recorded, occurred in May of each year, and the lowest condition of the river was during the

[1] Newell, F. H. Report of progress of stream measurements for the calendar year 1902, U. S. Geological Survey, Water-supply and Irrigation Paper No. 83, pp. 250-262.
Hoyt, J. C. Report of progress of stream measurements for the calendar year 1903, U. S. Geological Survey, Water-supply and Irrigation Paper No. 97, pp. 474-483.
Horton, R. E., E. Johnson and J. C. Hoyt. Report of progress of stream measurements for the calendar year 1904, U. S. Geological Survey, Water-supply and Irrigation Paper No. 129, pp. 20-24.

late summer and early fall months. (U. S. Geological Survey, Water Supply and Irrigation Paper No. 129, p. 23.) Conspicuous variations in volume of the river are recorded during each month concerning which measurements are available, but it should be understood in this connection that, during low water stages, the practice of retaining the water at certain times, by means of dams and of flushing the river so as to aid in the transportation of logs, makes the recorded fluctuations much greater than they would be under natural conditions.

The purpose in mind in presenting the above table at this time, is to direct attention to the truly remarkable facilities for developing water-power along the Menominee River. The resources in this respect are not all told, however, when the main river is alone considered. Several of its branches are of sufficient size to merit being termed rivers. and as is indicated in the table given below, also compiled from the reports of the Tenth Census, furnish facilities for the development of power.

Tributaries of the Menominee.[1]

Name.	Length in miles.	Drainage area in square miles.	Estimated low-water discharge in cubic feet per second.	Theoretical horse-power under 10 feet head.
Bois Brule, including the Mequacumecum (Paint river)	42	1,013	465	528
Michigamme river	72	756	347	391
Pine river (in Wisconsin)	53	586	269	305
Sturgeon river	50	409	188	214
Pembinebemon river (in Wisconsin)	23	163	75	85
Pike river (in Wisconsin)	43	292	134	152
Little Cedar river	32	149	68	77

While the above table is not to be understood as presenting precise measures, it serves to show that the tributaries of the Menominee are worthy of careful consideration when a demand arises for the abundant power they are capable of furnishing. As is apparent, even from a very imperfect inspection of these streams, they afford favorable sites for factories. Especially suggestive in this connection are the rapids in the Sturgeon near Loretto, in the Michigamme near Mansfield, and in Iron River and Iron Mountain. The water-power briefly considered above, is now utilized in part, but to only a small fraction of its total amount in any one instance. Dams constructed near the mouth of the Menominee, at Marinette, have been in operation some thirty years, mainly in connection with the lumber industry, and for similar purposes, dams of somewhat temporary character to the number of about 25, have also been placed at various localities along the main river and its tributaries, but at the present time are mostly out of repair and may be considered as things of the past.

Besides the use of the Menominee for transporting logs, two important developments of its water-power have been made. An extensive paper mill, at Little Quinnesec Falls, now utilizes about one-half of

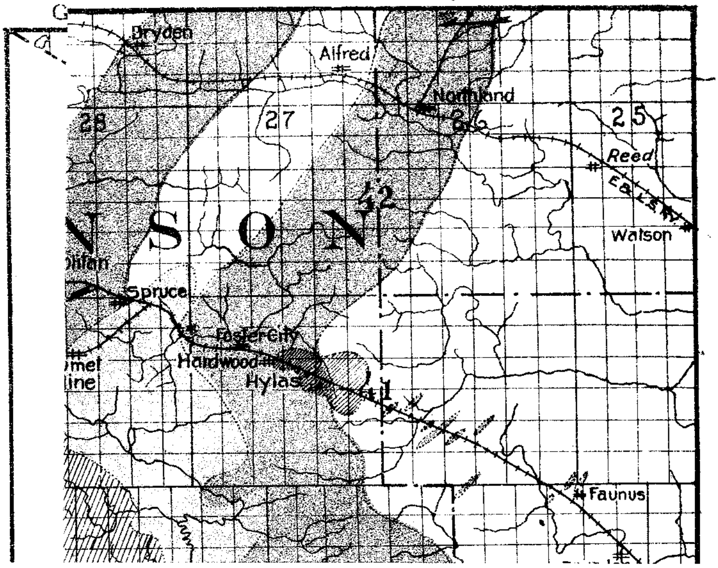
[1] To this table can now be added Iron River concerning which information is given in U. S. Geological Survey, Water-supply and Irrigation Paper No. 97, pp. 476-483, and No. 129, p. 24.

the available 10,000 horse power at that locality. At Big Quinnesec Falls an air-compressing plant has been erected, which delivers compressed air, by means of a large iron pipe, to the iron mines at Iron Mountain, but uses only a small fraction of the power the river is capable of furnishing at the fall referred to and at the neighboring rapids. Plans have also been perfected for utilizing Sturgeon Falls for compressing air for use in the iron mines at Vulcan, but as to the extent of the proposed developments I am not informed.

Persons seeking more information in reference to the water-power of the Menominee and its tributaries, will do well to consult the report of the Tenth Census and of the U. S. Geological Survey referred to above. An important increment to the industrial development of the Menominee region will, no doubt, be furnished by the careful measurements of volume, etc., now being carried on by the U. S. Geological Survey, but in connection with this study an investigation of the timber, mineral and agricultural resources of the region and their relation to means of transportation should be made. Water-power is here classed with the other industries mentioned, because it should be recognized as one of the leading natural assets of the region under consideration. This region was formerly a center for the production of pine lumber, but the formerly magnificent pine forests have disappeared. It is now the source of vast quantities of iron ore, but there is a limit to the ore deposits and if the active demands now being made on them continue for a few years or a few score years, the supply will, no doubt, be exhausted. Concerning the water-power, however, there will be no diminution with use, but on the other hand by means of storage reservoirs, the natural amount can be materially increased.

Stream Development: The streams of the Menominee region have had at least two important episodes in their history. The earlier of the two series of events referred to, occurred in ancient geological times, when the streams deepened their channels until they cut through a layer of nearly horizontal stratified rock, namely, the Potsdam sandstone, and uncovered a lower and older series of rocks which is folded and in part consist of nearly vertical strata. The later episode occurred after the Glacial epoch, during which the region was covered with a surface blanket of loose material, principally sandy clay and gravel, and the streams, displaced from their previous channels, took new courses and excavated their beds until, at numerous localities, they reached the hard rocks beneath the superficial covering of rock waste.

In reference to the first of the episodes referred to, many features of the present streams will be made clear, when it is remembered that the Potsdam sandstone formerly extended far to the west of the present position of its western margin in the region about Norway, Iron Mountain, etc., and as seems probable covered the whole of Northern Michigan and much of the adjacent portion of Wisconsin. Other formations of later date than the Potsdam and resting on it, had a similar but as yet not definitely known, westward extension. Movements in the earth's crust in the region now drained in part by the tributaries of the Menominee, caused the sediments of the Potsdam and late seas to be upraised and form land. The courses the streams took on this land were determined by the slope of its surface, or were what are termed



G
Bryden
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Faunus

consequent streams. The streams excavated channels and valleys for themselves and developed many branches. Erosion progressed until all of the Potsdam sandstone was removed from the extensive areas in the Menominee region where granite rocks and the iron-bearing formations now appear at the surface, and the streams were lowered on to these rocks in the positions they had occupied on the formations formerly covering it. That is, the drainage was superimposed from the nearly horizontal Potsdam sandstone, etc., upon the folded and highly inclined formations which occurred beneath it. The surface left exposed by the removal of the Potsdam sandstone, had previously been a part of a land area, and, on account of erosion, was moderately rough, the hard rock having been left in relief as the softer rocks adjacent were removed and valleys produced. Across this surface the streams flowed in channels inherited from the vanished cover of nearly horizontal rocks. The streams are not confined to the broader valleys, but, instead, give little heed, so to speak, to the hardness or softness or to the relief of the surface or the structure of the formations they cross.

The second episode referred to in the history of the streams, occurred when the glaciers which formerly covered Michigan, etc., finally melted. The glaciers left a sheet of sandy and bouldery clay or till spread over the country they had occupied, in places forming conspicuous moraines and oval, smooth-surfaced hills termed drumlins, which will be more fully described in a later page, but in general not sufficiently thick to mask the relief of the hard rocks on which it rests. During the last retreat of the ice, however, the heavily debris-charged streams fed by its melting, deposited great quantities of sand and gravel over the land adjacent to the margin of the ice. These glacio-fluvial deposits formed widely extended outwash-plains, and acquired sufficient thickness in several extensive regions, to bury not only the previously deposited till, but to conceal many eminences on the irregular surface of the land that had been re-exposed by the removal of the Potsdam sandstone. The broad outwash plains referred to, are typically illustrated by the so-called jack-pine plains adjacent to Menominee River, near Iron Mountain and Crystal Falls, and also have a wide development in Wisconsin, as for example, in the vicinity of Florence.

As the ice withdrew for the last time from Northern Michigan, the present streams came into existence, and in part followed the courses of pre-glacial rivers, but in the main took new courses over the surfaces of the glacial and glacio-fluvial deposits which had been left as a blanket of rock-waste over the land.

In the case of Menominee River and the lower portions of several of its larger tributaries, the waters at first flowed over gently sloping, but irregular and in part conspicuously pitted, sand and gravel plains, which conceal all but the higher knobs and ridges of the underlying hard-rock surface. As the streams deepened their channels, they here and there reached the rocks beneath the superficial deposits, and renewed the task of sculpturing them, which had been delayed during the Glacial epoch. Where the tops of knobs and ridges of resistant rock were met and crossed by the streams, rapids and water-falls came into existence. Several and as it appears, all of the rapids and falls of the Menominee had their sites determined in this manner. This interesting story can be read in great detail, in the records afforded in the vicinity of Big and Little Quinnesec Falls, at Sturgeon Falls, etc., and at several localities along the larger tributaries of the Menominee.

The two great interruptions in the progress of stream work referred to, the first caused by the subsidence of the land, which permitted the ocean to cover it and deposit thick sheets of sediment; and the second, due to the advance of glaciers over it and the laying down of glacial and glacio-fluvial deposits, have certain features of the same general nature. Each episode was characterized by the deposition of material on a previously deeply denuded land, thus giving it a new surface on which streams began afresh to deepen and widen valleys, and finally reached the underlying rocks which were more resistant and have a different structure than the beds resting on them. The last cycle of erosion is as yet in its infancy, and its duration has been brief, in comparison with the cycle of erosion that preceded the Glacial epoch. As yet but a small advance has been made in the task of removing the deposits the former glaciers left as a record of their invasion. In fact, numerous depressions in the surface of the glacial and related deposits, still endure and are occupied by swamps and lakes.

The outline sketch just given of the last great episode in the lives of the streams of the Menominee region, is perhaps sufficiently suggestive to permit persons living in the region under consideration, to fill in the details pertaining to a special locality. More facts, however, relating to the glacial and associated deposits will be presented later.

Lakes.

A highly characteristic feature of the portion of North America formerly occupied by ice sheets, is the multitude of lakes it contains. In the Menominee region, however, this result of the changes produced by glaciation is less pronounced than in many neighboring areas, the general reason being that the glacial deposits present are comparatively thin, and that the valleys and depressions in most instances became more or less completely filled with gravel and sand deposited by streams flowing from the last of the former ice sheets during its retreat. But notwithstanding these adverse conditions, several lakes of considerable size, and many lakelets as well as innumerable swamps, are present, and furnish some of the most pleasing features of the scenery.

All of the lakes owe their existence to the former glacial conditions, and may be classified in reference to the mode of origin of their basins, in two groups, namely; those retained by morainal dams, or held in depressions in the irregular surfaces of the glacial débris, and those occupying pit-like depressions, mostly of small size, in the surface of alluvial deposits. The lakes of the former class include all of the larger examples, such as lakes Fumee and Antoine near Iron Mountain, and Fortune, Chicagon, Stanley, Sunset lakes, etc., in the vicinity of Crystal Falls and Iron River. Although the lakes in general measure only a mile or two in their greatest diameters—the longest is Fortune Lake, which has a length of a little over four miles, but is exceptionally narrow—they are important on account of their beauty and utility. In several instances they are almost completely surrounded by forests, the primitive wildness of which has escaped the destruction that accompanies the advance of civilization. Chicagon and Stanley lakes are especially interesting on account of the unmarred beauty of the densely tree-clothed hills that are mirrored in their tranquil waters.

The lakes referred to, owe their existence, for the most part, to the irregularities present in the surface of the widely spread covering of stony clay which conceals the older rocks as with a blanket, but to the west of Crystal Falls the till deposits form massive morainal hills, among which most of the larger lakes of the region are interspersed. In but few instances does it appear that the deposition of moraines in pre-glacial valleys has led to the formation of well-defined dams, but in the case of Lake Antoine, the presence of an irregular moraine on its west border, shows that a true morainal dam was there formed in the bottom of a comparatively large valley bordered by rocky hills, and checks the free escape of its waters.

Of the lakes contained in pits and basins in alluvial deposits, abundant examples are furnished on the broad sand and gravel plains between Crystal Falls and Menominee River, and in several similar but smaller areas. The basins of these lakes are sunken in the surfaces of nearly level tracts of sand and gravel, and their steeply-sloping borders are composed of the same material. For the most part they are only a small fraction of a mile in length and in general are from a few to perhaps thirty or fifty feet in depth. The origin of the basins or pits they occupy is accounted for on the hypothesis that bodies of ice formerly occupied their sites, and were surrounded by sand and gravel laid down by streams, or else, that ice was covered by such accumulations and melting left depressions.

The largest and best example of the class of the lakes referred to appears to be Runkle Lake, near Crystal Falls, which occupies a depression about one mile in diameter and some sixty to seventy feet deep, in a broad sand and gravel plain, and is without a surface outlet.

In some instances lakes have resulted from the deposition of sand and gravel at the outlets of small valleys bounded for the most part by rocky hills, as is the case of Hanbury Lake in the vicinity of Norway, or are due to similar obstructions adjacent to the irregular border of morainal hills, as is indicated by the conditions at Crystal Lake near Iron Mountain.

The numerous swamps of the Menominee region which occupy irregular depressions in the general sheet of glacial deposits or occur in sags and hollows in sand and gravel plains, in part indicate the position of former lakes that have been filled by accumulations of vegetable matters. These areas, in many instances, are now cedar and spruce swamps, and in the case of the less completely filled examples, present meadow-like expanses of sedge, or are densely overgrown with water-loving shrubs. On the sand and gravel plains there are also numerous depressions similar to those holding lakelets and swamps, but sufficiently well underdrained to be dry at all seasons, and in the nature of their vegetation, do not differ in a conspicuous manner from the surrounding areas with their dense growths of sweet fern and its usual associates.

Although the lakes of the Menominee region present important scenic features and are of commercial value on account of the fishes inhabiting them, their chief interest to the geographer and geologist centers in the mode of origin of the basins they occupy. This phase of their history, however, is included in the account of the surface geology given on later pages.

The Primeval Forest.

In a state of nature essentially the whole of the Menominee region was occupied by a forest. The only exceptions were small isolated areas where rocks outcropped, and portions of the broader and more sandy alluvial plains which were too dry to be favorable for tree growth.

The forest presented conspicuous variations dependent on soil conditions, which, when understood, permit of a quite accurate determination of the kind of trees that grew on a given type of soil, or knowing the kinds of trees, to make prediction in the reverse direction.

On the soils composed of till, when so situated as to be more or less well drained, the primitive forest, much of which still remains, consisted principally of maples, birches, elms, basswoods, iron-wood and hemlocks. The last named trees, however, were less widely distributed than the hardwood trees, and usually grew in isolated groves.

Where the uplands were more sandy, and in consequence the soils less humid, pines flourished, and extensive tracts were well covered with Norway and white pine. These trees have now almost completely disappeared on account of the destructive lumbering processes that have been carried on. Associated with the pines just mentioned but growing on still drier soils and especially characteristic of sand and gravel plains, was the jack-pine, which is of but little value for industrial purposes, but on account of its picturesque shape adds greatly to the beauty of the scenery.

The low lands, where drainage was imperfect and marshy conditions prevailed, are the home of the cedar and spruce, together with a multitude of shrubs and luxuriant growths of lowly, flowering annuals. The lake margins and swamps upon the black muck soils are permanently wet and are clothed with thick growths of sedges and other water-loving plants.

The most conspicuous change that man has made in the forest conditions is in the removal of the pine, and in the results of the extensive fires that followed the work of the lumbermen. The sandy tracts of land denuded of their pines, and burned until even the vegetable portion of the soil over extensive areas has been destroyed, are now for the most part densely overgrown with bushes and young trees. The destruction wrought by fire, however, has been so nearly complete that but few young pines, other than the jack-pine, have reappeared. The denser portions of the hardwood forests have been but little changed. Recently, however, a demand for the lumber they furnish has arisen. Owing to the comparatively small amount of forest litter on the ground under natural conditions, fires do not sweep through them so as to destroy the larger trees, but as their utilization progresses this danger will be augmented.

The swamps have, to a great extent, been invaded by lumbermen in quest of cedar, and in recent years the spruce they contain has come into demand as a source of pulp-wood. Here also fires have burned the refuse left on the ground by lumbermen, and consumed the resinous living trees as well.

From a knowledge of the relation of trees to soil types, and hence to geological conditions, as stated above, the distribution of the species of trees may serve to indicate the nature of the deposits in which they grow.

In the Menominee region the hardwood forests show where till occurs, either in moderately well-drained plains, or forming morainal hills and drumlins. The white and Norway pines, now for the most part represented by their scorched and blackened stumps, are indicative of light, sandy soils, so situated as to be well drained, and mark the localities where sandy outwash from the former glaciers, margin terminal moraines, or eskers and kames are present. The jack-pines are, for the most part, confined to the broad sand and gravel plains, such as occur adjacent to Menominee River. A characteristic associate of the jack-pine on the plains, is the so-called sweet fern, which almost everywhere densely clothes the surface. Where the sweet fern is less abundant than usual the ground is frequently purple with blue berries and huckleberries in late summer.

The cedars and spruces indicate exceptionally humid soils and grow on any kind of material that is permanently wet. Usually, however, the peaty soil of the swamp is underlain by sand or gravel.

HARD ROCK GEOLOGY.

A classification of the geological formations of Michigan, of older date than the superficial blanket of glacial drift, etc., is presented in connection with the geological map forming Plate II. On the map, the surface distribution of the larger divisions of the "hard-rocks" of the state is indicated, and the general reader may obtain much assistance from it while reading the following sketch of the earlier chapters in the geological history of the Menominee region.

The brief popular account here attempted, of the geological formations of older date than the Glacial epoch, is based almost entirely on the detailed and carefully prepared reports of several geologists, and especially C. R. Van Hise, W. S. Bayley, J. M. Clements, H. L. Smyth and others, who have studied the iron deposits of Michigan. The reports referred to,[1] should receive special attention from persons living in the vicinity of the iron mines of Michigan, as they contain a vast amount of information, not only of economic importance but of great educational value.

As may be read on the map forming Plate II, the rocks of older date than the Glacial epoch, belong to four of the larger divisions of geological history. These are in ascending order, the Basement Complex (Laurentian and Keewatin of Plate II), and the Algonkian[2] (Huronian), Cambrian and Ordovician systems.

Basement Complex: In the region here considered, the rocks included under this term are crystalline, and consist principally of gneiss, granite and schist, together with various igneous intrusions. Examples are

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[1] Monograph No. XXXVI, of the U. S. Geological Survey: "The Crystal Falls iron-bearing district of Michigan," by J. Morgan Clements and Henry Lloyd Smyth, with a chapter on the Sturgeon River tongue by William Henry Bayley and an introduction by Charles Richard Van Hise, Washington, 1899. Quarto, pp. I-XXXVI, 1-512, 46 plates, and 14 figures. Price $2.00.

Monograph No. XLVI, of U. S. Geological Survey: "The Menominee iron-bearing district of Michigan," by William Henry Bayley, Charles Richard Van Hise, Geologist in charge, Washington, 1904. Quarto, pp. 1-513, 43 plates, and 54 figures. Price $1.75.

Folio No. 62, of the Geological Atlas of the United States: "Menominee special Folio," by C. R. Van Hise and W. S. Bayley, U. S. Geological Survey, Washington, 1900, pp. 1-14, 2 maps. Price 25 cts.

These reports may be obtained at the prices stated, by addressing the Director, U. S. Geological Survey, Washington, D. C. These reports contain full abstracts of the work of this survey under Rominger, C. E. Wright and Wadsworth, which are now mainly out of print.

[2] In view of Russell's decease, I did not feel at liberty to change the use of his term Algonkian. In this report, however, it is equivalent to the term Huronian, as used by previous writers, and the State Survey.—Lane.

furnished in an extensive tract of country with a rough topography, which begins on the south, adjacent to the iron-bearing rocks about Norway, Iron Mountain, etc., and extends north to beyond Metropolitan, and also by the rocks about Sturgeon, Little and Big Quinnesec falls.

These rocks are among the oldest on the earth of which a knowledge has been obtained, and are designated by certain geologists as being of Archean age. They consist chiefly of material that was once in a fused condition or a magma, which, on cooling, formed igneous rocks. But the original rocks have been greatly altered on account of the passage through them of water which produced chemical changes, and by heat and pressure, accompanied in part by movements in the material; that is, *metamorphism* has occurred. In part the present gneisses, schists, etc., may have been sedimentary deposits, of the nature of mud and sand, and later metamorphosed, but after intense metamorphism has occurred, it is difficult to determine what the previous state of a terrane may have been. In many instances the rocks have been intensely folded, owing to movements that have affected them, and are traversed by dikes of igneous rock, consisting of magmas which were forced into fissures after the receiving rocks attained their present condition.

The Basement Complex has no definite lower limit, but is supposed to merge by insensible gradations with the highly heated material forming the vast centro-sphere of the earth. Its upper limit in Northern Michigan is usually well defined, by an unconformable contact with later and less completely changed sedimentary beds, but in other regions rocks of the same character merge by insensible gradations with less metamorphosed sedimentary formations, and the surface of demarcation is indefinite.

Several widely divergent views have been advanced in reference to the mode of origin of the Basement Complex, but the one perhaps most generally accepted has been summarily stated by Van Hise as follows: "The Archean [Basement Complex] is igneous and represents a part of the original crust of the earth or its downward crystallization." But this view, like most other related explanations, is based on the assumption that the earth has cooled from a state of fusion so as to form a surface crust. With the substitution of the planetesimal hypothesis in the place of the nebular hypothesis to account for the origin of the earth, however, our ideas concerning the history of the Basement Complex must necessarily be revised. Under the planetesimal hypothesis, the earth is supposed to have been formed by the coming together of cold, solid masses of matter, like the meteors that reach the earth at the present time, which, previous to their aggregation, moved independently through space. With this mode of origin the earth's surface may never have been highly heated, and a crystalline outer crust not formed. The present heat of the interior of the earth as explained by T. C. Chamberlin, the author of the planetesimal hypothesis, is due to compression, and movements produced by gravitation as the planet grew in size. Beginning with a solid earth with a cool, rigid surface, an explanation of the crystalline or metamorphosed condition of the more ancient rocks near the surface, may be due to their having been depressed, owing to movements of the material forming the earth's outer portion, and the deposition of sediments, until they became highly heated, owing to the conduction outward of heat from the earth's interior. Under such conditions, rocks formed at the surface, owing to the arrival of meteorites or produced by the processes of erosion and deposition, might be metamorphosed and recrystallized in the various ways known to produce such changes. Not only the earlier sedimentary beds and their associated igneous intrusions, might be metamorphosed in the manner suggested, but formations of any age and of any character may have been altered in a similar manner.

This view of the origin of the Basement Complex seems to satisfy such tests as can be legitimately applied, and explains why the upper limit of the metamorphic rocks may be at any horizon in the geological succession, down to within the Tertiary division of geological history.

All explanations of the origin of metamorphosed rocks agree in the conclusion that the changes which gave them their crystalline structure, took place at a depth of at least several thousand feet in the earth. Where such rocks now form a part of the earth's surface, it is evident that upheaval and deep denudation has occurred. In the Menominee region the rocks of the Basement Complex were upraised until they stood above sea level, and deeply eroded before the next younger rocks of the region, i. e., the Algonkian [Huronian] terranes, or the iron-bearing formations, were deposited.

Between these two great systems of rocks there is an unconformity, which records a long interval during which, so far as the records show, no sediments were deposited in the region under consideration.

The great antiquity of the Basement Complex in Michigan, is indicated by the fact that sediments deposited elsewhere during the next succeeding Algonkian era, contain the oldest records of life of which we have definite evidence. Since the crystalline rocks referred to, were upheaved and eroded, essentially all recognizable sedimentary rocks thus far discovered, with their records of many successive floras and faunas, have been laid down. Not only do the hills of Michigan, composed of the crystalline rock in question, carry one back in fancy to beyond the beginning of what may be termed recorded geological history—the records being the stratified rocks and the fossils they contain—but the hills themselves, as topographic forms, are also of vast antiquity, as will be explained in advance, under the title "topography of the hard-rock surface."

Algonkian [Huronian] *System:* The formations next younger than the Basement Complex, in the Menominee region, includes the sedimentary beds and associated igneous terranes, which were deposited during the Algonkian period of the earth's history, so named after the Indian tribe which inhabited, and still occupies in part, the region where the rocks of this period form the surface.

The Algonkian system includes the iron-bearing formations, typically displayed about Waucedah, Vulcan, Norway, Iron Mountain, etc., in the Menominee iron district, and about Metropolitan, Crystal Falls, Mansfield, Amasa, Iron River, etc., in the neighboring iron districts. The rocks consist of definitely stratified quartzite, dolomite, slate, etc., and are clearly of sedimentary origin, although at present somewhat metamorphosed.

The Algonkian rocks in the Menominee iron district, as determined by Van Hise and Bayley, have a thickness of from 3,650 to 6,400 feet.

In the Crystal Falls district, as shown by J. M. Clements and others, they have a still greater vertical extent, but include a far greater proportion of igneous material. In each district, several well-defined subdivisions of the system have been recognized, separated by unconformities which record times of upheaval and erosion. Several of the more important members of the system, such as the Sturgeon quartzite, Randville dolomite, Vulcan formation, Hanbury slate, etc., have names which refer to typical localities at which the several divisions are well exposed.

From an economic point of view, the one prominent fact concerning the Algonkian rocks in Northern Michigan, is that they contain all of the great iron deposits of that region. From an educational point of view, however, the interesting records they contain are numerous and varied. A few salient facts in this connection are: The rocks are well stratified and consist of sedimentary beds, such as gravel, sand, clays, calcareous muds, etc., now hardened, cemented, and otherwise changed, so as to form conglomerate quartzite, shale, dolomite, etc. The lowest members in the series rest unconformably on the eroded surface of the underlying Basement Complex. In other words, the rocks composing the Basement Complex had been crystallized, upraised above sea level, and deeply eroded before the waters of the Algonkian ocean, owing to their having been again depressed below sea level, advanced over them. The Algonkian rocks, originally essentially horizontal sheets of sediment, are now highly inclined and in part occupy vertical positions. Their deformation was accompanied by folding and also by breaking and faulting. After they had been crushed into a series of great folds, and raised above sea level, the land thus formed was deeply eroded, and a plane produced. During the process of erosion the rocks were weathered and water passing down along the strata dissolved the iron they contained, and in part redeposited it, thus enriching the portion of the iron-bearing beds which were below the zone of weathering and leading to the concentration of iron ores. The long period of erosion, during which the Algonkian rocks were planed away nearly to sea level, was terminated by a movement in the earth's crust, which depressed the Menominee region, in common with a vast area of which it formed a part, and permitted the ocean once more to advance over it. This submergence occurred during the Cambrian period of geological history, and the first sheet of sediment laid down in the ocean waters, unconformably on the eroded surface of the previous land, is known as the Potsdam sandstone.

Paleozoic Systems: The rocks formed during the portion of the earth's history immediately succeeding the Algonkian period, constitute the Paleozoic system, and in the Menominee region include the Potsdam sandstone, the Calciferous cherty limestone, and the Trenton limestone.

The Potsdam sandstone is represented by brown and red, but in part white, sandstone of the Lake Superior region, and is largely used for building purposes. About Waucedah, Norway and Iron Mountain it forms the summit portions of prominent hills, as, for example, Brier and Iron hills, where it rests in a nearly horizontal position on the eroded and truncated edges of the steeply inclined strata of the iron-bearing formations. It also outcrops at White Rapids in Menominee

River, and, passing beneath the later sheets of sediment, principally limestone, with a gentle downward inclination to the southeast, underlies the whole of Menominee County. Its thickness in Brier Hill, near Norway, is about 150 feet, and at the shore of Green Bay, as shown by the records of dug wells, it is approximately 166 feet thick and its surface over 550 feet below the surface of Lake Michigan.

Resting conformably on the Potsdam sandstone near Iron Mountain, Norway and Waucedah are remnants of a sheet of silicious, magnesian limestone or dolomite, which, like the sandstone beneath, dips to the southeast at a gentle angle, and, to the east of Hermansville, passes beneath the next succeeding sheet of marine sediment. On account of the exposure of the Calciferous near Hermansville, the portion of the series present in the Menominee region has been named the Hermansville limestone.[1] Its maximum thickness is reported to be about 100 feet, but in the several exposures about Norway, Iron Mountain, etc., erosion has removed its upper portion.

Beginning near Hermansville, and extending east, and forming the surface portion of the hard rocks beneath the glacial drift, etc., is the Trenton limestone, which underlies nearly the whole of Menominee County. Its maximum thickness, where not eroded is (including the Galena) about 300 feet,[2] and like the immediately underlying beds, it dips gently to the southeast.

The Potsdam, Calciferous and Trenton series furnish a record of submergence and of the advance westward of the Paleozoic ocean over a previous land area. The first sheet of sediment laid down consists of sand derived from the waste of the land to the west and north. The next succeeding sheet of sediment formed when the subsidence became greater, is largely calcareous but contains sand grains and much silica precipitate in openings after the rock became compacted. The presence of sand in the highly calcareous material indicate that the margin of the land, although distant, was not so far removed from the localities where the ocean sediment was principally of organic origin, but that the currents brought some sand grains to it. During the deposition of the Trenton limestone, subsidence had progressed so that the margin of the land was far distant and only calcareous deposits derived from the life in the waters settled on the bottom.

The widely extended downward movement of the earth's crust just referred to, which permitted of the deposition of extensive sheets of marine sediments in a nearly horizontal position, was followed near the close of the Paleozoic era, by an upward movement which raised the beds above the sea and exposed them to the erosive agencies of the air. The center of the uplifted area was to the northwest of the Menominee region. During the time this upward movement occurred to the northwest, the region to the southeast, involving the whole of what is now Southern Michigan, and a wide extent of territory about its borders, continued to subside.[3] The results of the change from a region of upheaval to the northwest, to a region of subsidence to the south-

[1] Bayley, W. S. "The Menominee iron-bearing district of Michigan," Monograph of the U. S. Geological Survey, Vol. XLVI. Washington, D. C. 1904, pp. 31, 494.
[2] See annual report of the Geological Survey of Michigan, for 1903, pp. 126–136.
[3] Some account of the downward movement in the region now occupied by Southern Michigan, which permitted of the accumulation of thick sheets of Paleozoic sediments, and its influence on industrial development in recent years, may be found in the report of the State Geologist of Michigan for 1904, pp. 42–57.

east, becomes manifest in the vicinity of Waucedah. To the northwest of that locality, the rocks were raised higher than to the southeast, and in consequence were more intensely eroded.

Where the elevation was greatest, the Paleozoic sediments have been eroded away, once more exposing the underlying Algonkian rocks, or the still older Basement Complex, but where the elevation was less, as to the east of Waucedah, the Paleozoic sediments still persist. Along the border, between these two regions, outlying remnants of the Paleozoic rocks are present, as in the hills between Waucedah and Menominee River to the west of Iron Mountain.

Fossils: As stated on a previous page, no direct evidences of life have been found in the Basement Complex. It does not follow from this, however, that life was not present on the earth during the time the rocks in question were formed. Intense metamorphism has affected the rocks referred to, and even if they are in part of sedimentary origin, and formerly contained fossils, all evidence favoring such a conclusion has been obliterated.

In the Algonkian rocks, in the Menominee region, obscure and as it seems doubtful evidence of the presence of footprints of crustaceans, and equally indefinite impressions thought to represent plants, have been obtained.[1] Rocks deposited during the same period of the earth's history in other regions, however, have yielded evidence that an extensive and varied fauna existed previous to the Cambrian period. The oldest record of life as yet discovered in the rocks of Michigan, concerning the true organic nature of which there is no question, have been obtained in the Potsdam sandstone. These records, however, are meager, and consist of fragments of the hard parts of crustaceans (Trilobites), and the shells of mollusk-like animals (Brachiopods), obtained from the brown sandstone at Iron Mountain, referred by Walcott to the Ptychaspis zone.

Fossils are present in the Calciferous rocks near Hermansville, and at certain localities the Trenton limestone is highly fossiliferous.[2]

Topography of the Hard Rock Surface.

So far as the surface features of the Menominee region are concerned, the most important conclusion reached by the several geologists who have made critical studies of the iron-bearing formations during recent years, relate to the preservation to the present day, of the relief of the surface of the Basement Complex and Algonkian terranes, as it existed in pre-Potsdam times. This interesting result came about owing to the deposition of the Potsdam sandstone on the roughened surface of a preexisting land, thus preserving it until it was re-exposed owing to upheaval and the removal by erosion of its protective covering.

"The pre-Cambrian topography," as stated by Bayley,[3] "though in the main similar to that of the present time, nevertheless differed from it in some minor respects. The hills of the earlier period were not so lofty as the ones now existing, but they were sharper and more rugged. Moreover both hills and valleys were cut by deep and narrow gorges, which have been preserved to us by sandstone filling. The Cuff mine,

[1] Gresley, W. S., Transactions of the American Institute of Mining Engineers, Vol. 26, 1872, pp. 527-534.

[2] Geology of the Lake Superior Land District by Foster and Whitney, Part II; also, report of C. Rominger, Geological Survey of Michigan, Vol I. Part III.

[3] Bayley, W. S., U. S. Geological Survey, Monograph V. Vol. XLVI, p. 129.

for example, is situated at the top of an ancient north-facing bluff, for the sandstone, which forms a thin covering over the surface at the shaft, is found again at a considerable depth at the north ends of the mine levels. Prospect Bluff was narrower in these earlier times. The north side sloped steeply and its apex was sharp. A deep gorge crossed Hughitt Bluff on the property of the Pewabic mine. North of the Quinnesec mine, well up on the slope of a high hill, was formerly a deep basin, in which were accumulated boulders of ore and hematite sand worn from shores carved in Huronian [Algonkian] rocks. Finally, drill borings have shown that a deep narrow channel crossed the plain east of the Norway mine."

The uncovering of a long-buried land surface, or a fossil landscape, as it may be termed, is a unique but not unprecedented event in the physiography of the earth.

In the Menominee region, as the evidence seems clearly to prove, the present relief of the surface where rocks of the Basement Complex and of Algonkian age are exposed, together with their numerous igneous intrusions, etc., is essentially the same as when the Cambrian sea advanced over the region and laid down the Potsdam sandstone. How widely this pre-Potsdam land surface is now exposed to view is not safe to state with assurance, but the evidence indicates that throughout much if not all of the western portion of the Northern Peninsula of Michigan, and large portions of adjacent states, where pre-Cambrian rocks form the surface, the pre-Potsdam topography is present. The chief exceptions occur where the relief of the surface is due to the work of glaciers and of the streams flowing from them and where modern streams have excavated channels or spread out sediments.

The hills of quartzite, gneiss, schist, etc., have a systematic relation, in reference to the elevation of their summits, and form points in seemingly regularly sloping plains. Near Loretto the hills referred to rise to an elevation of about 1,000 feet; to the north of Lake Fumée, 1,200, and near Crystal Falls, some thirty or forty miles farther west, are 1,400 to 1,600 feet above sea level. These measures represent the net elevation or the algebraic sum of all up and down movements that have affected the region since the plain referred to was produced, less a small measure of erosion. The hill tops represent approximately the present position of the plain of erosion to which the rocks were reduced previous to the deposition of the Potsdam sandstone.

The surface of the pre-Potsdam land, as stated in the quotation presented above, is not a smooth plain, but moderately rough and diversified by hills and valleys. The roughness seems to indicate that the old land, after being worn down to a plain approximately at sea level, was upraised a few hundred feet and its surface weathered and eroded before the succeeding submergence. Over this irregular surface the Cambrian sea advanced and deposited the Potsdam sandstone. As already stated, the pre-Potsdam land is now in part re-exposed, owing to its having been elevated above its original position and its protecting cover eroded away, but it still retains essentially the form imparted to it previous to the Cambrian period.

The erosion which removed the Potsdam sandstone from the western portion of the Menominee region, probably began after the close of the Paleozoic era, and continued to the present day. A submergence of the region perhaps occurred during the Cretaceous period, but no conclusive evidence in this connection has been obtained.

In the region to the eastward of Waucedah, where the Potsdam sandstone and later formations still remain, the hard-rock surface has a gentle downward inclination towards the southeast, but does not furnish evidence that it was roughened by erosion previous to the Glacial epoch. It is nearly a flat plain and controls the surface topography as efficiently as does the rough surface of the older rocks in the topographic province to the northwest.

The hard-rock surface in the Menominee region on which the glaciers of the Glacial epoch advanced, as already stated, presented two somewhat sharply contrasted portions: 1st, a plain seemingly without eminences, which extended from the border of the Lake Michigan basin westward to about the longitude of Waucedah, and 2nd, the hilly region to the west of Waucedah, consisting principally of rocks of the Basement Complex and the Algonkian system.

As will be shown later, the hard-rock surface was but slightly modified, owing to the abrasion of the glaciers which advanced over it, but as the ice melted, was left with a nearly continuous covering of glacial and glacio-fluvial deposits.

Surface Geology.[1]

While the term "hard-rock geology" and "surface geology" are somewhat indefinite, the differences between the formations referred to are well marked and distinct. The former term includes the rocks which, in general, have become more or less compact on account of pressure, cementation, etc., and are of older date than the Pleistocene division of geological history; and the latter term is used to indicate such superficial material as sand, gravel, clay, glacial till, etc., which, in general, has not been notably compacted since its deposition, and is Pleistocene or younger in age. The contact between Pleistocene and earlier terranes is always an unconformity of fully as much importance as any other similar break in geological history.

The surface sheet of unconsolidated debris in the Menominee region, is composed almost entirely of material deposited by former glaciers, or by the streams flowing from them, and hence the study of the surface geology, deals principally with the history of the Glacial epoch.

Classification of Glacial Records: The more common records made on the surface of the land during the Glacial epoch, may be classified as follows:

[1] The record here presented concerning the surface geology of the Menominee region, is a continuation of an account given of the glaciation of a part of Northern Michigan, published in the Annual Report of the State Geologist of Michigan for 1904, pp. 57–150.

Glacial corrasion.	Smoothed, planed, polished and striated or grooved hard-rock surfaces, which also, at times, bear tapering ridges on the lee side (in reference to ice motion) of hard nodules imbedded in softer material, as well as chatter marks, crescentic cracks, etc. Roughened hard-rock surfaces due to the removal of blocks of rocks by glaciers, i. e., "glacier plucking." Pre-Glacial or hard-rock hills rounded by ice abrasion or steepened and roughened by ice plucking. Glacial erosion of previously deposited till, sometimes produces smooth, oval hills termed drumlins, with equally smooth concave troughs or grooves between them.
Glacial deposition.	Till consisting usually of sandy and stony clay, boulders, moraines of various kinds, and as claimed by certain authors, drumlins similar to those produced by glacial erosion.
Glacio-fluvial corrasion.	Canyons, gorges and valleys excavated by glacial streams.
Glacio-fluvial deposition.	Ridges of sand and gravel termed eskers. Irregular hills and knolls of the same kind of material, known as kames, and sand and gravel plains formed by glacial streams.

Records of Glacial Abrasion.

At many localities in the portion of Michigan represented on the map forming Plate III, the surface of the hard rock is smoothed, striated and bears other records of the fact that glaciers have passed over it. From this and other evidence it has been demonstrated that Michigan in common with approximately the northern half of North America was formerly covered by continental ice sheets of the same nature as the one beneath which Greenland is now buried.

Striæ: The localities at which the direction of ice movements, as recorded by scratches and grooves on rock surfaces, was definitely noted, are tabulated below. The bearings given are compass readings, and no corrections have been applied for the normal variation of the compass (about three degrees east of north), or for local magnetic attraction, which is considerable at certain localities where the rocks of the Basement Complex and the Algonkian system are near the surface.

Measurements of the Direction of Striæ.

(The compass readings as stated, indicate the direction from which the ice came.)

Locality.	Character of Rock.		Bearings of Striae.
Nathan, Menominee county. Two to three miles south of T. 38 W., R. 28 E., sections Nos. 26 and 35.	Limestone.		N. 67° E.
	"		N. 45° E.
	"		N. 60° E.
	"		N. 61° E.
	"		N. 60° E.
	"	(Dominant direction N. 60° E.)	
Spalding, Menominee county, one mile east of Ford river, Delta county.	Limestone.		N. 38° E.
	"	Strong series	N. 17° E.
		Weak earlier series	E. or W.
Hermansville, Menominee county, T. 38 W., R. 27 E., N. E. ¼ of sec. 11.	Limestone		N. 58° E.
Little Quinnesec Falls, Dickinson county.	Schist		N. 80° E.
Loretto, Dickinson county, one mile north of.	Quartzite.		N. 73° E.
	"		N. 88° E.
One half mile south of Metropolitan, Dickinson county.	Diorite.		N. 70° E.
Vita, 2½ miles S. W. of Waucedah, Dickinson county.	Slate.		N. 82° E.
Norway, Dickinson county.	Sandstone.		S. 70° E.
	"		S. 80° E.
Lower Twin Falls, Dickinson county.	Schist.		N. 82° E.
	"		N. 75° E.
	"		N. 85° E.
		(Dominant direction N. 80-85° E.)	
Iron Mountain, at Traders' Mine.	Slate.	(Local attraction.) About	N. 60° E.
Camp 6, 1½ miles north of Mansfield, Iron county.	Quartzite.		N. 80° E.
	Slate.		N. 90° E.

Locality.	Character of Rock.	Bearings of Striae.
Crystal Falls, Iron county, ½ to two miles west of.	Schist.	N. 16–18° E.
	"	N. 20° E.
	"	N. 47° E.
(Two series of striæ, the older and principal series, N. 18° E., the younger, N. 47° E.)		
Amasa, Iron county.	Schist.	N. 62° E.
	"	N. 16° E.
	"	N. 25° E.
Amasa, 1 mile south of.	Schist.	N. 16–25° E.
Amasa, ¼ mile north of.	Schist.	N. 42° E.
	"	N. 47° E.
Balsam, Iron county, 1¼ miles south of.	Schist.	N. 22° E.

The principal direction of ice movement at each of the localities mentioned above, is represented by an arrow on the map forming Plate III. As an inspection of the map will serve to show, the ice advanced from the northeast and as it moved over the land tended to change its direction of flow to an approximately east and west direction. The striæ observed were made by the last or Wisconsin ice sheet of the Glacial epoch, it is presumed, and pertain to the western portion of an ice lobe which had its position determined by the depression now occupied by the waters of Green Bay, as was demonstrated several years since by T. C. Chamberlin.[1]

In generalizing in reference to the direction of ice motion from the striæ left on rock surfaces, allowance should be made for the fact that irregularities of the surface over which the ice passed, influenced its basal currents, as is manifest in the hilly region about Iron Mountain, Crystal Falls, etc., where the striæ on the hill tops frequently differ in direction from those on hill sides and in valleys. It should also be remembered that striæ made during an early ice advance may be preserved, owing to the protection afforded by deposits laid down on the glaciated surface, and be closely associated with similar markings produced during a later ice invasion.

Crescentic Cracks: Concentrically arranged cracks are sometimes abundant on glaciated surfaces, as has been described by T. C. Chamberlin[2] and others, and are among the characteristic records which glaciers leave on melting. The cracks referred to occur most frequently on plane, glaciated surfaces, particularly of brittle rock, and form concentric series from a few inches to a foot or more in length. The individual cracks are from a fraction of an inch to several inches apart, and vary in length up to eight, ten or more inches. At times, one series of cracks overlaps another series, and the surface common to the two

[1] "Terminal moraine of the second Glacial epoch," in third annual report of the U. S. Geological Survey, Washington, 1883, pp. 291-402; see maps forming Plates XXVIII and XXIX.
[2] "The rock-scorings by the great ice invasion," in seventh annual report of the director of the U. S. Geological Survey, Washington, 1888, pp. 221-222.

series, is broken into lozenge-shaped surfaces bounded on each side by a fracture. The depth of the cracks in the larger examples, is sometimes from two to three inches. In the case of a specimen of glaciated quartzite, referred to below, from near Loretto, cracks about two inches in length penetrate the rock to the depth of from half an inch to nearly an inch.

Cracks of the nature just noted are common on the surface of the prominent ridge of white quartzite which passes about one mile north of Loretto, two and one-half miles north of Norway, etc., and trends about northwest. The joint faces present on the surface of the ridge, have, in many instances, been well striated, and are also covered by numerous sets of crescentic cracks. A photograph of a portion of such a surface is reproduced on Plate IVA, and shows several sets of crescentic cracks, as well as parallel striæ. The specimen is a part of a joint-face, which is inclined at an angle of 36 to 37°, and faces east. The ice advanced from the east and ascended the slope. The bearings of the striæ vary but a degree or two from true east. In this and numerous other instances observed on the quartzite ridge referred to, the crescentic cracks are concave towards the direction from which the ice came. The direction of ice motion is shown not only by the striæ, but by knobs and trains, rounded shoulders of ledges that face east, the irregular surfaces and edges of similar ledges facing west, are still other evidences.

In some instances curved cracks similar to those described above, occur in the glaciated surface of the quartzite, which present their convex sides to the direction from which the ice came, but these, so far as observed, do not occur in definite series. The evidence seems to show, as has been explained by Chamberlin, that crescentic cracks may generally be accepted as evidences of the direction of flow of the ice which produced them. Exceptions occur, however, and other similar fractures, but with a different curvature to simulate those under consideration.[1]

Crescentic cracks have not been observed in the Menominee region except on the glaciated surfaces of quartzite. They are abundant also in quartzite in other regions, and occur less commonly and less well-defined, in certain glacial limestones. The conditions leading to their formation appears to be inherent in the nature of the rocks over which glaciers pass, and not determined by local peculiarities of the glaciers themselves. The rocks, so far as known, in which they are best displayed are quartzite and compact fine grained limestone. These rocks break readily on their edges when sharply struck, and may be said to be brittle.

The precise manner in which the passage of a glacier over a rock surface causes it to become fractured in the manner noted above, is not known. The conditions present, however, are, heavy pressure of the moving ice and the presence of stones and boulders in its basal portion, and in contrast with the rock beneath. As the stones and boulders

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[1] In my previous paper (Report of the state board of geological survey of Michigan for 1904, p. 65) I made the statement that certain crescentic cracks near Garden, "present their convex sides to the northwest, the direction from which the ice came." This may be an error of record, or possibly the cracks were made by ice which flowed northwest from the Lake Michigan basin. It is to be borne in mind, however, that two series of glacial records may be made on the same surface, and also that two sets of crescentic cracks, or one set in company with striae made by ice coming from some other direction, might occur together.

are forced along by the ice, the friction on the rock-floor is concentrated where the larger fragments are present. An inspection of glaciated rock-surfaces bearing crescentic cracks and striæ, renders it apparent that stones of various sizes were instrumental in producing the fractures. This is indicated not only by variations in strength, depth, etc., of the striæ, but by the fact that the larger cracks as a rule are less sharply curved than the shorter ones—although the shorter cracks are at times nearly straight—and are more widely spaced, and also, in general, form longer series. Judging from the conditions present beneath glaciers and the nature of the records, it appears that the short crescentic cracks are produced by the forcing along of pebbles or other small rock fragments, while the larger cracks indicate the passage of cobbles or large boulders.

While no satisfactory hypothesis as to the origin of crescentic cracks has been published, I am indebted to G. K. Gilbert for the suggestion that they owe their origin to the production of an elastic wave in the rock over which pebbles and boulders were forced along under heavy pressure. That is, a stone carried forward under such conditions, would tend to compress the rock over which it passed, at its front and to exert a pull on the rock in its rear. The forward compression would tend to cause an elevation of the surface of the nature of a wave, and the pull as the stone advanced, would tend to produce a trough or depression. In either case if the elastic limit of the rock was exceeded, fracture would result. In the case of a nearly spherical boulder, the cracks produced at its front should be convex in the direction the boulder advanced, and those originating in its rear should be concave in the same direction. But as it seems, the tension in the rear of an advancing stone has a greater tendency to produce ruptures than the accompanying wave of compression in its front, and the resulting fractures as observation indicates, are most commonly concave in the direction the ice advanced.

This possible explanation seems to account not only for the characteristic shapes of the cracks under consideration, and the manner in which they occur in well-defined series, but also from the more common occurrence of cracks concave in the direction from which the ice advanced, than of cracks convex in that direction. Another fact to be noted in this connection is, that the crescentic cracks are most frequently from three to about six inches in length, although both longer and shorter ones do occur, and are abundant in certain instances. The greater prevalence, however, of cracks of what may be termed an intermediate size, suggests that there is both an upper and lower limit to the size of stones which, under like conditions of motion, pressure, etc., will cause fractures in the rocks, over which they pass. Above a certain limit in size the stones may be considered as presenting a broad surface of contact, thus distributing the pressure, while small fragments failed to localize enough force to break the rock on which they rested.

In brief, such information as is in hand concerning the mode of origin of crescentic cracks, seems to indicate that they are produced most commonly by the frictional pull in the rear of stones set in the bottoms of glaciers, and forced along under great pressure. The cracks are formed particularly in brittle rocks, as a stone passes, and extend at right angles to its direction of motion, but curve forward from the center of origin.

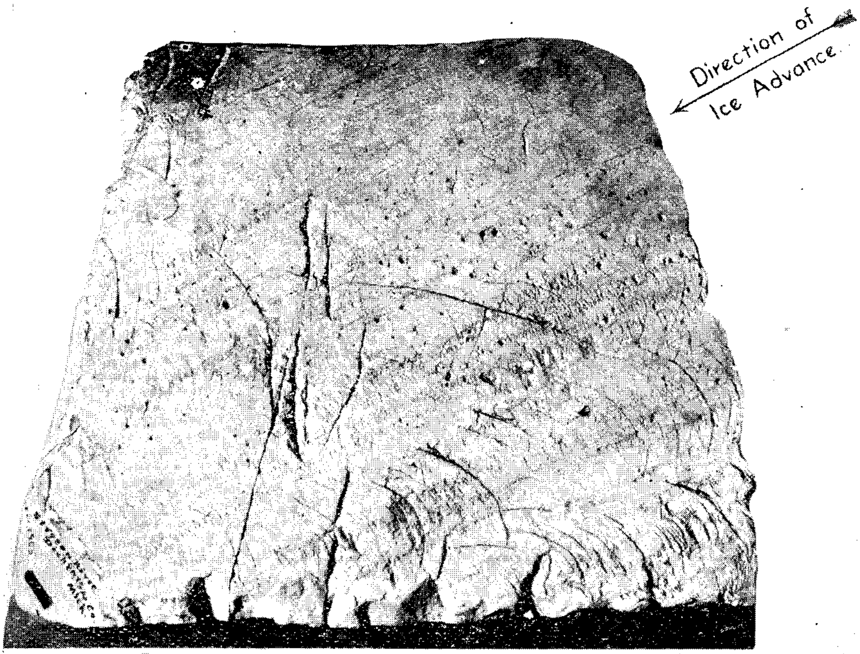
Roughened Rock-surfaces: Smoothed and rounded rock-surfaces occur so frequently in regions formerly occupied by glaciers, that they have come to be recognized as the characteristic products of glacial abrasion. The fact should be recognized, however, that glaciers, under certain conditions, roughen the surface of rocks over which they pass. These opposite results from the action of the same agency, are dependent on the nature of the rock that is subjected to abrasion. The conditions present in rocks which favor the smoothing of their surface and the rounding of elevations, under glacial abrasion, are a high degree of compactness, hardness, massiveness and fineness of grain. The conditions which favor the production of a rough surface, are principally, the presence of fractures, particularly joints, and steep inclination of planes of division such as accompany lamination, schistosity, etc.

The influence of joints in producing rough surfaces under the abrading influences of a glacier, is well shown on the lee side of certain of the quartzite hills to the north of Norway, etc., where glacial plucking has occurred. In some instances, also, blocks bounded by joints were removed by the ice from the stoss or scour sides of the same hills. In this connection, persons visiting the hills referred to, should note that some of the smoothest and best striated surfaces are joint faces, which have been exposed by the plucking away of adjacent blocks, and but slightly affected by glacial abrasion.

Illustrations of the manner in which glaciers sometimes roughen the surface of an outcrop in which the bedding planes are steeply inclined, are furnished at a number of the openings made for mining purposes, between Waucedah and Iron Mountain. In several of these instances the strata are nearly or quite vertical and were crossed by the ice-sheets at a high angle with the strike. Under these conditions, especially when the strata are thinly laminated slates, the rock is crushed and fragments plucked away leaving a rough angular surface. An example of a nearly flat surface, roughened in this manner, is presented on Plate IVB, which shows a portion of the outcrop of the ferruginous slate at the Traders' Mine, near Iron Mountain, from which a layer of till, about 12 feet thick, has been artificially removed. In this and other similar instances, the edges of hard cherty layers are smoothed and striated, while the edges of less rigid, and easily cleaved slate are crushed down in the direction the ice flowed. This crushing of the edges of weak laminated strata, causes them to resemble the edge of a book which has been sharply bent, except that the rock-leaves are frequently cracked and broken.

Changes in Hard-rock Topography: The records made by glaciers, briefly considered above, pertain to the surface features of hard-rocks when studied near at hand, but not as elements of a landscape. In their production, however, certain conspicuous changes in the relief of perhaps extensive areas are sometimes produced. Of the larger records of glacial abrasion only such are here cited as pertain to the Menominee region.

An ice sheet, in moving over a plane or nearly plane rock-surface, as is well known, tends to wear it away, but does not alter in a conspicuous manner its general topographic expression. An ice sheet in advancing



A.—CRESCENTIC CRACKS IN QUARTZITE.

B.—ROCK SURFACE ROUGHENED BY GLACIAL ABRASION.

over a rough rock-surface, however, abrades the sides of the elevations against which it impinges, i. e., the stoss or scoured side, and removes or plucks away loose rock fragments from the opposite or down-current side, i. e., the lee or plucked side.

The portion of Michigan under consideration, as has already been stated, presents two rather sharply contrasted divisions in reference to the topography of the hard-rock surface. East of Waucedah, where nearly horizontal sheets of Paleozoic sedimentary rocks occur, the hard-rock surface is nearly flat, and as seems probable had this characteristic before it was crossed by the ice sheets of the Glacial epoch; but to the west of Waucedah, the highly inclined Algonkian beds, and the schist, etc., of the Basement Complex with its numerous igneous intrusions, form conspicuous hills.

With these general features of the pre-glacial hard-rock surface in mind, a person familiar with the topographic changes produced by glacial erosion, would expect that the plain underlain by nearly horizontal rocks in the eastern portion of the field, would retain its pre-glacial monotony of surface, but that the irregularities in the western portion of the field would have been rubbed down, its eminences to a considerable extent removed, and such hills and bosses of rock as did survive, would present conspicuous contrasts between these stoss and lee sides. These expectations, however, were found on traversing the region to be fulfilled only in part.

The country occupied by nearly horizontal strata to the east of Waucedah, is still a plain, except for the glacial deposits laid down upon it, and the rocks wherever exposed reveal evidences of abrasion. The freshness of the striated surfaces, together with the absence of residual soils, etc., is evidence that a considerable thickness of the pre-glacial hard-rock surface has been removed. But how deeply the moving ice wore away the rocks, there are no means of determining.

In the hilly region to the west of Waucedah, it is evident that the glaciers either produced the present irregularities of the hard-rock surface, or failed to remove pre-existing elevations. As the hills and ridges are composed of resistant rock, and are adjacent to valleys which are underlain by less resistant rocks—that is, the relief is such as is produced by weathering, the action of streams, etc—and also because the elongated hills and ridges do not trend in the direction of former ice movements, but in many instances make a high angle with that direction, it must be concluded that the major features of the present hard-rock surface, were not produced by glacial abrasion, but are an inheritance from pre-glacial conditions. The glaciers passed over a conspicuously rough surface, and under the generally accepted view of the influence of a thick, moving ice-sheet on such a surface, should exhibit conspicuous evidence of ice erosion. One of the most surprising results of my examination, however, is the slight extent to which the relief bears evidence of having been shaped by the abrasive action of glaciers.

Favorable localities for studying the modifications of topography by glacial abrasion, are furnished by a prominent ridge of white quartzite to the north of Loretto. The ice crossed this ridge, as previously stated, with a direction of flow, as recorded by striæ, etc., of N. 73° to 88° E, that is, at an angle of from 35 to 45 degrees with its trend. The abrasion performed by the ice is clearly shown in the rounded and smoothed surfaces of the several hills forming the ridge, as is illustrated by the photograph reproduced on Plate V. In certain instances, also, the hills have smooth slopes facing the northeast, or their stoss sides, and abrupt and angular cliffs facing southwest, or their lee sides, but this relation is reversed in many instances, and a comparison of a large number of hills fails to show that cliffs with angular faces are more common on their southwest sides than when facing in the opposite direction.

An example of a glaciated hill, which appears to present a stoss and a lee side, is furnished by a prominent boss of gneiss, situated about three miles northeast of Norway (T. 40, N., R. 29 W., near the center of Sec. 35). A picture of this hill looking N. 50° W., or nearly at right angles to the direction of former ice motion, is presented on Plate VIA, and shows the rounded contours of the side facing the northeast, i. e., the stoss side, and the precipitous character of the opposite or lee side. The stoss side has been strongly abraded, as is clearly shown by the smoothness of the rock-surface, and by striæ, etc., while the lee side presents steep slopes, on which there is but slight evidence of ice abrasion, but angular ledges, such as might result if the ice, as it flowed over and around the hill, had carried away blocks of stone bounded by joints or otherwise loosened.

While several hills in the Menominee region have shapes more or less similar to the one just referred to with their rounded and their angular sides similarly oriented, there are seemingly as many examples in which the steeper angular sides met the onset of the ice and the rounded sides face the opposite direction. Most commonly, however, there is no conspicuous difference or systematic arrangement, in the slope and character of the hill sides with reference to the direction of ice movement.

In certain instances where a gentle or rounded northeast or east slope does occur, associated with a precipitous escarpment facing in an opposite direction, the controlling conditions do not include glaciation. The bold hill, for example, between Norway and Loretto, has a steep escarpment at its western end, and slopes gently to the eastward. The trend of its longer axis is about N. 70° W. and glacial striæ at its western end bear N. 70° to 80° W. This approach to a coincidence between the trend of the hill and the direction of ice movement, suggests that the major features in the relief were produced by glacial abrasion. But the hill is capped with stratified Paleozoic sandstone and limestone, which have a gentle dip to the eastward, and as the bluff at its west end is formed of the broken edges of these strata, a cliff in about the position of the one that is present would be expected from the action of the normal agencies of erosion if glaciation had not occurred. It is important to note, however, that other hills in the same region, capped with similar stratified beds, as, for example, Iron Hill to the north of Norway, the bold hills near Iron Mountain, etc., in several instances, present their steeper and more rugged slopes to the westward. While there is no doubt but that the passing ice assisted in shaping the hills in question, its influence is not conspicuously shown.

Another test of the degree to which the hard-rock surface has been modified by ice, is furnished by the valley in which Mansfield is located. This valley, now occupied by Michigamme River, is less than half a

GLACIATED SUMMIT OF QUARTZITE RIDGE, VIEWED.
A.—WITH THE BEDDING. B.—ACROSS THE BEDDING.

mile wide, trends north and south, and has bold, well-defined borders of resistant rock, rising to a height of a hundred or more feet above its bottom. The direction of ice motion over the region, as abundantly recorded by striæ, etc., was from east to west. The striæ occur on the tops of the bordering hills, and also well down their sides, nearly to the level of the valley's floor, showing that the depression is not of post-glacial origin. It is safe to say that if the glaciers eroded the Mansfield region vigorously, the hills on the west side which met the onset of the ice, should be rounded, and present other features characteristic of the stoss side of glaciated hills, and that the eastern border of the valley should be abrupt, and furnish evidence of plucking, etc., as is the case of the lee side of rocky knobs which have been shaped by glacial abrasion. A careful inspection of the borders of the valley, however, from various points of view, and in varying degrees of illumination, failed to show that one border is noticeably different than the other, in so far as a possible modification of form by glaciers is concerned.

Not only does Mansfield valley fail to show differences in the way the former glaciers modified its borders, but there is an absence of evidence to show that the ice cut deeply into the rocks. The valley was in existence before the glaciers occupied the region, and is evidently due to stream erosion, for the reason that it is underlain by weak slates and other thin bedded layers in a vertical position, and bordered by much more resistant rocks, that is, occupies such a position as would result from stream adjustment. Then, too, the valley trends at a right angle to the direction of flow of the former glaciers, thus confirming the conclusion that it is not due to ice erosion.

The fact that the valley was in existence before the Glacial epoch, is seemingly not questionable, and the fact that it still exists, shows that the bordering uplands were not planed away by the ice so as to remove the depression that separated them. To what extent the crests of the bordering uplands were lowered by ice abrasion, cannot be determined, but judgment, based on the general relief of the region, and all other considerations that seem to have a bearing on the question, lead to the conclusion that only a very moderate amount, in fact but a few feet, of the surface of the uplands in excess of their weathered portions has been removed.

The absence of evidence of vigorous ice abrasion of the bluffs bordering Mansfield valley, is no less instructive than the fact that the valley was not deeply filled by glacial deposits. There is, it is true, a layer of till, a few feet thick, in its bottom and also many boulders, but no indication that the depression was ever deeply filled with such material. As the evidence reads, the valley was crossed at a right angle by a great ice sheet, but was neither obliterated by ice erosion, or deeply filled with glacially deposited debris. In fact, the pre-glacial topography seems to have undergone but slight modifications on account of abrasion or deposition, during the passage over it of the former ice sheets.

The importance of Mansfield valley as an index of the slight topographic changes an ice sheet may produce, will, perhaps, raise the question: was the depression, excavated by a stream during some interglacial interval, instead of being of truly pre-glacial origin? No positive reply can at present be given to this inquiry, as there is an absence of local evidence to show that more than one ice sheet occupied the immediate region. So far as general considerations point to a conclusion, however, the valley at Mansfield, underlain by weak rocks—like the hills of the entire Menominee region composed of resistant rocks—is to be classed as a pre-glacial topographic form.

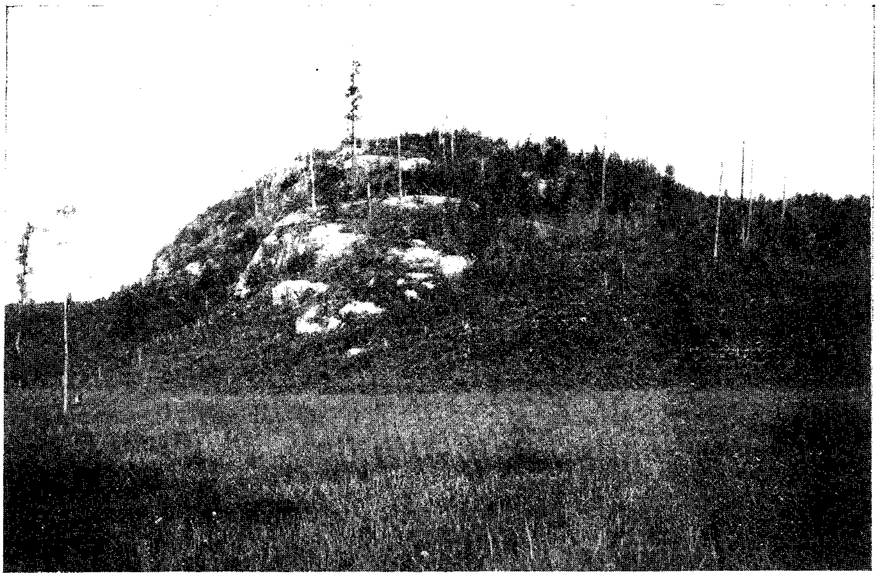
Other evidence in reference to the small extent of glacial abrasion is furnished by the hills in the neighborhood of Mansfield and Crystal Falls. Rising above the surface sheet of loose material, in this region, there are a number of hills, ridges, and isolated bosses of resistant igneous rock,[1] which owe their prominence to differential erosion. The rocks composing them are more resistant, mainly on account of their hardness, than the surrounding rocks, and were left in relief as adjacent areas were lowered by weathering and erosion. The general character of the hard-rock topography is such as is known to result from the work of wind, streams, etc., on a surface composed principally of rocks less resistant than certain other rocks, mostly dikes, which occur in it. Knowing that this rough surface has been crossed by at least one ice sheet, and presumably by several such sheets, it is to be expected, in case glaciers habitually modify in a systematic manner, the hills and bosses of rock over which they pass, that evidence of ice erosion should be declared by the topography of the eminences in question.

An examination of the hills and ridges about Mansfield and Crystal Falls, however, failed to show that they systematically or generally present gentle or rounded slopes in one direction, and precipitous or angular surfaces in an opposite direction, as is characteristic of glacial erosion in certain other regions. If a dozen or more hills are examined, it will be found that their steepest slopes face various points of the compass, and characteristically rounded slopes, such as give expression to the stoss sides of well-glaciated eminences, are absent. This generalization was found to be true in reference to the several isolated hills which rise through the extensive sand plains to the southeast of Crystal Falls, and in the case of ridges which trend approximately in the same direction as the flow of the former ice sheet, as shown by a prominent outcrop of dolerite, 3½ miles north of Crystal Falls, as well as by ridges which are aligned in a north and south direction or athwart the bearing of the glacial striæ on their sides and crests as in the case of the ridges of diorite at Mansfield. Not only do the shapes of the ridges fail to reveal recognizable evidence of glacial abrasion, but the same is true of the subordinate elevation of which they are composed.

Briefly summarizing the conclusions just presented, it appears that throughout the Menominee region there is lack of evidence to show that glaciers have produced conspicuous changes in the relief or altered in a characteristic manner the profiles of the pre-glacial hills and ridges.

The evidence is such as to warrant the conclusion that glaciers passed over the land without deeply abrading it, unless the energy of the moving ice was to a great degree expended in removing Paleozoic formations which rested unconformably on the rough surface of the Basement Complex and Algonkian systems and their associated in-

[1] The isolated areas referred to, consist of altered diabase, gabbro, granite, etc., and are represented on the geological map accompanying Monograph No. XXXVI of the U. S. Geological Survey.



A.—GLACIATED HILL SHOWING STOSS AND LEE SIDES.

B.—CHARACTERISTIC SECTION OF TILL.

trusive terranes. As has already been stated, outlying detached areas of Potsdam sandstone occur to the west of the western margin of the region bordering Green Bay, where the Potsdam and later Paleozoic terranes occupy the entire surface beneath the glacial drift. Possibly when the glaciers advanced over the country the Potsdam and later formations, extended in a continuous sheet much farther west than at present, and much of the energy of the moving ice was expended in removing this covering from the irregular surface of the older formations present beneath it. This hypothesis seems worth considering, for the reason that the deposit left by the glaciers is to a large extent sandy, and to the east of Fortune Lake, almost wholly of a red color, thus suggesting that it was derived largely from the erosion of the red Potsdam sandstone. In the eastern half of Northern Michigan there is no formation except the Potsdam which could have yielded notable quantities of red, sandy débris, but to the west of the region referred to, in addition to the Potsdam, there are several terranes, notably the Keweenawan formation, which would furnish similar material if mechanically eroded. In Canada, also, to the east of Lake Superior, the formations now forming the hard-rock surface would, in several instances, supply red, sandy débris if abraded. The basin of Lake Superior is seemingly underlain by the Potsdam and Keweenawan formations, and from this source the glaciers must certainly have derived red, sandy débris. With so many and such widely extended sources of supply for red, sandy débris, for glacial transportation, it cannot be said that in the Menominee region the abundance of such débris implies a former wider extent within its limits of the Potsdam formation.

The line of evidence just suggested, however, does not demonstrate that the Potsdam was not far more extensive at the beginning of the Glacial epoch than at present. In reference to this question some basis for reaching a decision is furnished by the topography of the isolated areas of Potsdam sandstone about Norway, Iron Mountain, Metropolitan, etc. At these localities the Potsdam sandstone forms prominent hills of such a character that they can be most reasonably accounted for on the hypothesis that, in the main, they were spared by stream erosion which excavated the valley between them, and are not remnants of a much more widely extended sheet of rock, the greater part of which had been removed by ice erosion. This conclusion seems valid, since, as is well known, stream erosion tends to roughen a region at least up to a certain stage in the process of subaërial denudation, while an ice sheet moving over a region of mild relief tends to plane away its surface and reduce the irregularities.

So far as the evidence now in hand points to any conclusion in reference to the origin of the hills capped with Potsdam sandstone, it favors the view that they were in existence and had essentially their present forms, except for the blanket of till, which covers them, previous to the Glacial epoch. This conclusion carries with it the additional inference that the ice sheet which passed over the Menominee region did but little in the way of abrading its surface.

In order to make the above interpretation of the evidence more apparent, attention is again directed to the statement that if the Potsdam sandstone was not widely extended as a continuous sheet to the west of its present margin, so as to shield the uncomformable rock-surface beneath, the ice, in passing over the region, not only failed to remove the capping of sandstone present on the hills in its path, but also failed to wear away the general surface so as to obliterate depressions like Mansfield valley, which were sunken below the general level of the country. The ice also failed, as has been explained, to impart characteristic topographic forms to the isolated hills and ridges which stood in its path.

Additional considerations in reference to the slight degree to which ice has abraded the Menominee region, is furnished at Iron River. Beneath thick accumulations of gray drift, in an artificial exposure at the iron mines south of the town, the surface of the iron-bearing formation is broken and weathered and does not present evidence of ice abrasion. Between the drift and the underlying iron-bearing formations, a bed of stratified gravel intervenes between the till and the subjacent slate and chert, showing that the ice passed over the country without removing loose stream deposits, previously laid down. The manner in which glaciers can over-ride loose deposits depends[1] on the fact that their basal portions become charged with débris, thus lessening the plasticity of the ice and enabling it to remain stationary while the clearer ice above passes on.

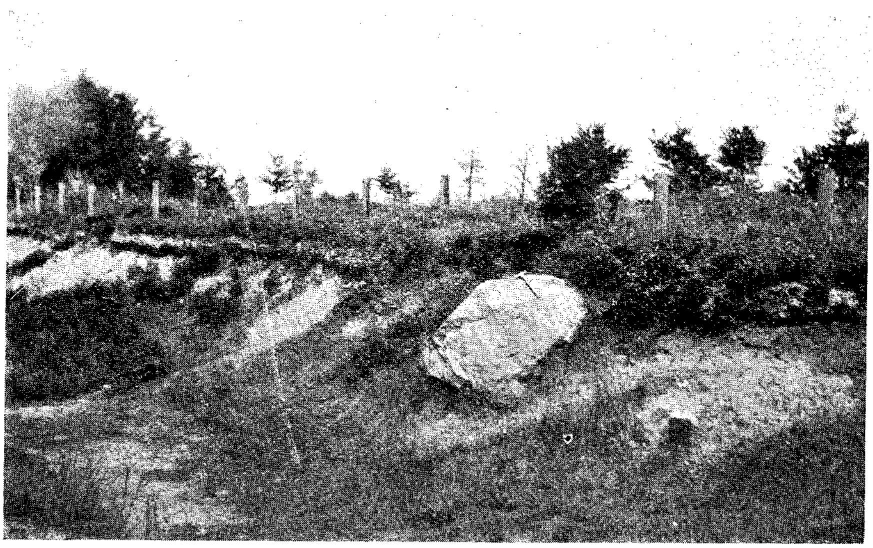
The facts bearing on the question of the amount of the glacial erosion in the Menominee region, has been presented somewhat at length, for the reason that geologists are divided in their opinions as to the efficiency of glaciers to deeply abrade the solid rock. While the evidence cited above is inconclusive, it favors the view that deep glacial abrasion did not occur. This is not equivalent, however, to saying that glaciers in general or under exceptional conditions do not vigorously erode the rock surfaces over which they pass. A glacier, like a river, may erode in one part of its course and deposit material at some other locality, and to fully consider the work that it does, all portions of its bed should be studied. The Menominee region includes but a small fraction of the total area covered by the ice sheet which crossed it, and as will be shown later, received a coating of glacially deposited débris, thus showing that during a part of the time the ice covered the country, deposition and not erosion was in progress. These considerations suggest that, in order to find evidence of maximum erosion performed by the former continental glacier of this continent, search should be made near the sources of the ice sheets.

Glacial Deposits.

The principal subdivision of glacial deposits are *till-sheets, drumlins* and *moraines.* This classification relates to topographic forms, as well as mode of origin. The members of each class are composed of *till.* By this Scottish term is meant the usually firm, tough, sandy clay, deposited by glaciers, which frequently contain large stones or boulders. Great variations in composition occur, however, ranging from nearly pure sand containing few if any stones, to nearly pure clay, perhaps highly charged with rock fragments. Its most characteristic features are absence of stratification, although one till sheet sometimes rests

[1] Russell, Israel C., "The influence of debris on the flow of glaciers," in the Journal of Geology, Vol. 3, 1895, pp. 823-832.

A.—PERCHED BOULDER OF GNEISS RESTING ON QUARTZITE.



B.—BOULDERS IN A SAND AND GRAVEL PLAIN.

on another of different character, and the presence of many kinds of rock fragments which are usually angular or but imperfectly rounded, although frequently battered and striated, and of various sizes up to several feet in diameter. These features, so far as they pertain to heterogeneity in size, absence of bedding, etc., are shown by the photographs of characteristic exposures reproduced on Plates VI, IX and X. The deposits may be of any color, dependent principally on the color of the rocks from which the débris was derived, but are usually bluish, changing to yellowish in their superficial and more or less weathered portions. Throughout large portions of Northern Michigan, however, the till is red, but to the west of Crystal Falls, gray till occurs over large areas. The superficial, weathered portion of the red till is frequently nearly white, on account of the removal of the iron oxide it contained through the solvent action of surface water charged with organic acids.

As stated above, two leading varieties of till are present in the Menominee region, i. e., red till and gray till. These subdivisions are of interest, not only because they indicate the direction in which two different lobes of the former ice sheets advanced over the land, but for the reason that they differ in agricultural value. The red till, as indicated on Plate III, extends from near the shore of Green Bay westward to the vicinity of Chicagon and Trout lakes, and is then limited by a line not as yet well determined, which divides it from the gray till forming the surface of the region about Iron River.

The red till, as implied in its name, is almost invariably reddish or pink in color. It is conspicuously sandy, and, in general, highly charged with stones of all sizes, up to some four or more feet in diameter. When the underlying rock is limestone, as in the region to the east of Waucedah and Foster City, the stones of such size as to be recognized by the unaided eye, are largely of the same character as the rock in the vicinity, but the larger are more massive boulders and consist principally of crystalline rock, of the same general nature as the rocks known to occur in places in Canada, and in the western portion of the Northern Peninsula of Michigan. On crossing the region occupied by red till, from east to west, and passing from the area where limestone is the country rock, to the area where the slate, quartzite, jaspilites, etc., of the Algonkian system, or the gneisses, schists, etc., of the Basement Complex, form the country rock, there is an abrupt change in the composition of the till, the principal feature of which is the disappearance of limestone fragments. The Algonkian terranes contain beds of dolomite, however, and fragments of this material occur sparingly in the till to the west of Waucedah, Foster City, etc., but should not be mistaken for fragments of the Calciferous or the Trenton limestone.

Not only is there a conspicuous difference in reference to the presence or absence of limestone fragments, as just stated, in the eastern and western portions of the Menominee region, but the few chemical analyses of soils that were available, indicate that the finer material of the till, below the influence of weathering, exhibits a similar contrast.

The relation of the till to the underlying or neighboring hard rocks just cited, is not peculiar to the Menominee region, but as is well known, pertains to similar deposits elsewhere. That is, a large percentage of till present in any region is usually of local origin and has been removed but a few rods or a few miles from the localities where the glaciers found it.

The fact that the till to the west of the west border of the Paleozoic limestones is without fragments of those formations, while to the east of that boundary boulders of iron ore, native copper and crystalline rocks, similar to the rocks outcropping in the northwestern portion of Northern Michigan, are present, suggests, as will be discussed more fully on a later page, that the glaciers which deposited the red till, moved from the northwest towards the southeast. At a later stage, during the Glacial epoch, as seems evident, an advance of ice from the northeast occurred in the same region.

The gray till, as the term implies, is of a gray color, and in this respect is conspicuously different from the red till, and must have been derived from a different source. In other respects, however, as in heterogeneity, presence of large boulders, etc., it has the features common to till deposits in general. As indicated on the map forming Plate III, the gray till occurs to the west of the region occupied by red till, and, as seems evident from the incomplete examination that has been made, was deposited by a lobe of the last or Wisconsin ice sheet, which extended southwest from the Lake Superior basin and invaded Chippewa valley, Wisconsin, after which it has been named.

Till-Sheets: Throughout the Menominee region where red till occurs, it forms a nearly uniform covering on the hard-rocks, but in certain localities, some of them many square miles in area, is itself concealed beneath later glacio-fluvial, lacustral and swamp deposits or accumulations. At certain localities, also, the till forms comparatively thick deposits, known as moraines and drumlins. Its most characteristic feature, however, is its nearly uniform distribution as a superficial sheet in general from fifteen to thirty feet thick, which extends over hills and forms the floors of valleys and depressions. It is literally a surface blanket of débris, beneath which the hard rocks are concealed. The great extent of the regions where the till has been spread out or a nearly uniform sheet, in comparison with the size of the areas in which it was bunched in moraines, or left as drumlins, is indicated on the map forming Plate III.

Characteristic exposures of till occur at many localities along the rail and wagon roads of the Menominee region, and in the numerous excavations made in searching for iron ore in the vicinity of Waucedah, Iron Mountain, Metropolitan, Crystal Falls, Amasa, Iron River, etc.

Drumlins: The leading characteristics of the smooth, oval hills composed of till and known as drumlins, were described in my previous report,[1] and a number of facts concerning those in Menominee County presented.

An attempt has been made to represent the distribution of the drumlins of the Menominee area on the map forming Plate III, but the result is far from satisfactory. One of the most notable facts brought out on the map, is the symmetrical change in the direction of the longer axes of the drumlins, indicating that there were currents in the glaciers to which they owe their origin.

But little remains to be added to the description previously given in

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[1] Report of the State Board of Geological Survey of Michigan for 1904, pp. 69-76.

reference to the absence of cores or nuclei of rock beneath the drumlins, or concerning the shapes of the hills, their uniformity in elevation over large areas, the characteristic smoothness of their surfaces, relation to striæ on neighboring outcrops of solid rock, composition, absence of lamination, etc.

In my previous report attention was directed to the presence of boulders of iron ore and of native copper in certain drumlins near Nadeau, etc., which seems to indicate that the glacier which transported the material of which they are composed, moved from the northwest toward the southeast. To this evidence may now be added the finding of native silver in association with native copper, in till of the same character as that composing the drumlins, at a locality on the border of Menominee River, about five miles south of Koss. This occurrence strengthens the deduction previously stated in reference to the direction in which the till was transported, but cannot be considered as conclusive, since both copper and silver are present on Michipicoten Island in the eastern portion of Lake Superior, and iron-bearing formations occur on the adjacent mainland.

The drumlins in the Menominee region are too numerous to be described in detail, but a representative group has been carefully surveyed, which exhibits their normal characteristics and one exceptional feature. The group selected for detailed description is situated about one mile west of Hermansville, and is represented on the contour map made by W. C. Gordon, which forms Plate VIII. A photograph of a model made from the map forms Plate IXA. These illustrations represent the drumlins in question with a high degree of accuracy, and need but little supplementary description.

The drumlins rest on the nearly level surface of the Hermansville limestone, as named by Bayley and Van Hise, a part of the Calciferous system, which is exposed in their vicinity, as indicated on Plate VIII. They are composed of reddish, sandy till, and contain many boulders of crystalline rock, as well as fragments of Potsdam sandstone and Hermansville limestone. The general appearance of sections of these and associated drumlins is shown in Plates IXB and X.

The main group of drumlins, as shown in the illustrations, consists of four members, those adjacent to each other being separated by concave troughs or grooves. Similar grooves are present between the drumlins in all instances in the Menominee region where they occur in groups, and are as characteristic of such groups, and seemingly as suggestive as to mode of origin as are the smooth-surfaced hills they separate.

The exceptional features presented by the group of drumlins under consideration, is the steepness and straightness of the west side of the hill farthest to the west. As shown on the map, and also by the profiles accompanying it, the hill referred to is essentially half a drumlin, cut parallel to its longer axis, and the western half removed. On the surface, which the drumlin would occupy if complete, the country rock is either exposed to view or but thinly covered with till. At one of the exposures glacial striæ are present, and parallel with the longer axis of the drumlin. The direction of glacial motion was from the northeast towards the southwest. The drumlins have been cleared and furnish excellent farming land. The stones and boulders formerly strewn sparingly over their surfaces have been removed, and the hills and the equally characteristic concave trough between them, are conspicuously smooth and even, and reveal in an admirable manner the gracefully curving contours so characteristic of drumlin topography.

There are two hypotheses entertained by geologists in reference to the mode of origin of drumlins. The generally accepted explanation is that they are due to the deposition of débris beneath glaciers, in a manner analogous to the formation of sand and gravel bars in streams; but a few geologists, following the lead of N. S. Shaler, consider that certain examples at least were given their characteristic forms by ice-erosion of previously deposited accumulations of till. The former of these hypotheses is based on the normal form that drumlins present, while the latter derives its main support from their irregularities and from the nature of the trough which so frequently separates them when they occur in groups. The evidence furnished by the drumlins of the Menominee region, in my opinion, as stated in my previous report, favors the ice-erosion hypothesis, and seem to show that a till sheet about fifty feet in thickness, was eroded by ice which advanced over it from the northeast and excavated troughs, leaving smooth, oval hills between them. In several instances, after well-shaped "drumlin troughs" and "drumlin hills" had been produced by ice-erosion, a continuation of the process removed portions of the previously well-modeled surface; that is, portions of drumlins and of the trough separating them, were eroded, leaving other portions of the previously normal forms undisturbed. In support of this conclusion, several abnormal examples were described in my previous report, and notably a drumlin about one mile northwest of Spalding, which has a well-defined groove about its northeast end, and extending along its sides.

To the irregularities previously described, is now added the half-drumlin represented on Plates VIII and IXA, which seems to have been spared by ice-erosion which removed a large portion of the westward side of a previously complete example, and left an abnormally steep and obscurely horizontally-grooved or fluted surface on the eroded border of the part remaining.

It should be noted, in connection with the explanation just suggested, that adjacent on the west, to the southwest end of the half-drumlin represented in the illustration just referred to, a group of complete drumlins is present. It is difficult to understand, however, the nature of the process by which a half of one drumlin could have been eroded away, leaving intact the adjacent hill which is nearly in line with the part assumed to have been removed. Possibly future studies of drumlins will show that both ice-erosion and ice-deposition was concerned in shaping of drumlin topography. Under this composite hypothesis, the complete drumlins at the southwest end of the incompleted examples near Hermansville, may be considered to have been formed by the deposition of débris at the same time, or subsequent to the removal of a part of its incomplete companion. The mode of origin of drumlins is still a subject of discussion among students of glacial phenomena, and the Menominee region furnishes an admirable field for the continuation of the investigation.

In certain instances, as stated in my previous report, drumlins have portions of their bordering troughs still attached to them, although the companion drumlin, on the opposite border of the trough, has been removed. The portions of drumlin troughs referred to, left attached to drumlins, appear as terrace-like shoulders on their sides. The terraces, however, have approximately the same convex longitudinal profiles as the drumlins with which they are associated, and resemble the grooves or flutings frequently to be seen on the border of glaciated valleys and the sides of glaciated hills, but in well-preserved examples, present concave cross profiles of the same character as drumlin troughs.

A good example of a drumlin with a broad terrace on its side is present about half a mile southeast of the area shown on the illustration just referred to. The drumlin is traversed by means of a cut, by the Minneapolis, Saint Paul and Sault Ste. Marie Railroad. A portion of the north border of the cut is shown on Plate IXB. A sketch profile of this drumlin and its attached terrace, as seen in the north side of the railroad cut, is here reproduced with the addition of a dotted line

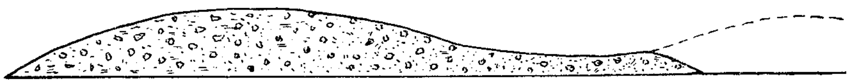


FIG. 1. Cross-profile of a drumlin and remnant of a drumlin-trough, near Hermansville, Mich.

to indicate the position of a companion drumlin which, as is presumed, has been removed by ice-erosion.

Many other examples occur in the Menominee region, to show that a number of the incomplete drumlins now present may reasonably be considered as remnants spared by ice-erosion, of formerly complete drumlins or of groups of drumlins. The series contains incomplete isolated drumlins, and similarly detached examples with portions of drumlin troughs connected with them, as well as groups of hills separated by troughs, like the one shown on Plates VIII and IXA, in which a portion of a former hill remains. Groups of drumlins, as thus indicated, are, as it seems, but remnants of formerly more extensive assemblages.

Perhaps the most suggestive conclusion furnished by the study of the Menominee drumlin area, is that drumlin troughs, as designated above, are fully as characteristic of drumlin topography as are the hills they separate. In certain instances, the troughs are conspicuous, while the intervening hills lack the symmetry of true drumlins. These criteria pertaining to ice-erosion, as indicated also by tests made in other regions, as, for, example, about Ann Arbor, Mich., seem to furnish a means for determining the mode of origin of certain grooves and valleys in till-covered regions which cannot be accounted for as products of stream-erosion, or as resulting from glacial deposition.

Moraines: The term *moraine,* as used in this report, refers to the irregular accumulations of till deposited by glaciers about their margins. No distinction will be introduced between "dump moraines" and "shovel moraines," as each of these varieties is marginal in reference to the glaciers to which they pertain. An intimate association frequently occurs between marginal moraines and the heaps and piles of sand and gravel formed by glacial streams, and known as kames, but such deposits will be considered later.

Moraines are distinguished from till-sheets by the fact that the former are more or less local accumulations, conspicuously irregular both in thickness and in relief, and in many instances effectively conceal all but the larger elements of relief of the surface on which they rest; while the latter are characteristically of broad extent, and moderately uniform in thickness, and without conspicuous variations in relief, and do not materially modify the topographic control exerted by the underlying surface. Moraines frequently occur at the margin of a till-sheet most remote from the center of dispersion of the glacier that formed it, or its outer margin, but moraines and till-sheets frequently merged one with the other without a well-defined line of junction. Moraines are understood to record halts in the recession of glaciers during which the onward flow of the ice was counterbalanced by melting, and the débris carried by the glacier was concentrated; while till-sheets indicate a continuous recession, the débris the ice contained, or carried on its surface, being left without local concentration in a more or less even blanket-like deposit on the surface of the land vacated.

A series of concentric moraines record successive halts of a glacier during its retreat, and from such a series the successive positions of the ice margin and changes in its alignment may be determined. Associated with moraines there are frequently deposits of sand and gravel concentrated by streams flowing away from the glacier which produced it, and known as outwash aprons, valley trains, etc. Such deposits are formed on the side or margin of a moraine opposite to the one adjacent to the parent glacier and furnish one of the criteria for determining in which direction former glaciers flowed. Assistance in this connection may also be had from the fact that the inner border of a moraine, i. e., the border formerly margined by ice, is usually bolder and steeper than the outer border.

The trend of moraines of the nature of those occurring in Michigan, is at a right angle, or nearly so, to the direction of movement of the glacier which produced them. This deduction may, in many instances, be clearly demonstrated by noting the trend of striæ on rock surfaces in the vicinity of the moraines. The ice sheet, however, which formerly covered the northeastern portion of North America, formed lobes at its margins with embayments between the lobes, and at such localities *interlobate moraines* were deposited. Such moraines, while trending at a right angle to the direction of ice movement immediately adjacent, for the reason that the ice of each lobe tended to expand fan-like from its central axis, in some instances are nearly parallel to the general direction of the advance or retreat of the ice.

Two Glacial Lobes.

As already stated, there are two sharply contrasted varieties of glacial deposits in the Menominee region, namely, red till and gray till. These two tills may evidently be correlated with two great lobes of the border of the last or Wisconsin ice-sheet which occupied Wisconsin, Michigan, etc., and described by Chamberlin,[1] as the Green Bay lobe, the position of which is indicated by the red till, and the Chippewa lobe which deposited

[1] Chamberlin, T. C. Terminal moraines of the second Glacial epoch, U. S. Geological Survey, 3d annual report, Washington, 1883, pp. 291-402.

massive moraines of gray till at least in the western portion of the region discussed in this report.

The Green Bay lobe occupied the basin of Green Bay, and extended southwest to the vicinity of Madison, Wis., but expanded westward. The Chippewa lobe was initiated in a similar manner by Keweenaw Bay, on the southern border of the Lake Superior basin, and expanded over the region to the south now occupied by the western portion of the Northern Peninsula of Michigan and the adjacent portion of Wisconsin. These two lobes met at the margins in the vicinity of Chicagon Lake, in Iron County, Michigan, and formed an important interlobate moraine. As the Glacial epoch drew to a close and the Wisconsin ice-sheet melted, the Green Bay lobe was contracted in width, owing to the melting especially of its western border which extended westward across the Menominee region, while the Chippewa lobe receded northwestward and northward.

Moraines of the Green Bay Lobe: At various localities during the shrinkage of the Green Bay lobe, halts occurred, during which more or less definite moraines were deposited. Between the moraines which record a lingering of the ice margins for a time at certain localities, a till sheet was spread over the country, and to the west of the various moraines in several instances outwash aprons were laid down by glacial streams, on the surface of the previously deposited till. The moraines, however, are seldom massive or well-defined and for this reason and also in part because they are to a great extent concealed by forests through which there are but few roads, their position and outlines have not as yet been well determined.

To the west of Crystal Falls and Mastodon, or more definitely about Bush and Fortune lakes, and to the east of Chicagon Lake, the red till effectively conceals the underlying rocks, and has the irregularities of surface characteristic of moraines. Although this region has not been examined in detail, enough is known concerning it to indicate that its covering of till is a part of the most westerly deposits made by the Green Bay lobe, and is of the nature of an interlobate moraine. Adjacent on the east, to this deeply moraine covered region, as at Crystal Falls, Mastodon Mine, etc., the till covering barely conceals the underlying rock, and, as it seems, can with greatest propriety be termed a till sheet.

Eastward from Crystal Falls and Mastodon Mine to beyond the valley of Michigamme River, the valleys are in the main occupied by sand and gravel, but the uplands are veneered with till. Adjacent to Michigamme River in the east, the uplands are composed of red till, which has an irregular surface and contains many boulders, thus indicating that it is of the nature of a broad moraine, which is several miles broad and trends about north and south. This tract of hilly country extends to Menominee River, and separates sand and gravel plains on its west border from similar plains at a lower level on its eastern border. The sand and gravel plains to the west may be interpreted as being in part due to the outwash of débris from the retreating glaciers, but supplied principally by the streams which flowed towards the ice front and were partially dammed and turned aside by it; while the sand and gravel plains to the east, have a similar history, but were formed late at a time when the ice front had withdrawn still farther eastward.

In recording observations concerning the moraines referred to above, and other similar deposits farther eastward, I wish to avoid giving the impression that the ridges and hills the glaciers left, are in all or even in many instances strongly defined. There is an indefiniteness in the records, and obscurity due to the density of vegetation, which makes the mapping of the boundaries of the moraines exceedingly difficult. Coupled with the indefiniteness of the moraines, is the fact that they merge with the nearly universal till-sheet, and in many instances it is impracticable to decide whether a given deposit is a somewhat thickened till-sheet, or a true marginal moraine.

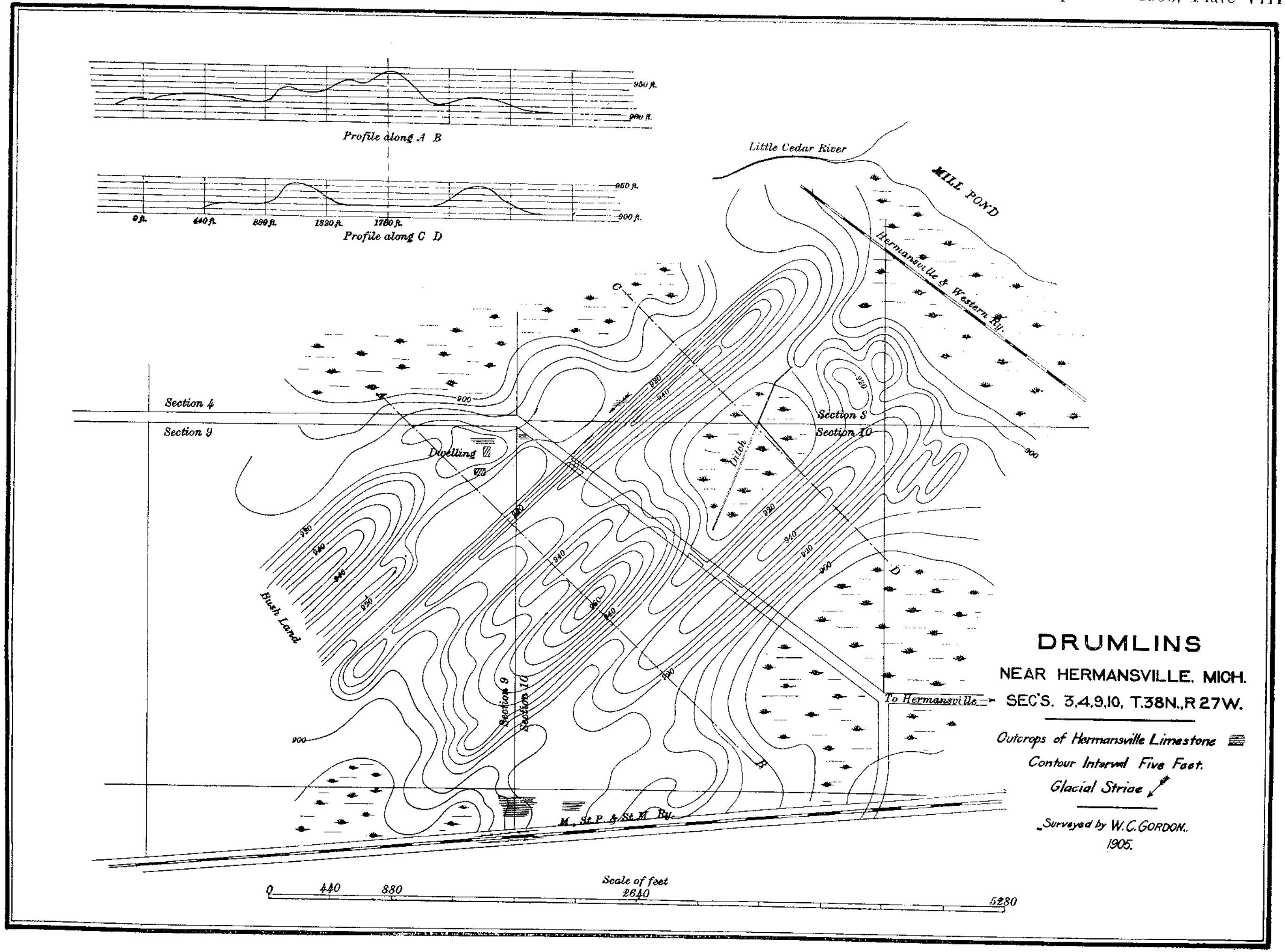
Another feature of the deposits in question, and one which will perhaps be found to be characteristic of other glaciated regions, is the presence of hilly tracts with morainal topography, which are not clearly portions of marginal moraines, and not systematically arranged with reference to the direction of ice retreat. These local thickenings of the general till-sheet, due as it seems to the addition of boulders and other débris to the surface, are considered provisionally, as owing their origin to local accumulations of morainal material on the surface of the former ice-sheet, on account of its having been concentrated in depressions in the ice, and lowered upon the sub-glacial till as melting occurred. Examples of the local moraines referred to, occur in the rough region of crystalline rock, between Norway and Metropolitan, in the hills east of Runkles Lake, etc., and are deemed worthy of more attention than has as yet been devoted to them.

When the last ice-sheet withdrew eastward from the country between Iron Mountain and Waucedah, where bold hills and ridges of hard rock trend about east and west, and coincide with the direction of ice recession, the margin of the glacier had decreased in thickness so that it occupied the valleys after the hills were exposed. The records on which this inference is based, are small moraines trending north and south athwart the valleys, but failing to cover the intervening hills.

Valley moraines of the nature referred to, are present near Iron Mountain, where they occupy an area of about a square mile to the west of Silver Lake, and again on the west side of Lake Antoine. Similar moraines occur about Lake Fumee, which, like its companion, Lake Antoine, owes its existence to a morainal dam, in the bottom of a valley which trends east and west.

A good example of a valley moraine is present about a mile southeast of Iron Mountain, and extending from the base of a prominent hill on the north, to Menominee River at Big Quinnesec Falls, on the south. It has an irregular knob-and-basin topography, with elevations rising about a hundred feet above its visible base, and separates a sand and gravel plain on its western side from a similar plain about one hundred feet lower, on its eastern side. To the west of the moraine and merging with it are kame hills, and the lake is also bordered in part by the irregular and much-pitted margin of the higher of the two adjacent sand and gravel plains.

Eastward from the region about Iron Mountain, small moraines occur, for the most part directly assimilated with the range of hills intervening between Iron Mountain and Norway, as at Quinnesec, and again midway between Quinnesec and Norway, and crossed by the highway connecting the two towns. These are local deposits, and indicate



MAP OF DRUMLINS NEAR HERMANSVILLE.

that the retreating glacier did not halt at the localities where they occur, for a sufficient length of time to permit of the formation of a moraine completely across the valley in which they occur.

When the ice had withdrawn eastward so that the terminus of the portion occupying the valleys of Menominee River and of Pine Creek, respectively, was situated near the present site of Vulcan, a halt again occurred and two moraines were formed, one in each of the valleys mentioned. One of the moraines is situated about a mile south of Vulcan, and the other a mile and a half northeast of it. Each moraine trends about north and south and the two are approximately in line, but separated by the bold till-veneered elevations designated as Brier Hill on the Menominee Special Map, issued by the U. S. Geological Survey. The moraines are small, being less than a mile in length in each instance. The southern one is conspicuously irregular, and culminates in a conical hill which rises about eighty feet above the adjacent Sturgeon River plain, at its eastern base; and the other is from 20 to 30 feet higher than the surface of the irregular country about it. In each case the deposits consist principally of sand, but contain irregular stones and a few large boulders. Their topography is conspicuously irregular and comprises prominent knobs and undrained basins. The moraines are transverse to the valley in which they are respectively located, but do not at present completely dam them. The one at the north has been cut through at its southern end by Pine Creek, and the one to the south terminates at its southern end at the margin of Menominee River. To the west of each moraine there is an out-wash apron forming a sand and gravel plain, showing that at the time they were formed, the glacier which they margined completely closed the valleys in which they are located. To the east of the northern moraine, there is a bouldery till-plain, but at the eastern base of the south moraine, glacial silt deposits conceal the underlying till. The moraines do not cross the intervening portion of Brier Hill, thus indicating that at the time they were formed, ice occupied the valley, leaving exposed the hills it margined and partially surrounded.

The halt in the eastward retreat of the ice from the Menominee region recorded by the two small moraines just described, was seemingly brief, but the records it left are well defined. The next halt as the ice continued to retreat eastward, occurred when its margin was located approximately along what is now the west border of Menominee County, and extended northward, curving to the northeast, past Waucedah. This rather broad but indefinitely defined morainal belt is indicated in a very general way on the map forming Plate III.

The moraine is represented, in the western portion of Menominee County adjacent to the river of the same name, by low hills of reddish, bouldery till, which begin at the south, about four miles from the river's mouth, and extend in an irregular belt from one to some two or three miles wide, northward into Dickinson County. These same topographic features are continued southward into Wisconsin, but as to the course the moraine takes after crossing the Menominee, I have no information.

The range of hills in question is, as a whole, but poorly defined, although at certain localities its morainic character is well pronounced, and its course, as indicated on the accompanying map, is much generalized. From its first appearance at the south, on the east bank of

Menominee River, northward to Koss, the irregular hills marking its course, reveal morainal topography, but no outwash apron on their western side has been recognized. At Koss, and extending north to Kells, morainal hills merging on to the west with hills and ridges of gravel and sand, furnish a record of a halting of the former glacier. To the west of this belt lies a swampy plain, in part composed of till, and in part of sand and gravel which appears to be of the nature of a glacial outwash. Still farther north, there are still other irregular hills composed of bouldery till, as for example about Pemene Falls, and Nathan, and thence northward past Faithorn Junction to Summit. A probable continuation of this morainic belt has been traced by Frank Leverett, northeastward from its northern portion, as represented on Plate III, a few miles into Marquette County, to where it becomes associated with a moraine with northwestward trend. To the east of the morainic belt just described, lies the till plain of the central portion of Menominee County, on which are numerous drumlins, many eskers, and small kames, but no definite evidence of the presence of moraines is known. The next halt of the retreating ice margin appears to be rendered by indefinite drift hills in Delta County to the west of Escanaba, but concerning this inference the information in hand is indefinite.

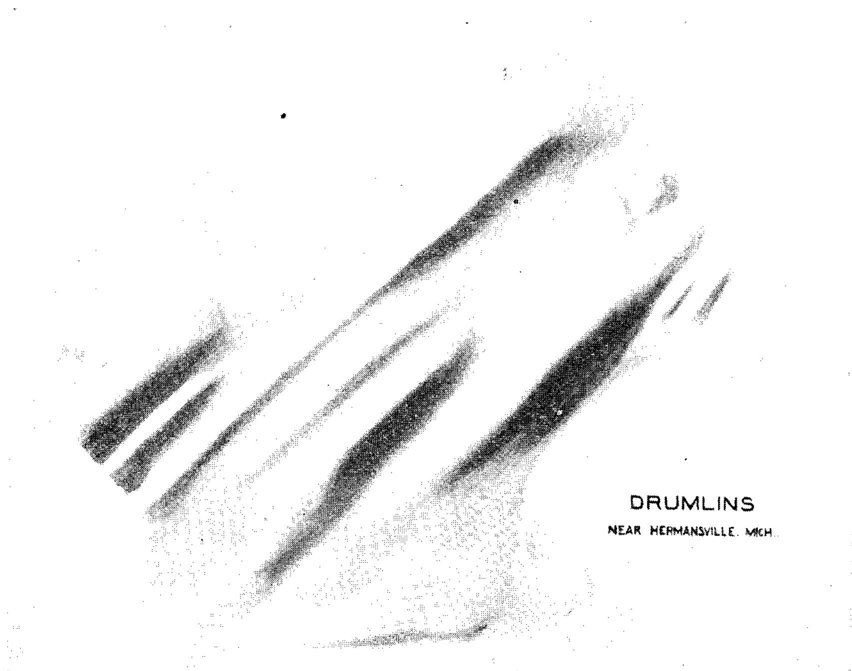
The retreat of the ice outlined above, taken in connection with previously recorded information, indicates that the region considered in this report, which is mantled with red till, was occupied by the Green Bay lobe of the Wisconsin ice-sheet. The axis of the lobe lay in the central portion of the basin of Green Bay, and its western expansion occupied the Menominee region. As the ice melted, the width of the lobe was contracted more rapidly than its length, and the lobation was maintained up to a late stage in the process of melting. It was for this reason that the retreat of the ice from Menominee region was eastward.

Moraines of the Chippewa Lobe: In traveling west from Crystal Falls on the road leading to Iron River, one passes from a region where red till forms a veneer on the surface underlying rocks, to a region of massive moraines composed of gray till. The change occurs at the slough connecting Chicagon and Trout lakes, but whether these two lakes and the sluggish water channel connecting them are precisely on the boundary or not remains to be determined.

The boundary referred to, not only separates two regions in which the color of the soil is different, but several other contrasts in conditions accompanying this change, such, for example, as the thickness of the surface blanket of débris, prevalence of hard-rock outcrops, character of the topography, abundance and nature of the boulders strewn over the surface, etc., as well as variations in the aspect of the forests and conditions favoring agriculture. These contrasts are so definite and important that they demand a somewhat detailed consideration:

The red till on the uplands in the vicinity of Crystal Falls, is on an average some ten feet thick, and forms merely a veneer on the glaciated rock surfaces. The gray till in the numerous bold hills to the west of Chicagon and Trout Lakes, is in general from one to two hundred feet thick, and at least one locality, as shown by a well at Bates, is in excess of 212 feet deep.

In the region occupied by the red till, particularly where the Base-



A.—MODEL OF DRUMLINS NEAR HERMANSVILLE.

B.—SECTION OF DRUMLIN.

ment Complex and Algonkian systems are present, outcrops of solid rock are common, and the summits of the hills are bare or but imperfectly concealed beneath a thin covering of débris; to the west of Chicagon and Trout Lakes, solid rock outcrops are rare and occur principally in the bottoms of the valleys.

The topography in the region where the red till forms the surface, is controlled, to a great extent, by the relief of the hard-rock on which the till rests, and the hills are characterized by the comparatively small size and irregular outlines; while the topography of the gray till, as for example between Chicagon and Stanley lakes, has for its dominant features, bold, steep sided, convex hills, with symmetrically curved bases, which efficiently conceal the relief of the rocks on which they rest. Accompanying this change in topography is an increase in the general elevation of the land above sea level. As one travels westward from Green Bay, the land rises gradually and in the vicinity of Iron Mountain and Crystal Falls, etc., the hill tops in general have an elevation of from 1,400 to 1,500 feet, but in the region to the west of Chicagon and Trout Lakes the broad uplands attain an elevation of 1,700 feet, and, in some instances, approach 1,800 feet. The marked increase in elevation that occurs where one passes westward from the red to the gray till, coincides with the increase in the thickness of the glacial débris, and seems to be due principally to this cause.

The heavy moraine of gray till, to the west of Chicagon and Trout Lakes, has a breadth of at least ten miles, and trends approximately northeast and southwest. No striæ have been observed which might serve to demonstrate the direction of glacial flow, but, judging from the topography and the presence of gravel and sand deposits in the valleys of Iron and Brulé Rivers, etc., the ice lobe which formed the moraine lay to the northwest, and, on melting, its margin withdrew in that direction. Although only a beginning has been made in the study of the gray till, the conclusion is ventured that in the region examined, it pertains to the terminal moraine of the Chippewa lobe of the Wisconsin ice-sheet.

The gray till is less sandy than the red till adjacent to it on the east, and as is judged, contains a larger percentage of clay-like material. A mechanical analysis of a representative sample is presented on page 80, together with similar data concerning several samples of red till. This one sample, however, as is shown by a comparison with the other samples in the list, is not richer in fine silt-like material than certain samples of the red till. As shown in connection with the mechanical analysis, the gray till is lacking in calcium carbonate. The till is conspicuously bouldery, and large masses of metamorphic and igneous rocks are abundant on the surface and throughout the deposit, but there is an absence also of limestone fragments. The cleared fields are, in general, surrounded by piles of stones that have been gathered from their surfaces, and in part built into walls. In this and other respects, as for example the gray color of the soil and the contours of the bold hills, the region resembles the moraine-covered portions of New England. Throughout the area where the gray till occurs, the land, when first traversed by white man, was almost completely covered with a fine hardwood forest, by far the greater part of which is still in its primitive condition. Swamps are less numerous than in the region of the red till, owing to the greater extent and more pronounced relief of the hills, but in the generally narrow valleys, there are sand and gravel deposits, formed by glacial streams, and at a few localities, as in the valley of Paint River, near Atkinson, sand and gravel plains, with open growths of jack-pine and its usual associates, exhibit, on a small scale, the characteristic features of the similar plains bordering Menominee River.

The physical condition of the gray till, the free drainage of the moraines it forms, and the favorable results obtained where its surface has been cleared and cultivated, show that the region it occupies is destined to become highly valuable for agriculture. The large extent and, in general, favorable slopes of the gray moraines, favor their use, especially for hay and grazing lands.

Certain suggestive facts in reference to the relation of the red to the gray till may here be mentioned, although they require supplementary evidence before their full significance can be satisfactorily determined. At the excavation made in connection with iron mining near Iron River and Stambaugh, gray till rests on reddish stratified gravel, and along the road between Iron River and Atkinson, to the northwest of a belt of bold moraines composed of gray till, the surface deposits consist of red till of the same general character as the main body of red till which extends eastward from Crystal Falls, etc. These occurrences and others of a similar nature, seem to show that the gray till was deposited at a later time than the red till and overlaps its westward extension. That such is in reality their true relationship, however, is little more than a suggestion, but certain observations made by Rollin T. Chamberlin,[1] in the western portion of Wisconsin and adjacent part of Minnesota, are significant in this connection.

According to Chamberlin, there is red sandy till in the St. Croix region, which was deposited by a lobe of the Wisconsin ice-sheet that advanced over it from the northwest, and, resting on the red till, is a gray till deposited by a later ice advance which came from the west. These two till-sheets, so far as can be judged, are closely similar and have the same relative positions as the red and gray tills of the Menominee region. These two regions, however, are some two hundred miles apart, and the conditions present on the St. Croix are here referred to, simply for the reason that they suggest problems for investigation when the surface geology of the country to the west of the Menominee region is studied.

Glacio-Fluvial Erosion.

The streams flowing in tunnels beneath glaciers and also the surface streams produced by the melting of glaciers, supplemented by rain and, in some instances by the drainage of adjacent land which is not ice covered, leave records in two principal ways, i. e., by eroding the rocks over which they flow, and by depositing débris. These changes, produced by streams in association with glaciers, may be classified as glacio-fluvial erosion, and glacio-fluvial deposition. Of these two classes of records, those produced by deposition are the more common, and

[1] "The Glacial Features of the St. Croix Dalls Region," in the Journal of Geology, Vol. XIII, 1905, pp. 238-256.

TILL IN THE CENTRAL PORTION OF A DRUMLIN.

will be discussed below, but at least one instructive example in the Menominee region, of erosion by a glacial stream, deserves to be mentioned.

The Norway Spill-way: As the ice front receded eastward in the vicinity of Norway, as already stated, its thin margin was divided into two lobes of small dimensions, by the east-and-west trending hill to the east of the site of that town. One of the lobes occupied the valley of Menominee River, and the other and more northern one, partially filled the valley of Pine Creek. The position of the extremities of these two ice tongues at a certain stage in their existence, is recorded by small moraines trending north and south, as already described. Each of the ice lobes referred to, obstructed the valley it occupied, and the streams on the land to the west of the ice flowed toward the obstructions. In the Menominee valley the waters were turned aside, and, as seems probable, skirted the margin of the glacier, but the waters of Pine Creek and its tributaries, were ponded and formed a lake which became almost completely filled with sand and gravel. The lake found an outlet to the south, across a ledge of rock near the Curry Mine, in the eastern part of Norway, over which it plunged, forming a small cataract, and flowed to the Menominee, through the now swampy channel occupied by a small brook which has its source near Norway and its mouth about a mile west of the locality where Sturgeon River joins its master stream.

The former spill-way near Curry Mine, is a notch from 80 to 100 feet wide and some 50 feet deep, in hard siliceous breccia. Its depth, however, is due to only a small extent to stream erosion, as it is one of the features of the pre-Cambrian land surface exposed to view by the removal of its protective covering of Potsdam sandstone.

The bottom of the spill-way is nearly on a level with a sand plain in the valley of Pine Creek, and the hard rocks forming its floor still bear the polish imparted to them by sand-charged waters. The polish extends upward only a few feet on the side-walls of the channel, thus indicating that the former stream was not deep. At the south end of the spill-way there is a steep descent of about 20 feet into a marshy basin, now in part cultivated, and from this "plunge-basin" an irregular depression with a sandy bottom, extends southward to Menominee River, as stated above.

Spill-ways, similar to the one at Norway, are well known in other formerly glaciated regions, and may be seen with streams still flowing through them, about the margins of existing glaciers, as is the case of Malaspina glacier, Alaska, for example. They should be looked for on the sides of valleys formerly occupied by glaciers, and in localities where ice-sheets withdrew down the slope of the land. In the Menominee region the glacial streams were heavily loaded with débris, and in most all instances aggraded instead of eroding their beds. The example just described is the only instance noted in the portion of Michigan under consideration, where a well-defined spill-way occurred, in which the waters were enabled to erode.

Glacio-Fluvial Deposits.

The streams flowing from glaciers, as is well known, are usually heavily charged with silt, sand, gravel and large boulders, and, in many instances, make deposits of greater volume than the moraines with which they are frequently associated.

These glacio-fluvial accumulations may be divided into two groups: 1st, those laid down by streams in immediate association with the glaciers from which they flow, as for example, *eskers* and *kames,* and 2nd, those deposited after a stream leaves a glacier and is no longer directly influenced by it, and termed *outwash aprons, valley trains,* etc.

Eskers are ridges of sand and gravel, which, in some instances, contain boulders or have large rock masses on their surfaces, and are believed by most geologists to have originated in tunnels beneath or in the basal portions of stagnant ice-sheets. They are frequently forty to sixty or more feet high, have rounded crests and follow sinuous and frequently interrupted or broken courses, which, in a general way, correspond in direction with the direction of flow of the glacier beneath which they were formed.

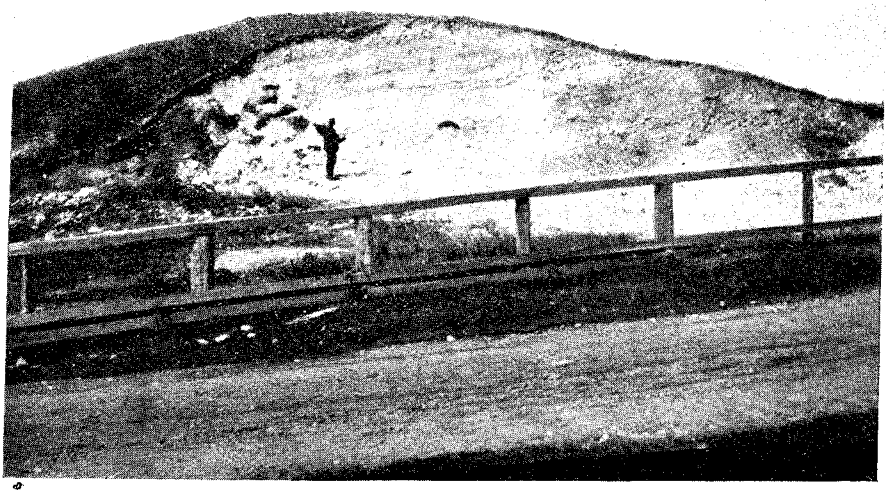
At various localities in the region represented on Plate III, characteristic examples of eskers are present. In my previous report already referred to, attention was directed to several ridges of the type just mentioned, in the vicinity of Spalding, Powers, etc., and a brief account given of two instances where they rest on the surfaces of drumlins and are thus shown to be subsequent to them in time of formation. This association is consistent with the generally accepted idea, that drumlins are produced by moving or flowing ice-sheets, and that eskers originate in connection with ice-sheets that have become stagnant and are traversed by tunnels. In my former report, also, a description was given of an esker near Spalding, which extends each way from the ends of a steep-sided notch in the surface of a drumlin, at a right angle to its longer axis. The significance of this association is that the esker was formed in a tunnel at or near the base of an ice-sheet.

During the journey which furnished the basis for the present report, a number of eskers, in addition to those previously examined, were observed, and their location is in part indicated on the map forming Plate III.

As a rule the eskers occur in valleys, and trend in about the same direction that the last ice-sheet of the Menominee region advanced, but several conspicuous exceptions to this rule are present, as, for example, the esker near Spalding, referred to above, which extends about east and west or at a right angle to the direction of advance and retreat of the last ice lobe that occupied the region. In general, also, the eskers occur near existing streams, which occasionally cross their trend by passing through gaps which break their courses. The significance of this association is, that the sub-glacial streams had their general direction determined by the depression in the land which the former ice-sheet occupied, and when the ice melted the surface streams which came into existence took similar courses. Although a similarity exists in the direction of flow of the esker-building and its uneven streams in the Menominee region this association is believed to be somewhat exceptional, as one of the general characteristics of eskers is their independence of associated topographic features, and may be apparent rather than real, on account of the small differences in relief of the hard rock surface beneath the till.

Of the numerous eskers examined during the past field season, per-

A.—AN ESKER.



B.—SECTION OF AN ESKER.

haps the most instructive is situated about nine and one-half miles north of the city of Menominee, in Sections 29 and 32, T. 33 N., R. 27 W., and is traversed by the State Road leading north from that city. It is well exposed to view for the reason that it occurs in cleared fields, and furnished a good example of the type of topographic forms to which it belongs. Its observed length is about one mile, but at the north it enters a tree-covered swampy region, into which it was traced but a short distance. A similar ridge, however, about a mile in length, occurs a mile to the eastward of the locality referred to, and the two are probably portions of the same deposit, but separated by a natural break or gap.

A photograph of the eskers near the State Road, taken from the north end of the portion which has been cleared and looking south, forms Plate XIA. The course of the ridge is tortuous and its crest line irregular. It is not continuous, but broken into segments of various lengths by gaps, one of which is traversed by the brook to be seen in the picture, which flows south through the opening, and another is occupied by the State Road, which passes a white bluff also recognizable in the accompanying illustration. The bluff referred to, is the wall of a gravel pit, in which a good section of the esker is furnished. A near view of this excavation forms Plate XIB. The ridge extends about half a mile south of the gravel pit and terminates on the border of a swamp through which Menominee River flows.

The esker is about 250 to 300 feet wide at the base, and 30 to 40 feet high. It is composed of assorted and in part well-smoothed and rounded pebbles, and sand, in distinct layers which reveal current bedding. The pebbles are, in many instances, from 5 to 6 up to 10 to 12 inches in diameter; a few are composed of limestone and a considerable number consist of reddish spotted sandstone (Potsdam), but for the most part they have been formed by the wear of fragments of crystalline rock. The pebbles and the sand between them are well packed and adhere so firmly that it is difficult to loosen them with the hand. The compactness of the material permits the wall of the pit that has been dug to stand vertical, and furnishes a reason for the preservation of the steep side-slopes of the ridge, which have retained their original constructional shapes. As shown in Plate XIB, the main bedding planes of the gravel and sand are oblique and descend from the west side of the eskers towards its east base. This oblique bedding is exceptional, as eskers usually reveal in cross sections a more or less complete arching of the strata, due in part, as seems probable, to the lateral sliding of the material after the bordering walls of ice were removed.

As shown indefinitely in the foreground of the picture forming Plate XIA, a second ridge joins the one just described, on its eastern side, nearly at a right angle to its course, and is prolonged eastward. This second ridge is composed almost wholly of sand, and a continuation of it occurs, but at a lower level, to the west of the main esker, is recorded by a covering of sand, and expands at its west end into a sand plain several acres in area. The sand esker is lower than the main or gravel esker and has less steep sides and a broader crest. The conditions observed seem to show that the sand esker is not a branch of the gravel eskers, but was formed first and subsequently crossed by its companion.

Eskers similar to those just described are present at several localities in the Menominee region, as is indicated in part on the map forming Plate III, and when the more complete studies are made many others will, no doubt, be discovered. In general, those observed are composed mainly of coarse gravel, and, in many instances, large boulders are present on their crests, or, as revealed where excavations have been made, embedded in their interiors. With the gravel there is always more or less sand, and in most instances their sides and margins are more sandy than their crests, for the reason that the sand has been washed down from their higher portions since they were exposed to the rain, and concentrated on their sides. This same process of rain wash also furnishes a reason in part for the usually greater abundance of boulders on their summits than on their sides.

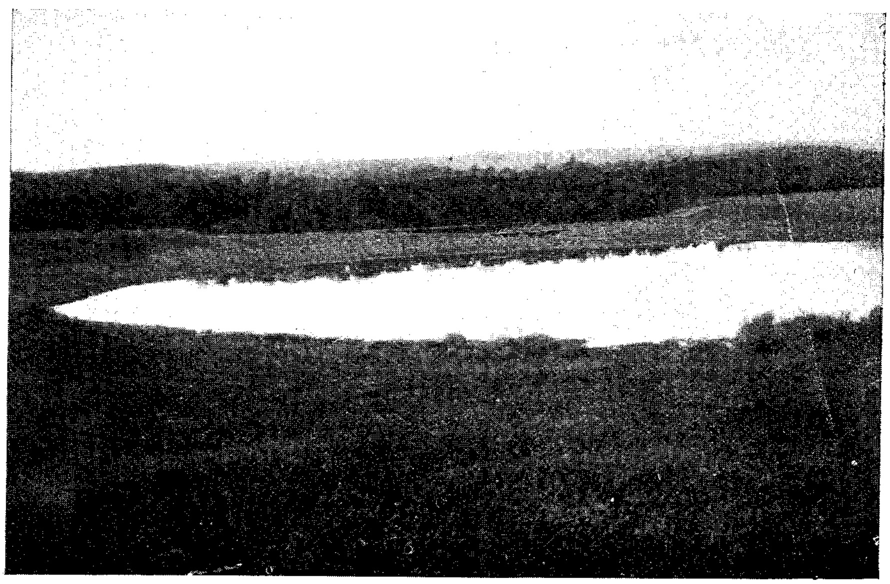
To the topographic forms usually assigned to eskers, those under consideration furnish an additional variety; namely, knolls and hillocks composed of sand and gravel and occasionally containing large boulders, which are situated on their crests. Good examples of such elevations occur on an esker in Menominee County, about a quarter of a mile north of Birch Creek station, which have a height of ten to fifteen feet above the adjacent portion of the summit of the ridge. The most prominent knolls are situated at localities where abrupt bends occur in the ridge on which they are located. The crest of the ridge adjacent to the knolls on each side is, in several instances, nearly level and regular, showing that the elevations are constructional forms, and have not resulted from a sagging or displacement of portions of the material of which the deposit is composed, leaving other portions in relief.

An explanation of the manner in which knolls and hillocks of the nature of those just cited, were produced, is difficult, for the reason that a stream flowing in a tunnel and depositing débris on its bottom, as in the case of a surface aggrading stream, must have a slope down which to flow. The crest of an esker should be considered as representing the graded channel of a stream, and departures from a uniform slope are evidently due to secondary conditions, supplementary to those which govern the normal action of such streams.

The departures from an even slope presented by the crest lines of eskers form two classes, 1st, elevation such as knolls and hillocks, which rise above its general level, and 2nd, sags, notches and gaps, which form depressions below the general level of the crest, where most uniform and continuous. In the former class, it is evident that material has been added to the surface of an esker, and in the latter instance, as observations indicate, there was less than the normal amount of deposition, or else material has been displaced.

The addition of material to the surface of an esker so as to produce knolls and hillocks on its crest, may reasonably be assumed to be due to contributions of débris brought by streams which descended through openings in the roofs of the ice tunnels in which it was formed, as is suggested by the well-known fact that streams on the surface of glaciers frequently plunge into crevasses and form *moulins*. While perhaps as a rule, erosion occurs at the bottom of a moulin, as is suggested by the pot-holes they are known to produce, it is evident that under certain conditions, as, for example, when much coarse débris is carried into them, deposition might result. Under this hypothesis the knolls on the crests of eskers are to be considered as being of the nature of kames,

A.—MODEL OF GRAVEL BARS NEAR STURGEON FALLS.



B.—GRAVEL BARS NEAR STURGEON FALLS.

and analogous to the alluvial cones formed by surface streams on emerging from a steep gorge and entering a plain. The suggestion which presents itself in this connection is that eskers are formed by streams flowing in channels in a stagnant ice sheet, and that these sub-glacial streams had tributaries some of which joined them from above, by descending through well-like openings in the ice. So long as the sub-glacial stream was vigorous the débris brought by the descending tributaries was carried away and utilized in the general process of aggrading, but when the trunk stream was too weak to remove all the material brought to it from above, deposition occurred and mounds were formed on its bed. The process here outlined is analogous to the manner in which slow-flowing surface streams sometimes receive more débris from swifter tributaries than they are able to remove, and obstructions are produced. Such locally abundant deposits on the beds of sub-glacial streams would vary in their effects on the flow of the streams themselves, from a slight check of velocity to complete damming. Where prominent elevations are present on the crests of eskers, as is apparent in several observed instances, the esker-building stream on reaching the obstruction ceased to flow.

The idea that sub-glacial and englacial streams may receive tributaries at any angle with the trend of their channel, and situated in any plane from horizontal to vertical, may at first seem novel, but is consistent with the conditions pertaining to tunnels in ice. The fact that eskers frequently branch or are joined by lateral or secondary ridges, has long been known, and is explained on the hypothesis that the streams which formed them were connected after the manner of surface streams. It is evident, however, that the conditions pertaining to streams flowing in tunnels or caverns, differ from those controlling the development of surface streams, and that tributaries may join them from the side at the same level, or descend obliquely or even vertically through the enclosing ice forming their roofs. The deposits made by tributaries which joined an esker-building stream at greater or less vertical angle, but not vertically, would be displaced when the enclosing ice melted, and the record destroyed, but in the case of vertical tributaries, if deposition occurred, heaps of débris similar to alluvial cones and eskers might remain intact.

The reasons for sags and notches in the crests of eskers, and the presence of gaps which divide them into segments, may, perhaps, be best understood when it is remembered that eskers are stream deposits and represent the "fills" that sub-glacial streams have made in the process of aggrading their beds, and establishing an even gradient. Streams flowing in tunnels which are not completely filled, grade their channels in the same manner as surface streams; that is, by filling depressions, and cutting at localities where the current is sufficiently swift to bear along all the débris present, thus preventing sedimentation.

If a stream flowing through a glacial tunnel completely fills its conduit, the water will be under pressure, as, for example, in the case of the water-mains of a city supplied by a reservoir at a higher level, and deposition of débris might occur, but under different conditions than if the tunnel was not completely occupied. In a tunnel without a uniform gradient, and varying from place to place, in area of cross section, it is evident that sedimentation might occur in depressions of the bottom and where the opening was exceptionally wide, even though completely occupied by water. In this manner deposits might be made in certain portions of an ice tunnel and not in other portions.

Before attempting to apply the principles briefly stated above, in explaining the irregularities of eskers which are depressed below the general level of their crests, one should know whether the streams in glacial tunnels completely fill them or not. In this connection observations show that both conditions are present in the tunnels beneath existing glaciers, and as there is no reason for doubting, the same is true concerning the tunnels in former ice-sheets. The most rational conclusion concerning esker-building streams, seems to be that they flowed through irregular tunnels, and at certain localities eroded their bottoms and at other localities made deposits upon them. The conditions seem to have been the counterpart of what may be observed in caverns at the present time, as the Mammoth Cave, for example, through which streams are flowing. Such subterranean streams, as is well known, in portions of their courses do not completely fill the caverns, but behave in essentially the same manner as surface streams, and in other portions of their courses do completely occupy the opening, in the same manner as the water in the water-mains of a city.

Sub-glacial and en-glacial streams, as it appears from the above brief discussion, should deposit débris at certain localities, and corrade their channels at other localities. The bottom of a glacial tunnel may consist of drift or rock or of ice, or of rock in part and in part of ice, and in localities where drift or rock was corraded, a channel should remain as a record of the streams' work when the glacier melts. A case in point is the notch in a drumlin near Spalding, described on page 44, which is in line with the eskers extending in each direction from it. If one portion of the floor of a glacial tunnel is composed of ice and adjacent portions consisted of stream deposited débris, when the glacier melts, a break would appear in the esker left exposed, thus explaining the gaps that form such a common feature of most gravel ridges of the class under consideration. The sags and notches in eskers evidently permit of a similar explanation.

So long as a stream does not completely fill the glacial tunnel through which it flows, and this, as it seems, is the most usual condition, it would tend, especially if heavily loaded with débris (which is also a normal condition), to establish a uniform gradient through the combined action of corrasion and deposition, in the same manner as surface streams. Hence, in general, the crest line of an esker should have an even descent in the direction of flow of the stream to which it is due, unless deformation of the deposit has occurred since the melting of the glacier within which it was formed, or material has not been laid down upon it.

This principle furnishes an important aid in the study of eskers, and should apply to all such deposits unless they were formed by streams that completely filled the tunnels through which they flowed. Such a condition, however, was seemingly of rare occurrence, and a temporary phase in the history of a given stream.

Having ascertained the normal gradient of an esker, special explanations should be sought for knolls and hillocks situated on it, due, in part if not generally, to deposits made by vertical or nearly vertical tributary streams, and for sags, notches and gaps, due, in general, to the melting of the sub-esker ice or of ice which formed the floor of the esker-building streams at localities were deposition of gravel, sand, etc., did not occur, or were small in amount. In addition to these two classes of irregularities, there are frequently others due to the displacement of the deposit on account of the melting of the glaciers in which it was accumulated, thus removing lateral support. Such irregularities, however, are usually easily assigned to their true cause, for the reason that the displaced material is near at hand and, as in the case of a landslide, corresponds in volume, etc., with the notch or sag from which it was derived.

Kames: On formerly glaciated areas there frequently occur knolls and hills known as kames, which are composed, principally, of gravel and sand, which, in some instances, contain till masses, irregular stones and even large boulders.

These piles of water-laid débris sometimes form isolated conical hills, but more often are indefinitely grouped and appear as irregular mounds, hills and short ridges, with depressions and undrained basins among them. The height of the piles is as irregular as their shape, but frequently ranges from fifty to seventy feet and, at times, exceeds one hundred feet. Their irregular shapes frequently cause them to resemble dump-moraines. In many instances such piles of stratified material merge with true moraines, and it is evident that a glacier and the streams flowing from it deposited débris in the same or closely associated areas. When two or more isolated kames or groups of kames occur in the vicinity of each other, their general alignment records the position occupied by the margin of a glacier during its retreat, in much the same manner as do terminal moraines.

The conditions which controlled the formation of kames, were evidently various, but they are distinctly stream-formed in association with glaciers. A stream on leaving a glacier, usually experiences an abrupt decrease in gradient, and for this reason being no longer able to continue to transport the débris carried in its swifter upper courses, lays it aside. This process is the same as that by which surface streams form alluvial cones, but the ice against which the alluvial deposit rested in the case of the alluvial cone of a glacial stream finally melts, leaving the accumulation in what may be termed a free or detached position.

In distinction from eskers, the class of glacial-stream deposits here considered, seems to have been laid down principally by streams flowing down the surface of glaciers, rather than in tunnels, and to have deposited débris on leaving the ice. This distinction is not strictly true, however, since any stream leaving a glacier, whether it emerges from a tunnel or not, might undergo an abrupt decrease in gradient and thus be forced to lay aside a portion of its load. But in most instances the streams flowing on the surfaces of glaciers appear to be the ones that make the most voluminous and most conspicuous deposits about their borders.

The mental picture of the most usual conditions under which kames were found, embraces a bold ice front with notches or embayments in its margin, due to the melting of the ice by outflowing streams, and serving to concentrate the water furnished by the melting of the ice. The embayments, as is illustrated about the margins of certain of the glaciers of Alaska, being of the nature of steep-sided valleys or canyons with walls of ice. Into these depressions the streams from the glaciers brought débris, and as their currents slackened, owing to a flattening of their gradients, or perhaps greater freedom for the water to expand laterally, sedimentation took place. The deposits rested on or against the margin of the glacier, and when the glacier receded they were left as isolated piles. When ice was present beneath them, their irregularities were increased when it melted.

Another variation in the combined process of glacial and stream work, which should be considered, is, as is well known, that the streams flowing on the surface of glaciers frequently enter crevasses which are enlarged by melting until they become well-like openings, termed moulins. A stream in plunging into a moulin carries with it the débris it sweeps along, and boulders may also fall into the opening from its walls or from the adjacent surface. The conditions at the bottom of a moulin are usually considered as favoring erosion, and the pot-holes present in many glaciated regions are clear evidence that a conspicuous amount of grinding frequently takes place at the bottom of such glacial mills. Under other conditions, however, and especially if a large amount of débris is swept into a moulin, deposition might occur, and a deposit of irregularly bedded material result. This might happen, especially in a stagnant ice-sheet, and when the ice melted, a conical pile of irregularly bedded débris or a *kame,* would result. Certain conical kames, surprisingly regular in shape and standing on broad plains, can be best accounted for under the hypothesis just outlined, and are, in fact, the most complete alluvial cones that have been observed.

More or less extensive areas within which kames form the leading features of the topography, occur in various portions of the Menominee region, principally in valleys and near the present streams, but in certain instances, especially to the west of Iron Mountain, are present among morainal hills and in association with somewhat prominent hard-rock outcrops. The number of known kame areas is perhaps a score, and are indicated on the map forming Plate III, but the total number which would be discovered if the forested tracts were thoroughly traversed is, no doubt, several times as great. Only a few of the more characteristic examples that were observed can here be described, but these may be taken as types, and together with the general account of kames given above, will enable residents of the region under consideration to recognize other examples which may be known to them.

In the western portion of Mellen Township, Menominee County, in Section 21, T. 27 N., R. 34 W., there is a group of prominent sand-hills occupying an area of several score acres, the highest of which is a conical pile rising about 80 feet above the surrounding plain. The deposits consist almost entirely of yellowish quartz sand, and are sparsely clothed with vegetation. A person standing on the highest summit is enabled to see for a distance of many miles in all directions over the top of the forest growing on the surrounding country, and cannot avoid being impressed with the fact that the hill beneath his feet is a peculiar and exceptional topographic feature. No other similar hill can be recognized from its summit. It rises with steep slopes from a widely extended till-covered and in part sandy plain, and there seems no escape from the conclusion that it is a kame, composed of sand. The only explanation of its mode of origin which seems tenable, is that the sand of which it is composed was carried by water which flowed over the surface of a former glacier and entered an opening in the ice of the nature of a moulin, and there deposited its load. The glacier subsequently melted and the sand was left as a mound on the plain it vacated.

A mile or two to the west and southwest of the sand kame just described, and near Menominee River, there are several much lower knolls composed of sand and well-rounded gravel, which are evidently kames of the normal type. Much of the west-central portion of Mellen Township is occupied by sand resting on the universal till-sheet, which, at various localities, forms low hills and ridges resembling flattened and subdued dunes. Although much of the present relief of this deposit is plainly the result of the work of the wind, its concentration is seemingly due primarily to the action of glacial streams.

Conspicuous sand and gravel hills, with an irregular relief and surrounding undrained basins, occur about Wallace, near the center of Mellen Township, and illustrate the normal characteristics of kames.

In Stephenson Township, short eskers and kames are present in considerable numbers adjacent to the streams flowing to Haywood Lake, and also at numerous localities along the course of Cedar River. In fact, throughout the length of Cedar River and its principal tributaries, low mounds of sand and gravel are a feature of the smaller elements of the relief of the surface. In many instances these kames and also the eskers of the same region, are crossed by roads, and furnish gravel for road grading.

About Koss (or Fisher as it was formerly termed), where the Wisconsin and Michigan Railroad crosses Menominee River, about six miles west of Ingalls, there is an extensive group of hills and knolls of gravel and sand, interspersed with numerous undrained basins containing marshes and lakelets, which furnish typical illustrations of kame topography. The hills rise with steep slopes, some 50 to 60 feet above the adjacent basins, certain of which contain perhaps 10 to 20 feet of water and peaty material. Adjacent to this deposit of outwash débris and merging with it on the east and south, there are low hills and ridges composed of till, which are morainic in character, and, as previously stated, record a halt in the eastward recession of the last ice-sheet which covered the region.

Irregular knolls, composed of sand and gravel with swampy areas interspersed among them, form a characteristic feature of the surface over an area of several square miles situated to the south and southeast of Waucedah, and are a part of the series of kames associated with the moraine previously described which margins the west side of Menominee County, and extends northward across the southeast corner of Dickinson County.

At Big Quinnesec Falls, and extending north to the base of the prominent hill east of Iron Mountain, there is a series of kames, associated with a small terminal moraine, and having undrained basins among them. Similar hills occur about Fumee and Antoine Lakes, and also throughout an area of several square miles adjacent to Menominee River on the east, at Twin Falls.

Kames are present, also, at several localities in Iron County, as, for example, about the town site named Balsam, and in the valleys of Hemlock and Little Helmolck Rivers, near Amasa. Again, in the valley of the Bois Brulé, from near Armstrong down stream to the junction of that river with Paint River, there are many gravel knolls, adjacent to basins several of which hold lakes and swamps, which have characteristics of kames. The valley of the Bois Brulé, however, is in general a pitted sand and gravel plain, as will be described later, and it is difficult to discriminate between the hills and ridges of the in part conspicuously pitted plain, and true kames.

The journey which furnished the data for this report did not permit of such an examination of the country visited as would admit of the mapping of all the kame areas. Even those which were discovered were not in all cases completely examined, for the reason that they are usually forest covered, and more time would be required to traverse them than was available.

Kame Terraces: When a glacier occupies the central portion of a valley, but fails to fill it from side to side, débris washed from the adjacent uplands or contributed by the glacier itself, may accumulate in depressions between the ice and the sides of the valley, and when the glacier melts, deposits of débris formed in this manner, are left as terraces on the sides of the depression it occupied. Such shelves or steps are analogous to kames but have the general characteristics of terraces and are termed kame-terraces.

The conditions leading to the formation of kame-terraces are not confined to narrow valleys, however, but whenever there is a depression between the border of a glacier of any type, and adjacent uplands, it may become more or less completely occupied by débris, and when the glacier melts, a terrace-like deposit remains on the slope formerly bordered by the ice.

Kame-terraces may be composed wholly of gravel and sand, but they frequently contain angular stones and boulders especially on the border formerly margined by a glacier. In some cases, also, the margin of the terrace which was formerly supported by ice, is higher than its general surface, but this is not a distinctive feature. Then, too, the marginal escarpment of such a deposit which was formerly supported by ice is usually conspicuously steep, and at times suffers deformation, owing to the occurrence of land slides.

In the Menominee region, during the melting of the last ice-sheet which formerly occupied it, the margin of the glacier withdrew eastward, but its front was irregular and tongues of ice simulating valley glaciers, lingered in the depressions trending east and west, after the intervening uplands had become uncovered. The ice lingering in the valley melted most rapidly on its borders, particularly where the adjacent land rose steeply, and in the depressions thus produced débris was deposited. Where the land sloped southward the conditions were more favorable for this process than where northern slopes descended to an ice margin, but still more favorable conditions seem to have been furnished where the eastern end of a hill or ridge between two ice tongues, occupied a reentrant angle between them. In brief, as the ice withdrew towards the east, kame-terraces were formed in several instances on the sides and particularly at the eastern ends of the steeper and more prominent hills.

Perhaps the best examples of kame-terraces in the region here considered, occur at Norway, on the eastern and southern slopes of the hill which rises to the west of the town. The higher portion of the town itself is situated on the deposit referred to. The terrace is composed of fine yellow sand, which is banked against the hill-side, and presents a steep escarpment towards the adjacent valley. The terrace has a maximum width of perhaps two or three hundred yards, is essentially level, and has an elevation of about 1,035 feet. Its surface is 60 to 70 feet above the sandy plain at the foot of its margining escarpment. Its valley border is conspicuously irregular in ground plan, and an eastward extension from its main portion forms a narrow flat topped ridge with precipitous borders, nearly half a mile long, which terminates at the east at a rugged knob of solid rock near the Curry Mine. The knob of rock referred to, forms the western border of the former stream channel or spill-way, already described on page 53, on the eastern border of which is another similar rocky eminence. To the east of the second knob mentioned, and resting against the slope of the bold hill next east of Norway, there is another sand terrace on the same level as the one on which the western portion of the city is situated. These two terraces were no doubt formerly united, but have been separated by stream erosion.

It is apparent that the sand forming the terraces at Norway could not have been deposited in its present position unless the margins of the deposits facing the adjacent valley had been supported. The support, as already suggested, was furnished by an ice body which occupied the valley, the surface of which was at least as high as and no doubt considerably above, the level of the surface of the terrace. The margin of the ice was irregular and gave an irregular outer border to the sand deposited against it. A narrow opening was present between the ice which occupied the valley of Menominee River to the south of the site of Norway, and a similar ice body in the valley of Pine Creek to the north of that locality, and in this opening the sand forming the flat-topped ridge mentioned above was deposited. When the ice which occupied the valleys melted, the sand on its border, in part, flowed down into the space it vacated, producing the present marginal slope of the deposit.

Other deposits similar in character and mode of origin, to the kame-terraces at Norway, occur at several localities in the adjacent region, but none of them, so far as known, consist of such well-assorted sand.

At Quinnesec a terrace, composed of sand and gravel, banked against a southward and eastward facing hill-side, presents a steep slope some 40 feet high, towards the adjacent valley, and illustrates the normal characteristics of kame-terraces. Again, at a locality between one and two miles west of Quinnesec, adjacent to the wagon road leading to Iron Mountain, there is a similar terrace composed principally of sand, which rests against a southward sloping hillside, and presents a steep escarpment some 60 feet high, facing the valley on the south. Still other examples of a similar character occur on the sides or ends of rocky hills in the vicinity of Iron Mountain, etc., and, no doubt, when the region is more completely studied, many additional examples of like character will be discovered.

While the presence of kame terraces is to be expected, particularly along the southern border and at the eastern ends of the higher hills in the Menominee region, it does not follow that they will invariably occur at localities where the topographic conditions are favorable for their production. In the case of ice-sheets bordering uplands, tunnels in the ice may permit of the escape of the water which would otherwise be wholly or in part ponded in marginal depressions, as is well illustrated in the case of the Malaspina glacier, Alaska, at the present time, and the formation of kame terraces be prevented.

Sand and Gravel Plains: In a brief account given above, of the characteristics and mode of origin of kame-terraces, no limits were stated in reference to the breadths such deposits might attain. If a broad glacier or a lobe of a continental glacier withdraws down the slope of a region, it is evident that kame terraces of such great width might be produced, that they would lose their terrace-like aspects and become sand and gravel plains. The withdrawal of an ice-sheet, however, in the manner referred to, frequently leads to a ponding of water and lakes are formed. In some instances both of these results follow the withdrawal of an ice-sheet and kame terraces margining sheets of lacustral sediment are left.

Again, if an ice-sheet recedes from a region whose downward slope is in the opposite direction from the line of ice retreat, that is, away from the glacier border, the streams flowing from the melting glacier may be so heavily loaded with débris that deposition will occur when they leave the ice and continue in channels with a less gradient than they had above that locality. In this manner deposits of sand and gravel, known as *valley trains, outwash aprons*, etc., are produced. Such accumulations present a wide range of variation, dependent principally on the nature of the load with which the glacial streams were supplied, its amount relative to the volume and velocity of the streams, the topography of the land on which deposition occurred, coarseness or fineness of the débris transported, and still other conditions.

One feature of outwash deposits of special significance, is that their generally level or gently undulating surfaces, in numerous instances, contain basins or pits, with steep borders composed of the same kind of material as the surrounding plain. These basins frequently contain swamps or lakelets. The depressions vary in size from a few rods to a mile or more in diameter, and may be nearly circular or conspicuously irregular in outline. In some instances they are widely scattered and furnish an exceptional feature in the topography of the broad plains in which they occur, and in other instances are so numerous and closely set that they are the leading factors in the relief of areas embracing several square miles.

The explanation of the mode of origin of the pits and basins referred to is that the sand and gravel forming the plains in which they occur, was spread out by streams over bodies of ice or surrounded isolated ice-masses, and that when the ice melted cavities resulted.

Two leading variations in the topographic conditions in connection with which sand and gravel plains are produced, were noted above; one in which a glacier in its retreat withdraws down the slope it occupies and plains of the nature of broad kame-terraces are produced by the deposition of débris in the space vacated by the ice; and the other, when the downward slope of the region in front or margining a glacier draining it, had freedom to flow away. Each of these combinations of conditions formerly obtained in the Menominee region.

A highly characteristic feature of the relief of the land building each side of Menominee River, from the vicinity of Vulcan, westward to the locality where Paint and Bois Brulé rivers unite to form the main stream, is the presence of broad sand and gravel plains, which at numerous localities have pitted surfaces. Continuations of this same series of alluvial deposits occur along Paint and Bois Brulé Rivers, and on a less extensive scale adjacent to the Michigamme, Iron and other streams of the same system. Bordering the smaller streams, however, and on the upper or headward portions of the larger tributaries of the Menominee, the sand and gravel deposits in the valleys are narrow, and form alluvial terraces.

The general sequence of events which should be retained in mind while studying the valley gravel just referred to, is that the last ice-sheet of the Menominee region, which occupied the country to the east of Chicagon Lake, receded eastward, as already stated, or down the slope of the land. That is, the land drained by Menominee River was first freed from ice near the head waters of the tributaries of that stream and the margin of the glacier withdrew in the same general direction that the river flows. This process was equivalent to the recession of a dam down the course of the river, and a succession of lakes would have been produced, had it not been that the land to the south was in general low and of mild relief, and the water escaped in that direction at different localities as the ice margin receded. So far as known, the records of only one glacial lake in the region here considered, are at present distinguishable. The lake referred to occupied the valley of Sturgeon River, where it merges with the valley of the Menominee, as will be described later.

The control that the receding glacier exerted on the direction of flow finally assumed by the Menominee is indicated by the fact that each of its principal bends, as one descends its course, forms an offset to the south. This may be seen by inspecting the map forming Plate III, and indicates that the river was striving, so to speak, to follow an eastward course, but was turned southward each time the glacier halted. There is also a direct relation between the principal right-hand bends of the river, and the moraines which cross its course or margin its left bank.

The water concentrated in front of the receding glacier was supplied in part by its melting, but principally by streams from the still ice-covered land lying to the north, and deposited vast quantities of débris, thus aggrading the valleys through which it flowed. The courses of the heavily loaded glacial streams, may be traced by the abundant deposits they left, which have since been modified in only a minor way, and, as is judged but not as yet demonstrated by observation, the southward deflection of the Menominee referred to above, should be recorded by extensive valley trains on the Wisconsin side of its present course.

At localities where the glacier halted during its retreat, moraines and kames were deposited, on the outer or western border of which alluvial plains were spread out. This process was repeated several times during the ice retreats and alluvial plains at successively lower levels resulted.

In the description of local examples of alluvial deposits, which follows, attention is directed principally to the broad sand and gravel plains, but it should be remembered that these are a part of an extended system of valley gravels, which extends widely throughout the low-lands of the portion of Northern Michigan under consideration. Where the valleys are narrow, the alluvium in their bottom appears for the most part in stream terraces, owing to the fact that the streams have deepened their channels since the time active aggradation was in progress; and where the valleys are broad, extensive sand and gravel plains still remain, and are essentially wide terraces bordering the narrow channels which the streams that formed them have since excavated. The entire system of valley deposits along the Menominee and its principal branches, is for the most part in adjustment in reference to surface slope, and has a descent in the direction in which the present streams flow, but the surface slope of the highest of the terraces and of the sand and gravel plains is a little greater than the gradient of the present streams. Exceptions to this generalization are furnished by alluvial deposits in valleys which at present have no surface streams, and by localities where the direction of flow of the glacial streams was different from that of their modern representatives.

In the following account of the sand and gravel plains of the Menominee region they are considered in their general order from west to east, in which direction also they occur at successively lower and lower horizons.

A characteristic sand plain about a square mile in area, occurs in the valley of Paint River, at Atkinson, Iron County. Its surface elevation is about 1,480 feet, or from 30 to 40 feet above the river which has cut a channel across it. The plain is occupied by an open growth of jack-pine, and its usual associates—illustrative of the response of vegetation to soil conditions. Rising through the sand plain there is a prominent rocky crag, forming a rugged island-like elevation about 80 feet high, from the summit of which a comprehensive idea of the relief of the region about it may be obtained. Along Paint River, below the sand plain, there are characteristic stream terraces. As is judged from the data given on the contour map forming the Iron River quadrangle, published by the U. S. Geological Survey, a sand plain similar to the one at Atkinson, with a surface elevation of 1,430 feet A. T. is present at the mouth of Net River.

To the north and east of Crystal Falls, there is a good example of the several sand and gravel plains to which attention is here invited. The outline of the plain is irregular as it extends into lateral valleys opening from the one through which Paint River flows, and its monotony is broken by a number of rocky hills, in some instances coated with ten to twenty feet of reddish till, which rise above its surface like islands, to heights ranging from a few to over a hundred feet. By estimate, the area of the plain is about four square miles, but on the east and northwest, it merges with extensive swampy tracts which may be underlain by an extension of the same sheet of sand and gravel. Sunken in the portion of the plain situated on the east side of Paint River, opposite Crystal Falls, is the basin of Runkle's Lake, which is eight-tenths of a mile long from east to west, and on an average one-fourth of a mile wide, and is without a surface outlet. The banks of the lake are approximately thirty feet high, and several soundings in its central portion gave a depth of thirty-seven feet of water. This is a typical example of the numerous lakes in the western portion of the Menominee region, which occupy pits or depressions in sand and gravel plains. As the conditions present clearly indicate, the basin of Runkle's Lake was formerly occupied by an isolated or residual mass of glacial ice which was left in the central part of the valley after its marginal portions had melted, and became surrounded with stream deposited sand and gravel. Other depressions in the surface of the plain can be satisfactorily accounted for on the hypothesis that ice has melted from beneath or within it, and that irregular settling of the material of which it is composed has taken place.

Since the plain was formed, Paint River has cut a channel through it, and reached the underlying bed rock at the small cascade from which the town of Crystal Falls derived its name. The sections exposed in the banks of the river, as well as the depth of Runkle's Lake, show that the sand and gravel deposit is, in general, about seventy feet thick, but the surface on which it rests is irregular, and, as stated above, eminences rising from it in several instances extend above its present surface. Beneath the sand and gravel, as is the case generally beneath similar plains of the same region, there is a sheet of reddish, sandy and bouldery till, of the same character as that blanketing the uplands. Paint River in deepening its channel in the vicinity of Crystal Falls, after the sand and gravel plain was formed, removed the finer débris it encountered, but left the larger boulders. The effect of this process of concentration of coarse material, and particularly of large boulders, is well shown on the sloping surface in the eastern portion of Crystal Falls, adjacent to the river.

The surface elevation of the sand and gravel plain about Runkle's Lake, and of its extension northward along Paint River for some four miles, is about 1,390 feet. The surface rises gradually, however, towards the northwest, or up stream in reference to the direction of flow of Paint River. The presence of this gradient is difficult to demonstrate, owing to local irregularities and minor undulations, but can be detected by using a hand level. A rise is also apparent when the plain is traced into the tributary valley opening northward from it, through which no streams at present descend. The significance of these conditions is that the sand and gravel flooring of the valley was deposited by several streams, but chiefly by the main river. Consistent with this deduction is the fact that the narrow valley of Paint River, to the northwest of the broad sand and gravel plain north of Crystal Falls, is, in part, occupied by an extension of the same deposit, through which the river has excavated a channel, leaving well-defined alluvial terraces.

During the time Paint River was re-excavating its channel as just stated, new streams were developed on the sand and gravel plain, and became tributary to it. One of these streams has its source near the southern border of Runkle's Lake, and joins Paint River about a mile south of Crystal Falls. It is a mere brook about a mile long, which is in adjustment at its mouth with the river to which it is tributary, and has excavated a steep-sided channel, some thirty feet deep. The brook is supplied principally by the percolation of water from its banks and by springs near the head of the more northern of the two branches into which it divides. Attention is here directed to the brook, not only because it is an example of a number of streams which have originated on sand and gravel plains, and are engaged in the process of dissecting them, but for the reason that the springs, which are its main source of supply, are fed principally by water derived from Runkle's Lake. The water percolating through the sand and gravel forming the borders of the basin of the lake, emerges as a series of springs at the head of the gulch the brook has excavated, and an extension of the gulch headward, due to the undermining of the banks above the springs by outflowing water, is in progress. The distance from the lake to where the springs appear, is in the neighborhood of a thousand feet. If the present process continues, as no doubt it will, an instructive example of an enclosed lake acquiring a surface outlet may be witnessed in the course of a few years.

The plain about Runkle's Lake is bordered on the south by a descending escarpment about forty feet high, which divides it from a far larger plain of similar character, bordering Paint River on each side, and extending south to Menominee River. The full extent of the plain is unknown, but its area is not less than fifty square miles. It has also a broad development on the south side of Menominee River, as for example, about Florence, and the portion in Wisconsin is thought to be of even greater area than the portion situated in Michigan. The boundaries of the portion of the plain on the north side of Menominee River, are indicated in part on the map forming Plate III, but its eastern border has not been determined. Such facts as are known concerning its eastern margin, however, indicate that it extends some two to four or five miles east of Michigamme River, in the lower six or eight miles of its course. Its limit on the east seems to be determined by a moraine which crossed Menominee River between three and six miles below the mouth of the Michigamme.

The general surface level of the plain is about 1,370 feet, but many extensive portions are below this horizon, and numerous depressions, basins and pits, are also present, some of which have a depth of forty to sixty or more feet, and, in a number of instances, are occupied by swamps and lakelets.

The plain is about thirty feet lower than the one in which Runkle's Lake is situated, and, as stated above, the descent from the higher to the lower plain is abrupt. At the locality where the change occurs, about a mile southeast of Crystal Falls, the valley of Paint River, at the level of the higher plain, is less than a mile wide, and is bordered on each side by till-covered uplands. The presence of till in the escarpment separating the two plains, suggests that a moraine there crosses the valley, but in this connection the information in hand is inconclusive.

The fact that the two plains just referred to are at different elevations, as well as the abruptness of the escarpment separating them, suggest that the higher one was formed while a receding glacier still occupied the country to the south. This explanation is consistent with the history of other similar plains farther down the course of the Menominee, but difficulties in the way of accepting it, without the support of more evidence than has as yet been obtained, are suggested by the fact that no avenue for the escape of the water which assisted in forming the higher plains—under the supposition that the narrows a mile south of Crystal Falls were closed by ice at the time the higher plain was formed—has been found. A suggestion, however, may be offered in this connection, namely, that an escape for the water was provided by a tunnel in the ice.

The next extensive sand and gravel plain to the southeast of the one just described, begins at the north in the vicinity of Twin Falls and extends along Menominee River to Big Quinnesec Falls. Its general surface level in its broadest portion, to the south of Iron Mountain, is about 1,130 feet, or approximately 240 feet lower than the similar plain near Crystal Falls. The present descent of Menominee River in the same distance is approximately 200 feet, or something less than the difference in surface elevation of the two plains.

At Big Quinnesec Falls, and extending north to the base of the bold hill situated east of Iron Mountain, there is a small knob and basin moraine, with associated kames, as briefly described on a preceding page. This short range of till and gravel hills intervene between a gravel plain to the west, the one referred to in the preceding paragraph, and another similar plain to the east, which has a surface elevation of 1,120 to 1,130 feet. That is, the surface of the plain on the east side is about 100 feet lower than the surface of the similar plain on the west side of the intervening moraine.

The higher plain is conspicuously pitted near its junction with its limiting moraines, thus indicating that the margin of the glacier which built the moraine, and associated kame, became buried beneath the sand and gravel deposited about its border. The higher summits of the till and gravel hills referred to, rise about sixty feet above the surface of the plain to the west, and the depressions between them are on a level with it.

The evidence just outlined, shows that the last glacier which withdrew eastward from the Menominee region, halted for a time at the locality where the moraines and kames extending north from Big Quinnesec Falls, is located, and to the west of its margin an extensive sand and gravel plain was formed.

The sand and gravel forming the plain was contributed principally by Menominee River, as is shown by the fact that its surface rises when followed up the course of that stream.

Although the plain is conspicuously flat, and seemingly horizontal over an area of about four square miles, just above its bordering moraines, the same deposit, when traced northward to the vicinity of Twin Falls, about eleven miles up stream, measured along the windings of the river, rises gradually to about 1,100 feet. Extensions of the same deposit, near Twin Falls, which were laid down by small streams coming from the uplands to the northeast, also have an upward gradient towards the sources of the streams with which they are associated.

Since the alluvial plain extending west and north from Big Quinnesec Falls, was formed, the Menominee has excavated a channel through the deposit, leaving well-defined terraces on the borders of the recent channel. In the process of re-excavation, the river was lowered upon an eminence in the bed rock at Big Quinnesec Falls, and a channel about 100 feet deep and a mile in length has since been excavated in the highly resistant material encountered.

It was the discovery of a rocky eminence beneath the sand and gravel of the plain which led to the origin of Big Quinnesec Falls, and of the Horse Race rapids above them. The work the river has done since its present course was established, is shown principally by the steep-sided canyon above the falls, a photograph of which is presented on Plate IB.

The sand and gravel plain below Big Quinnesec Falls, extends down the course of the Menominee to the vicinity of Vulcan, and there terminates abruptly against another small moraine trending north and south, which meets the river about half a mile west of the mouth of Sturgeon River. The relation of this plain to its limiting moraine, is essentially the same as the relation of the plain above Big Quinnesec Falls to the moraine with which it is associated. The lower plain is conspicuously pitted near its junction with the small moraine south of Vulcan, showing that in part the débris of which it is composed was deposited on or about residual masses of ice. Its surface, although seemingly level in its broader portions between the pits and basins and where spared by recent stream erosion, descends from about 1,020 feet near Quinnesec to approximately 900 feet adjacent to its limiting moraine. This descent is not gradual, however, but occurs principally on the west border of the small stream tributary to the Menominee, which has its source in the city of Norway. This valley was not excavated by the brook flowing through it, but the brook inherited the depression so to speak, from the preceding glacier. It is conspicuously irregular in outline, floored in part by till and bordered by escarpments of sand and gravel, which rise steeply to the border of the adjacent plain. The plain to the west has a surface elevation of about 1,020 feet, and extends westward to the moraine at Big Quinnesec Falls, and the much smaller plain on the east has an elevation of 900 to 920 feet, and merges with the moraine south of Vulcan.

The significance of the conditions just described is that the irregular valley, now occupied by the brook which flows southeast past Norway, was occupied by ice during the time the adjacent sand and gravel deposits were laid down, and is of the nature of a large pit or basin, similar in origin to the more definite and usually smaller and more regular pits in the surface of outwash deposits formed on the margins of glaciers.

The sand and gravel plain below Big Quinnesec Falls, like the similar plains up stream from that locality, has been extensively eroded by Menominee River, and conspicuous terraces produced, especially on the north side of the recent channel. The lowest of the step-like shelves in the series is the present flood plain of the river, which, in places is half a mile wide. Little Quinnesec Falls came into existence when Menominee River, in deepening its channel in the broad alluvial plain it had previously spread out, encountered an eminence in the bed rock beneath. The history of the falls is essentially the same as in the case of Big Quinnesec Falls, referred to above.

The thickness of the sand and gravel forming the plain below Big Quinnesec Falls, as shown by sections in the borders of the recent channel, is, in general, about eighty feet. Beneath the alluvium, is a sheet of reddish till, which is of the same character, and plainly a part of the extensive sheets of the same nature as the veneer of till on the adjacent uplands.

Special Features: The examinations that have been made of the sand and gravel plains briefly described above, serve to illustrate certain characteristics pertaining to such deposits, more completely than has, perhaps, previously been described.

One instructive series of facts is that the plains are not horizontal but have a downward slope in the direction of flow of the streams that formed them. Again, they are compound deposits and along each stream entering the depressed areas where they occur, extensions from their main or central portions are present, each tributary having a downward-sloping surface corresponding essentially with the grade of its associated stream, but as it seems with a somewhat steeper slope. In some instances extensions of the main alluvial deposits occupy valleys or depressions in which there are at present no surface streams. On leaving the broader portions of the deposits, where they form extensive plains, and entering the tributary valleys, one finds that the plain-like character changes to a narrow, valley-floor of alluvium, which, if trenched by a stream, is usually terraced on the sides of the channel that has been excavated.

The general features just referred to show that even the broader plains were stream-formed, and do not differ in mode of origin from the alluvial terraces of many stream valleys.

The surfaces of the alluvial deposits where they form plains tens of square miles in area, are not in general flat, as they would appear if affected only by the gentle slope the depositing stream gave them, but broadly undulating, and consist of a series of gentle swells perhaps half a mile or a mile across, separated by usually narrower depressions. The difference in elevation between the swells and sags, is, in general, some twenty or thirty feet.

The reason for this unevenness of surface seems to be due to unequal settling of the deposits in various parts since they were laid down. The depressions, however, merge by insensible gradations with well-defined basins and pits, such as are due to the melting of ice which was at one time covered or surrounded by the deposits, and some of the broad undulations may have been produced by a similar cause.

The bottoms of the larger and better defined basins and depressions are, in some instances, floored with till, and occasionally the elevations of the surface of the till rise higher than the surrounding plain of sand and gravel. In some instances, also, a depression of this nature is margined for a part of its periphery by till hills, and throughout the remaining part, by a sand and gravel plain. These features evidently indicate that the basin was formerly occupied by ice, thus preventing the deposition of alluvium. At times the isolated ice masses lay adjacent to till hills and were only partially surrounded by alluvium, and, in other instances, were completely margined by the alluvial deposits.

In association with certain well-defined pits in the plain to the south of Iron Mountain, there are large boulders imbedded in the sand and gravel deposit. One of these, exposed in a cut on the line of the Chicago, Milwaukee and St. Paul Railroad, about half a mile north of

Menominee River, is shown in the photograph forming Plate VIIB. To the north of where the boulder occurs, and beginning about 700 feet distant from it, is an extensive group of pits and basins. The explanation of the presence of the boulders in the midst of a broad deposit of sand and gravel, at a distance of fully two miles from the nearest upland, is that it was contained in or rested upon the surface of a detached mass of ice, which, on melting, gave origin to the neighboring depressions. This suggestion needs further confirmation, but, as it seems, the boulder rolled to its present position from the surface of an elevated mass of ice, which formerly occupied the depression referred to. Another suggestion which is pertinent in this connection, is that the boulder may have been carried to its present position by the stream which deposited the associated sand and gravel, assistance having been had from ice frozen to the stone. This process is illustrated, at the present time, by our northern rivers which break their coverings of ice during spring freshets and boulders buoyed up by attached ice are floated down their courses.

In one instance, about a quarter of a mile north of Menominee River, midway between the upper and lower Twin Falls, a depression in a sand and gravel deposit is margined for about two-thirds of its periphery by a raised rim of till. The basin is approximately five or six hundred feet across, and the rim partially enclosing it some twenty to forty feet high. In this instance, the débris composing the raised rim, seems to have come from the ice body which formerly occupied the depression.

The reason why elevated rims about the pits in sand and gravel plains are not more common, and also the scarcity of large boulders in the vicinity of such depressions as in this bottom, is, as one seems justified in concluding, because on the melting of the ice which once occupied the depressions, the adjacent material left unsupported, flowed into the cavities that were left, and the material which immediately margined the ice, was displaced and more or less completely buried.

The Sturgeon Plain.

To the east of the small moraine south of Vulcan, referred to above, there is a plain with a remarkably even and nearly flat surface, some four or five square miles in area, across which Sturgeon River flows in a narrow channel, for about four miles on nearing its junction with Menominee River. The plain is about half a mile wide where it margins Menominee River, but from a mile to two miles up the course of Sturgeon River, widens to two miles, and again contracts when followed farther to the northeast, and unites in the vicinity of Loretto, with ordinary alluvial terraces in the narrow valley which continues far to the northward. The surface of the deposit declines in the direction the Sturgeon River flows, but in its expanded lower portion is a seemingly flat plain. The material of which the deposit is composed, is, in large part, a coarse, well-worn gravel near Loretto, but in the plain near the Menominee, consists of exceedingly fine silt, which forms a layer about ten feet thick resting on coarse gravel.

The features of the alluvial deposit just referred to, and still others which it does not seem necessary to record at this time, indicate that it was laid down principally by Sturgeon River, and is of the same character as the Glacial or post-Glacial alluvium in many neighboring valleys, except in its broadly expanded southern portion adjacent to Menominee River. In this part the fineness of the silt of which it is composed and its essentially flat surface, shows that the waters of Sturgeon and Menominee Rivers were ponded and formed a lake at the time the silt was deposited. There are no terraces on the morainal hills bordering the plain, such as a deep lake might have been expected to leave, but the evidence indicates that the water was shallow, and the lake became completely filled with silt. The obstruction that held the lake was the rocky ridge which is crossed by Menominee River half a mile below the mouth of Sturgeon River and produced Sturgeon Falls. The river at the falls flows through a short post-Glacial gorge similar to the gorges at Little and Big Quinnesec Falls. The post-Glacial deepening of the channel of the Menominee at Sturgeon Falls has led to the drainage of the lake which formerly existed just above that locality, and permitted the streams, which subsequently flowed across its abandoned bed, to excavate channels in the silt of which it is composed, to a depth of between thirty and forty feet. The silt is yellowish or perhaps pinkish-brown in color, very fine in texture and sufficiently coherent to stand in vertical escarpments for several months and, as it appears, for one or two years. It is obscurely jointed, the joints being vertical or nearly so, and on the steep river banks favor the breaking away of portions of the material, leaving vertical and sometimes slightly overhanging escarpments.

Under the microscope, the silt is seen to consist principally of sharply angular quartz fragments, with which there are occasionally well-rounded sand grains of appreciably larger size. Some of the small angular grains adhere one to another as if lightly cemented, and as tests fail to show the presence of calcium carbonate, it is presumed the cementing material is silica or iron oxide. Occasionally a brownish or yellowish grain of some mineral other than quartz is present, which assists in giving a faint color to the material.

On subjecting a typical sample of the material to mechanical analysis, the results presented below, in the column headed silt, were obtained.

Mechanical Analysis of Silt and Loess.

	Silt.	Loess.	
Material retained on a 12-mesh sieve[1]........	0.00	0.000	per cent
Material retained on a 50-mesh sieve........	2.40	0.110	per cent
Material retained on a 100-mesh sieve........	4.69	0.285	per cent
Material retained on a 200-mesh sieve........	5.34	0.575	per cent
Material passing a 200-mesh sieve............	82.57	99.030	per cent
	100.00	100.00	per cent
Calcium carbonate, ($CaCO_3$)...........	None	0.98	per cent

On examining the portions retained on the coarser sieves with a microscope, it was apparent that they consisted principally of masses of fine angular grains of the same character as those which passed

[1] The sizes given refer to number of meshes to the linear inch.

through the 200-mesh sieve, but are adherent and apparently cemented together. Allowing for the grains thus united, it is judged that over ninety-five per cent of the material is sufficiently fine to pass through the finest sieve used.

The appearance of the silt in the field, and especially its yellowish color, evenness in texture, absence of stratification, and the manner in which it stands in vertical walls as well as its fineness of grain, etc., indicate a similarity to the loess of the Mississippi valley and other regions. Some comparison of the size of the grains composing the silt, and those of a typical sample of loess from near St. Louis, Mo., is given in the above table.

The Sturgeon River plain is highly favorable for agriculture, on account, as seems evident, of the physical condition of the soil, thus again suggesting a similiarity to loess. The silt, like the loess, also, is deficient in calcium carbonate, as is shown by the partial chemical analysis given above.

The incomplete comparison of the silt and loess, just made, is presented not only as an aid in describing the silt, but as a suggestion tending to strengthen the hypothesis that loess, in certain instances at least, is a stream deposited silt, and, in other instances, has been blown away from dry-flood plains and deposited on adjacent uplands.

The source of the quartz grains composing the silt of the Sturgeon plain is evidently the region occupied by crystalline rocks, presumably gneiss for the most part, which is drained by Sturgeon River. Some of the grains were, no doubt, derived from the quartzite near Loretto and perhaps also from the Potsdam sandstone in the same region. It is an assorted portion of the glacial meal which former ice-sheets ground from the surface of the rocks over which they passed.

The silt plain of Sturgeon River, as stated above, extends to Menominee River, on the north border of which it terminates in an escarpment about thirty-five feet high, which descends to the water. Adjoining the plain, and on a level with its surface, is a sand and gravel deposit which extends, for several miles, up the valley of the Menominee above the mouth of Sturgeon River, and forms a stream terrace. Below the highest terrace margining the river there are several other terraces. These features are similar to the corresponding records in many other portions of the valley of the Menominee, and of associated streams, but in one particular there is a conspicuous and instructive exception. On the north border of the river, a mile west of the mouth of Sturgeon River, there is a lake which is connected with the Menominee by a short water-way or bayou. The lake has an area of perhaps eight acres, and is adjacent on the west, to the south end of the small moraine referred to above as forming the west border of the Sturgeon plain. The basin of the lake is bordered on all sides by morainal hills and kames, except to the southwest where it is in part separated from Menominee River by conspicuous embankments of sandy gravel.

The conditions mentioned are represented on the photograph of a model of the lake basin and associated gravel deposits which form Plate XIIA. The model was made from the data presented on the contour map known as the Menominee Special Map, published by the U. S. Geological Survey, supplemented by field sketches, photographs, etc., but is not based on a detailed survey, and is to be considered simply as a sketch map. Photographs of the gravel bars partially enclosing the basin, are presented on Plate XIIB. The gravel bar marked A on the model, is a continuation eastward of the highest terrace on the north border of the valley of the Menominee upstream from the locality under consideration, and, as indicated in the illustration, is bounded on all sides, except the west, by a steep escarpment. The surface of the gravel bar is nearly level, and about thirty-five feet above the adjacent lake. Crossing the gravel bar near its west or proximal end, is an irregular steep-sided channel approximately seventy-five feet wide at the top, and about ten feet deep. This channel, at its southern end, opens out into the recent channel of the Menominee, and coinciding with it in elevation is a stream terrace. The bottom of the channel descends, when traced northward, to the level of the lake with the basin of which it communicates. This cross channel, is a small "hanging valley," its southwest end being above the bottom of the depression into which it opens. The appearance of the bar, as seen from the north shore of the lake it borders, is shown on Plate XIIB.

To the southeast of the broad distal end of the bar just described and also in part separating Menominee River from the adjacent lake, is another gravel deposit, having a tapering end which is curved and extends into the lake basin, as shown on Plate XIIA. Something of the form of this gravel spit may also be recognized in the photograph forming Plate XIIB., where it is marked by the letter B. This curved or hooked spit, like its associate, is composed of gravel and sand. Its broad southeast portion has the same elevation as its companion to the west of the bayou, and on the east expands and becomes a part of the adjacent Sturgeon plain. In reference to the direction of flow of Menominee River, the curved spit is directed up stream, and its curved distal end is prolonged into the lake basin.

Between the two gravel deposits, as shown in the accompanying illustrations, the ground is low and marshy, and during times of high water in Menominee River, is flooded, and the lake becomes larger than during low water stages.

The mode of origin of the gravel deposits to which attention has been invited, was as follows: The basin of the lake partially enclosed by them, is of the nature of a pot-hole, left when the last ice-sheet melted, which formerly covered the region. As the border of the former glacier withdrew eastward, the lower portion of the valley of Sturgeon River was occupied by a shallow lake, which extended into the valley of the Menominee up stream from the locality where the Sturgeon now joins it, and flooded the pot-hole referred to. The water contributed by the Menominee formed a current in the narrow arm of the former lake which it entered, and the débris brought by the river was deposited and formed the broad, flat-topped embankment to the west of the bayou. After this embankment had acquired its present form, a current from the west set across it and excavated the curving channel which crosses its distal portion. This cross channel continued to be occupied by water until the Menominee subsided to the level of the second terrace bordering its modern channel. At the same time that the western embankment was being built, an eddy flowed into the embayment formed by the lake basin from the southeast, and built the curved spit. When the lake, which occupied the Sturgeon plain, was drained, owing to the deepening of the channel of the Menominee at Sturgeon Falls, the river excavated its present channel, the depth of which is about thirty-five feet below the surface of the embankments under consideration.

The valley of Menominee River, for a distance of a few miles above the mouth of Sturgeon River, has, to a considerable extent, been cleared of its primeval forest, and is now under cultivation. The river terraces are well exposed, and together with the associated gravel embankment, moraines, kames, silt plains, etc., serve to make it one of the most instructive as well as one of the most beautiful portions of the Menominee region.

Below Sturgeon Falls, no alluvial deposits similar to the extensive sand and gravel plains, etc., have been definitely recognized on the Michigan side of the Menominee, but, as is presumed, extensive accumulations of the nature referred to, will be discovered, when search is made for them, on the Wisconsin side of the river.

Post-Glacial Stream Erosion.

Since the widely extended alluvial plains and valley gravels described above were deposited, the streams to which they owe their origin, have, in a large number of instances, excavated channels in them. It is evident that the streams which at one time deposited gravel and sand in the valleys through which they flowed, so as to deposit débris and *aggrade* them in a conspicuous manner, have been able to remove a part of the material they previously laid aside.

The explanation of the change referred to, as is well known, is that the streams, as long as they were supplied directly by the melting of glaciers, received more débris than they could carry away, and deposition occurred. This process led to a steepening of the gradients of the streams in an endeavor, so to speak, to produce a slope sufficiently steep to insure greater velocity and hence better facilities for transportation. As soon, however, as the glacier disappeared, the chief source of supply of débris for transportation was discontinued and the streams, although perhaps of smaller volume than before, were no longer overloaded, and in flowing down aggraded slopes of considerable declivity, began to carry away the material they had previously laid aside. That is, a readjustment of the grade of the stream channels was begun to meet changing conditions. When the streams began to erode instead of aggrade, they deepened their channels along the courses they chanced to occupy on their previously formed flood-plains and alluvial bottoms of valleys, and did not necessarily follow their pre-Glacial channels, but took new courses in many instances and especially in crossing broad sand and gravel plains. During the preceding process of aggrading, the stream deposits were laid down on a more or less uneven, till-covered, rock-surface. In places rocky hills and ridges were surrounded by alluvial material, and still stand like islands above the surfaces of the alluvial plains, but in other instances considerable elevations were completely buried. When the streams, in excavating their modern channels, chanced to cross a buried hill or ridge, their work of erosion was delayed, cascades and rapids produced, and the energy of the stream above the obstructions was largely directed to the broadening of their valleys and the spreading out of new flood plains.

Illustrations of the encountering of bed rock by the post-Glacial streams, in the manner just cited, and the occurrence of water falls or rapids on the down stream side of the sills of hard rock that were encountered, are furnished at each of the several falls in Menominee River and its larger tributaries. The most conspicuous example of stream erosion of post-Glacial date, is furnished by the picturesque gorge of the Horse Race rapids, just above Big Quinnesec Falls, a photograph of which is reproduced in Plate IB.

The industrial importance of the numerous water-falls and rapids just referred to, is indicated by the data concerning the water-power along the Menominee, presented on a previous page, and furnishes an illustration of one of the many ways in which the Glacial epoch exerted a direct and important influence on human affairs.

When a stream, after deepening its channel in alluvium, and encountering bed rock, continued to deepen its channel, the rate was not uniform, but the stream was held by certain sills of resistant material, longer than at other horizons. At each halt in the process, the stream above the obstruction widened that portion of its channel, perhaps leaving portions of previous and higher flood plains as terraces. Throughout the post-Glacial stream channels of the Menominee region terraces on the sides of the modern channels, are of common occurrence. Conspicuous and beautifully shaped examples occur above Sturgeon Falls, and above Little Quinnesec Falls, particularly to the south of the town of Quinnesec, and are present adjacent to the Menominee to the south and west of Iron Mountain, along the border of Bois Brulé, Iron, Paint and Michigamme rivers, and, in fact, along every considerable stream of the region.

In the numerous instances referred to, when a series of terraces is present, the highest is the surface of the alluvial deposit left by a stream when supplied with glacial débris, and represents the level to which the valley it occupies was formerly filled. In the case of the recent channels excavated by Menominee River, through broad alluvial plains, the highest terrace is the surface of the plain itself, and, in some instances, is from five to ten miles across. The lower terraces are portions of flood plains, left in succession from above downwards, as the streams deepened their channels, and the lowest of all, usually not recognized as a terrace, but which may, in part, be left as a terrace of the adjacent stream continues to deepen its channel, are the present flood plains or bottom land.

The process of terrace forming outlined above is, however, not the only one by which stream terraces may be produced.

If a stream which has aggraded its valley enters a lake, and later the surface of the lake is lowered, the stream will seek a new adjustment with its receiving water body, and deepen its channel at its mouth to the lower horizon. This would give greater energy to the stream in the lower part of its course, and the process of deepening, progressing up stream, would lead to the abandonment of the previous flood plain, and the production of another flood plain at a lower horizon. During this process, portions of abandoned flood plains might remain as terraces. It is evident, also, that a similar result might be produced if the land down which streams flow to a lake, should be elevated, the lake surface retaining its former position.

In the Menominee region the streams flow to Green Bay, an arm of Lake Michigan. The water occupying the Lake Michigan basin, however, formerly stood higher on its shores than at present, and one or more terraces along the lower courses of the streams which discharge directly into Green Bay, corresponding with former levels of the water in that basin, should be present. Sufficiently critical studies to bring out the correlation of terraces with lake levels, however, have not been made.

In the case of each of the changes in conditions just cited, namely, variations in the rate at which a channel is deepened across a sill of rock, and the lowering of the surface of a lake into which a stream flows, the terraces that result are up-stream from the locality where the changes occur which furnish the control. In certain instances, however, as below Sturgeon Falls, terraces are present below an obstruction, through which a channel was excavated, and appear to have resulted from another variation in the conditions present.

As already stated, when a stream receives more débris in its upper course than it can carry through its less steep lower course, deposition results; and in case the supply of débris is stopped or sufficiently decreased in amount, the stream will begin to erode a channel in its previously formed deposits, and terraces may result. In the case of the obstructions which lead to the production of Big Quinnesec Falls, and of other similar falls and rapids in the Menominee region, the river above the obstructions flowed across thick deposits of sand and gravel, and when their channels were lowered in the resistant sills, rapid erosion was initiated up stream from where the change occurred, and, as it seems, the débris removed furnished too great a load for the stream to carry in the portion of its course below the sill in which it had cut a notch, and deposition resulted. Later, when the portion of the river above the obstructions became adjusted to the change in conditions, the supply of débris from above decreased in amount, and the stream was enabled to deepen its channel in the débris deposited below the obstruction, and terraces may result.

Terraces formed in this manner are due to changes that take place up stream from the locality where they occur. That is, the controlling condition is located where the terraces begin as one descends a stream, and not at their down-stream ends, as is most commonly the case.

Examples of terraces which, so far as indicated by the evidence in hand, seem to have been formed in the manner just considered, are present on the border of the post-Glacial gorge of the Menominee, below Sturgeon Falls, and are best displayed on the Wisconsin side of the river. The terraces have a conspicuous down-stream gradient, and begin at their up-stream ends at the falls. How far down stream they extend has not been determined, but the steepness of their gradients, indicate that they cannot be prolonged for more than a few miles before reaching the level of the present stream. And, besides, no obstruction is present in the river below the falls, which would lead to such an accumulation of débris as is indicated by the terraces present, although, as is obvious, a former ice dam may have performed this function.

The suggestion just offered in reference to the origin of the terraces immediately below Sturgeon Falls, seems to be applicable also to similar terraces present down stream from other falls in the same river, but in these instances the records are more complex, and other conditions than those just referred to appear to have exerted the major control.

The explanation just suggested of the mode of origin of certain terraces down stream from obstructions in the course of Menominee River, is not based on sufficient evidence to make it worthy of unqualified acceptance, but is offered provisionally, and with the hope that it will stimulate additional observations, on the part of future visitors to the instructive localities referred to.

Soils.

Owing to the scouring action of the glaciers which have passed over the Menominee region, practically all the products of pre-Glacial rock-disintegration and decay, which may have been present, were removed and only an insignificant amount of weathering of the hard rocks has subsequently taken place. All of the blanket-like deposit of loose débris covering the land and consequently the soil, is essentially of glacial, or glacio-fluvial origin. To some small extent the material has been removed and redeposited through the action of post-Glacial streams, and over large areas the partially decayed vegetation of swamps and marshes, has accumulated and formed layers of peat. The surface portions of these various deposits are suitable in various degrees for the growth of plants, and may be designated by the general term soil. Beneath the surface film, usually of a few inches deep which is more or less enriched by vegetable débris, is the sub-soil, consisting of essentially the same material as the soil, but lacking its organic ingredients. The soils and sub-soils grade one into the other, and in the present discussion are not separately considered.

As the soils are a portion of the superficial blanket of rock waste, and for the most part owe their leading characteristics directly to the nature of the deposits on which they rest, and into which they merge by insensible gradations, they may, with the exception of the swamp accumulations, be classified in the same manner as the various glacial, glacio-fluvial deposits, etc., to which they pertain.

Knowing the character of the soil pertaining to each of the classes of deposits which is indicated on the map forming Plate III, the map can be read in terms of soil and much be determined in reference to the agricultural nature of the region represented. It should be remembered, however, that, owing to the small scale of the accompanying map, no attempt has been made to represent the many swampy areas in which peat or muck soils overlie the deposits of glacial, fluvial and lacustral origin. Swampy areas occur throughout the Menominee region, and, as is probable, nearly one-half of its entire surface is at present too wet to permit of cultivation. With proper drainage, however, large numbers of the swamps can be rendered serviceable for agriculture, but it is doubtful if such reclamation, on a large scale, will be profitable for several decades to come.

On areas represented on the accompanying map as being covered with till, except in the swampy depressions as already stated, the soils are sandy loams, at times containing numerous stones and boulders. Of the till soils there are two general classes; one the red sandy loam of the region formerly occupied by the Green Bay lobe of the Wisconsin ice-sheet, and, in general, extending from Chicagon Lake eastward to Green Bay; and the other the gray sandy loam of the moraines deposited by the Chippewa lobe of the same ice sheet, and forming the surface to the west of the lake mentioned. The red and gray soils differ in composition, as is indicated by the nature of the stones and boulders they contain, and is shown also by a few partial chemical analyses that have been made.

The red till, particularly to the east of Waucedah, consists largely of limestone fragments, and its finer portions are calcareous, except when leached by weathering; while the gray till, so far as observed, is without limestone fragments, and, as shown by one analysis, is free from calcium carbonate. The gray till is more stony and contains a larger proportion of clay-like material than the red till, and, as it seems, is also better adapted for agricultural purposes. The favorable returns obtained from cultivating the soils composed of gray till, is an assurance that the region it occupies will, in time, become one of the richest agricultural portions of the Northern Peninsula of Michigan.

The red till presents some variations, the most pronounced of which is the fineness of the surface portions of drumlins and of drumlin troughs in contrast with the generally coarse material at a depth in excess of a few inches. Some account of these soils and of the advantages the drumlin areas for farming purposes were stated in my previous report.

The physical character of the till soils is indicated to some extent by the following mechanical analyses of several samples from various localities. The samples, after pebbles or stones, if any were present, were removed, were separated into different portions by means of sieves ranging from 12 to 200 meshes to the linear inch, as stated in the following table:

Mechanical Analyses of Soils.

BY R. A. PLUMB.

	No. 1.	No. 2.	No. 3	No. 4.	No. 5.
Residue on 12-mesh sieve...	.88	6.63	1.39	1.52	2.4
Residue on 50-mesh sieve...	18.16	20.60	26.58	19.69	38.44
Residue on 100-mesh sieve...	8.59	44.62	25.52	17.67	18.00
Residue on 200-mesh sieve...	12.44	9.8	12.73	10.23	3.32
Passed thro' 200-mesh sieve..	59.93	18.37	33.78	49.1	37.84
Total	100.00	100.00	100.00	100.00	100.00
Per cent of Calcium Carbonate, $CaCO_3$...........	None	24.72	10.75	None	None

Sample No. 1.—Red till from one foot below surface of a drumlin, one-half mile south of Faithorn Junction (N. E. ¼ of Sec. 21, T. 38 N., R. 28 W.) Underlying formation; Basement Complex.

Sample No. 2.—Red till from six feet below surface of a drumlin, one mile west of Hermansville (N. W. ¼ of Sec. 10, T. 38 N., R. 27 W.) Underlying formation; Calciferous.

Sample No. 3.—Red till from one foot below surface of till sheet, two miles north of Waucedah (Sec. 15, T. 39 N., R. 28 W.) Underlying formation; Potsdam sandstone.

Sample No. 4.—Red till from one foot below surface of till-sheet at Mastodon Mine (Sec. 1, T. 42 N., R. 33 W.) Underlying formation; Algonkian [Huronian].

Sample No. 5.—Gray till from one foot below surface of moraine. five miles west of Iron River (Sec. 7, T. 45 N., R. 35 W.) Underlying formation; Algonkian.

The fractional parts of the several samples, when examined with a microscope, are seen to be composed principally of angular quartz sand. In the case of the red till the color is due, for the most part, to a ferruginous incrustation on the sand grains.

Determination of the per cent of calcium carbonate, as was surmised, might indicate whether or not the till in the several instances was derived from the neighboring bed rock, but the data in this connection are too incomplete to be of much value. The depth at which samples were taken seems to be an important condition in this connection, as the leaching of the surface portions of the deposits has produced changes in the per cent of the more soluble constituents they contain. In order to make a satisfactory comparison of the chemical composition of the material forming till-sheets, drumlins, etc., and of the neighboring hard rock formations, samples of the former, from a uniform depth below the superficial zone of weathering, need to be collected.

The till soils are, in almost all instances, highly favorable for agriculture, providing the conditions of slope insure sufficient drainage, which is usually the case. The best of the till soils, however, are those occurring on the surfaces of drumlins and of drumlin troughs, and on the gray moraines. In a few instances, as in the case of the small moraines near Vulcan, the till soils are conspicuously sandy, resembling in this respect the soils of eskers, kames, etc., and too light for general agricultural purposes. The surfaces of the moraines referred to are in part under cultivation, however, and at least during humid seasons produce favorable results when sown with certain cereals.

The soil of the eskers, kames and alluvial plains are, in almost all cases, highly sandy and open textured, or "light" in distinction from more clayey or "heavy" soils. They are not, in general, favorable for agriculture, and especially on the broad sand and gravel plains, are so thoroughly under-drained that the upper limit of the zone of saturation, or water-table, is deep below the surface and only such plants as are adapted to dry soils can survive. For the most part, the sand and gravel plains are occupied with an open growth of jack-pine, which serves as a label indicating this usually dry condition.

The peat or muck soils which occupy the depressions among the morainal hills, drumlins, etc., are, in many instances, so far as physical and chemical conditions are concerned, favorable for agriculture, and especially for celery raising, etc., but, owing to their permanently wet condition, are at present uncultivated. The principal economic value of the extensively wet area seems to be for the growth of timber, such as spruce and cedar, and on account of the peat they contain. The moss, *Sphagnum*, growing in many of the swamps, furnishes a desirable material for certain stable uses as bedding for stock and for packing living plants, such as nursery shrubs, for shipment.

Although lumbering and mining are at the present time the leading industries of the Menominee region, even the hasty examination of the soils that has been made, and such facts as are known concerning the climate, as well as the evident prosperity of the comparatively few farms that are under cultivation, show that the future industrial development will, to a large extent, be based on agriculture. The principal agricultural industry for which the region is best adapted, is hay raising and dairying, the growing of cereals, sugar beet and other root crops, and hardy fruits and vegetables. The lands that are now under cultivation are, for the most part, occupied by immigrants from central and northern Europe, and every inducement should be offered which will lead to an increase in the numbers of these people.

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