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Professional Paper 154—A

MORAINES AND SHORE LINES OF THE LAKE SUPERIOR BASIN

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CONTENTS

ILLUSTRATIONS

INTRODUCTION

SCOPE OF THE REPORT

The district discussed in this report embraces the entire northern peninsula of Michigan and the parts of northern Wisconsin and northeastern Minnesota that were covered by a readvance of the Superior lobe of the Labrador ice sheet late in the Wisconsin stage of glaciation. Part of the northern peninsula of Michigan is outside the limits of the Lake Superior drainage basin, but the Superior lobe passed over it in this readvance to reach the basins of Lake Michigan and Lake Huron. There is, however, a small area in Iron County and southeastern Gogebic County, Mich., which was not overridden by the readvancing Superior lobe. This area is included in the present report in order to bring out the contrast between its features and those produced by the Superior lobe at the later time. A similar comparison is also made between the glacial features of the Superior lobe in northern Wisconsin and northeastern Minnesota and those immediately outside the limits of the readvance.

TIME GIVEN TO THE INVESTIGATION

The studies on which this report is based began in the field season of 1905, during which three or four counties in the east end of the northern peninsula of Michigan were examined. No further work was done in this district until 1909, when studies were made along the immediate border of Lake Superior in Michigan and to some extent in Wisconsin and Minnesota. This work was continued in 1910 and 1911, so that nearly the entire district had been examined by the end of the 1911 field season. In 1912 about three weeks was spent in running levels to shore lines in the northern peninsula, and in each of three subsequent years—1913, 1914, and 1916—this district received three or four weeks' attention in connection with other studies in Minnesota. In 1919 about five weeks was spent in Menominee County, Mich., and a number of places farther east, including Drummond Island. The entire time taken in field work in the several years amounts to about 163^ months by the writer and about 6 months by his assistants.

WORK BY ASSISTANTS

The assistants were furnished by the Michigan Geological Survey during part of the work in that State. Although they did very little independent work on the surface geology, they were very helpful in running out side lines and filling in intervals between traverses made by the writer, as well as by their companionship in breaking courses through the woods in unsettled or very thinly inhabited parts of the district.

G. E. Tower, a student of the University of Michigan, and W. C. Gordon, of the Michigan Geological Survey, assisted in 1905; L. H. Wood, of the Western Normal

School of Michigan, in 1908; I. D. Scott, of the geological department of the University of Michigan, in 1910; L. G. Hornby, university student, in 1912; and R. W. Peterson, of the Michigan Agricultural College, in 1919. In the Minnesota work assistance was furnished by the State Geological Survey, connected with the University of Minnesota. This included the services of A. H. Elftman for a few days in 1913 and a considerable part of the services of F. W. Sardeson for a period of years. The expenses of the work by Doctor Sardeson prior to 1912 were met by the United States Geological Survey. The Wisconsin Geological Survey contributed the services of F. T. Thwaites and an assistant in running levels to high shore lines at Bayfield and on Oak Island. Some of the writer's work in Wisconsin was done in company with Samuel Weidman, of the Wisconsin Geological Survey, who was making investigations preparatory to a general report of his own on northern Wisconsin for the State survey.

NATURE OF COUNTRY AND CHARACTER OF INVESTIGATION

The present report on the glacial and lake features of the Lake Superior Basin is made as a report of progress rather than of a completed study. Owing to the imperfect development of roads or lines of travel, the sparseness of settlement, and the uncleared and brushy condition of much of the land bordering this basin, it was found to be impracticable to work in the detail that is done in more fully cleared and well-settled districts. As a consequence there has been very little consecutive tracing of the courses of shore lines and of other features that need close work for complete mapping. The entire set of beaches has been crossed along a number of lines leading from the shore of Lake Superior up to the limits of lake action, but these traverses have only served to show that the development of beaches was not at all uniform, there being a larger number of definite beaches on certain lines of traverse than were found on neighboring lines. It has thus become apparent that a complete correlation of beaches can be made only by detailed work that will entail much more time and expense than it has seemed best to allot to the study of the region at present. The extent of lake action has been determined with close approximation, however, and a large amount of information concerning the tilting of shore lines has been collected. The direction of the melting away of the border of the ice sheet has been somewhat fully worked out, and the relation of the lake stages to the ice has been determined to some extent. There are, however, a few matters of uncertainty as to the correlation of some of the moraines with shore lines that it has been found difficult to clear up, and for these a tentative correlation is the best that can now be given.

RESTRICTION TO LATE PART OF GLACIAL EPOCH

This region has experienced not only repetition of glaciation from one direction but also a marked shifting of ice movement in the last glacial stage, so that transportation of glacial debris and striation of rock ledges are far from uniform in direction. Thus at times the ice passed southward across the west end of the Lake Superior Basin with a surprising disregard of the topography, whereas at other times the ice movement was markedly controlled by the topography, and the axial direction was through the basin from its northeast to its southwest end. The present report deals almost entirely with the latest ice movement that affected the Lake Superior Basin. The disappearance of the ice from this basin occurred very late in the Wisconsin stage of glaciation. Indeed, this basin seems to have been about the latest part of the northeastern quarter of the United States to lose its ice covering.

This report supplements Monograph 53 by carrying the description from the north end of the Huron and Michigan Basins to the west end of the area of the great Laurentian lakes. Taken in connection with that monograph, it sets forth how the ice front made its final retreat and how ponded waters were formed in front of it; how earth movements as well as ice barriers have been influential in controlling the extent and the outlets of the waters; and how the present Great Lakes have come to have their drainage connections and discharge to the Gulf of St. Lawrence. As yet there j is lacking an adequate report on the Green Bay Basin and certain other parts of the west side of Lake Michigan, though the features on the west side of the south end of the basin have been covered by the writer in Monograph 38 and those of southeastern Wisconsin by W. C. Alden in Professional Paper 106. There is also lacking an adequate study and treatment of the Ontario Basin, the Georgian Bay Basin, and the northern part of the Superior Basin—much of which falls to the Canadian geologists.

EARLY EXPLORATIONS AND INVESTIGATIONS

The Lake Superior shores were visited by missionaries, explorers, and traders as early as the second half of the seventeenth century, or fully 250 years ago. A map of Lake Superior coast line published in Paris in 1672 shows that most of the shore had been explored by persons skilled in observation and mapping. This map is reproduced in the Foster and Whitney report on the Lake Superior land district published in 1850. An interesting compilation of journals of these early explorations, by Louise Phelps Kellogg, entitled "Early narratives of the Northwest, 1634-1699," was published by the Scribners in 1917.

Over a century ago, in 1820, Henry R. Schoolcraft conducted a scientific expedition to the upper Great Lakes, giving attention to their shore features as well as

the mineral formations. He noticed evidence of lake action at high levels in the form of both shore lines and lake deposits. These features were also noted by the British traveler Dr. John Bigsby at an even earlier date, his observations having begun in 1817 and his papers being published in 1821. A paper by H. W. Bayfield outlining the geology of the Lake Superior basins appeared in 1829. A report by Douglass Houghton on the copper of the Lake Superior Basin appeared in 1834, and his offical reports as State geologist of the First Geological Survey of Michigan for 1840, 1841, and 1842 deal to some extent with the northern peninsula. After the discontinuance of this geological survey arrangements were made by Houghton with the United States General Land Office to combine a geological survey with the linear land survey in the northern peninsula. This work, which began in 1845, was terminated near the end of the first field season by the drowning of Houghton in Lake Superior in October, 1845. His notes and maps, however, were brought out the following year by Bela Hubbard, and with them the notes of William A. Burt, an engineer in the land survey. The township plots made in the survey carry numerous notes on the geology and topography. The cliffs marking high shore lines are accurately shown in many places and for considerable distances. The Land Office report for 1847 contains geologic observations by John Locke on the northern peninsula of Michigan.

Brief reports on the Lake Superior mineral land district were issued in 1845 and 1846 in congressional documents, which the writer has not seen. One of 22 pages, with maps, by John Stockton included reports by J. B. Campbell, G. N. Sanders, and A. B. Gray. Another of about 25 pages was prepared by William Bartlett and David Tod.

The transportation of a boulder of copper from the south shore of Lake Superior by drift agencies and the occurrence of drift furrows, grooves, scratches, and polished surfaces were brought to notice in 1847 by Forrest Shepherd in two articles in the American Journal of Science.

In 1847 Congress passed an act providing for geologic exploration of the Lake Superior land district, and C. T. Jackson was appointed to lead the survey. His explorations were carried on for two field seasons and a report of about 800 pages was issued.[1] This report refers briefly (p. 389) to the occurrence of several terraces, each of which marks an ancient lake level; also to lake action at high level on the Pictured Rocks, between the present towns of Grand Marais and Munising. The bouldery tracts on the site of the present city of Sault Ste. Marie were also correctly interpreted as the product of a higher lake level.

On the resignation of Jackson the survey was continued and completed under the direction of J. W. Foster and J. D. Whitney. Their reports, commonly known as the Foster and Whitney reports, embrace a volume of 224 pages on the copper lands, submitted as Part I in April, 1850, and a report of 406 pages on general geology and the iron region, submitted as Part II in November, 1851. Foster and Whitney were aided in the field work by S. W. Hill and E. Desor and by James Hall, who served as paleontologist. Their report contains papers by I. A. Lapham and by Charles Whittlesey, chiefly on the Wisconsin portion of the district. The studies set forth in Part II extended around the entire lake border of the northern peninsula as far as the head of Green Bay and embraced the islands from Drummond Island to Mackinac Island. Desor presented in this report and also in papers for the Boston Society of Natural History, the American Journal of Science, and foreign journals discriminating and interesting discussions of the surface geology. He inclined, however, to the view that the surface boulders and the surface sand at all altitudes are due to the action of lakes rather than of glaciers, but was correct in holding that the lakes succeeded the glaciers in occupying this country. He discussed in some detail old shore lines on Mackinac Island. Whittlesey contributed a chapter to the Foster and Whitney report on the fluctuations in the level of the present lakes and on magnetic variations.

In 1847, by congressional action, a survey of the Chippewa land district of Wisconsin was authorized, and D. D. Owen was appointed as the head of the survey. His report of 134 pages, submitted in April, 1848, appears as Senate Executive Document 57 of the Thirtieth Congress. It embraced a report by his assistant, J. G. Norwood, and covered a considerable part of northern Wisconsin, including notes of journeys through the district on different routes. These notes are essentially a journal, with but little generalization or interpretation, owing to the insufficiency of the data. Pains were taken with barometric observations, in order to obtain reliable data as to the altitude of Lake Superior. The report is embellished with artistic sketches by Owen, and the map is of interest in showing the state of knowledge of lakes, drainage, and rock outcrops. Studies were continued by Owen and Norwood after making this preliminary report. Norwood's work, embracing the field seasons of 1847, 1848, 1849, and 1850, was the basis for a report of about 200 pages, included in Owen's "Geological survey of Wisconsin, Iowa, and Minnesota," published in 1852. It comprised the Minnesota as well as the Wisconsin shore of Lake Superior and extended across to Mississippi, St. Croix, and Wisconsin Rivers. The conditions of streams as to rapids and rock outcrops, the lakes, and the general topographic features are well brought out. It was also noted that there are swampy channels across the divide between the Great Lakes and Mississippi drainage basins at several places. In this final report only a few pages were contributed by Owen on the district bordering Lake Superior.

[1]Messages and Docs. 1849-50, pt. 3; 31st Cong., 1st sess., S. Ex. Doe. 1, vol. 3, 1849.

A chapter by Charles Whittlesey on the Wisconsin part of the country bordering Lake Superior appears in Owen's report just cited. It discusses the features

resulting from glaciation and from lake occupancy and considers the clays to be fresh-water deposits. In 1851 Whittlesey brought out two papers, one of which is incorporated in Foster and Whitney's report, and deals with low beaches on the borders of the lakes now referred to the Nipissing Great Lakes, and the other is a general paper on the superficial deposits of the "northwestern part of the United States" (that is, Ohio, Michigan, Illinois, and Minnesota), published in the Proceedings of the American Association for the Advancement of Science. Whittlesey also published brief papers in the Cleveland Annals of Science in 1853 and 1854 on the drift and "drift etchings" of this region.

At about the time surveys were in progress under Foster and Whitney and under Owen a study of the features of the Lake Superior region was made by Louis Agassiz, the results of which appear in the volume of 428 pages entitled "Lake Superior; its physical character, vegetation, and animals compared with those of other and similar regions, with a narrative of the route by J. Elliott Cabot," issued in 1850. This was preceded by a short paper published in the Proceedings of the American Association for the Advancement of Science for 1849 on the "Terraces and ancient river bars, drift, boulders, and polished surfaces of Lake Superior" in which the terraces were referred to lake action. A chapter of the volume mentioned, "Erratic phenomena about Lake Superior," was published in the American Journal of Science in 1850. The opinion is expressed in this volume that earth movements rather than the cutting away of a land barrier have brought about changes in the lake level. The influence of the ice sheet as a barrier was not mentioned, though Agassiz, like Desor, considered glacial action to have operated during at least part of the period of drift deposition.

From about 1855 to 1870 there appears to have been little study of the surface features of the Lake Superior Basin in progress in any of the three States bordering the lake, and writings on this subject were restricted to an occasional brief paper. A paper by Charles Whittlesey on "Fresh-water glacial drift of the Northwestern States" (Ohio to Minnesota) was issued in the series of Smithsonian Contributions to Knowledge in 1866. In 1870 G. R. Stuntz, a land surveyor, published a note in the Proceedings of the American Association for the Advancement of Science on the rise of water in the southwest end of the Superior Basin and the encroachment of Lake Superior on areas that once sustained forest growth, as shown by the presence of stumps. In 1871 N. H. Winchell contributed a short paper to the American Journal of Science suggesting that Lake Superior at a former high stage had discharged southward through the Au Train-Whitefish Valley to Little Bay de Noc, at the north end of Green Bay.

There was in this period a State Geological Survey of Wisconsin, under the direction of J. G. Percival in 1855 and 1856 and of James Hall and J. D. Whitney for a few years later, but its investigations pertained largely to the fossiliferous rock formations, including the geology of the lead region. A State Geological Survey of Michigan, under the direction of Alexander Winchell, was instituted in 1859 and issued a report in 1860. This report pertains almost entirely to the southern peninsula, and studies by Winchell in the northern peninsula were restricted largely to the vicinity of Drummond Island and along St. Marys River up to the Sault.

The State Geological Survey of Michigan was revived in 1869 and, under the direction of Alexander Winchell, studies were pursued for four years in the northern peninsula on the iron-bearing formations by T. B. Brooks, on the copper-bearing formations by R. W. Pumpelly, and on the Paleozoic formations by Carl Rominger. The results of these investigations are embraced in volumes 1 and 2 of the Geological Survey of Michigan, which contain only incidental notes on the surface geology, chiefly in the Rominger report. A continuation of the investigation of the iron formations of the northern peninsula was made by Rominger as State geologist in 1876 to 1880, and his report forms volume 4 of the Geological Survey of Michigan. This volume also contains but little material on the glacial deposits, but it covers the topography in some detail.

A State Geological Survey of Wisconsin was organized in 1873, with I. A. Lapham as State geologist and R. D. Irving, T. C. Chamberlin, and Moses Strong as assistants. The northern part of the State was assigned to Irving, who, with E. T. Sweet, covered most of the area bordering Lake Superior. The variations in the topography and structure or texture of the glacial deposits are set forth in a general way in volume 3 of the Wisconsin Geological Survey, and also the evidence of lake action up to heights of 300 to 500 feet above Lake Superior. The reports were published under the administration of T. C. Chamberlin as State geologist, and the glacial interpretations were thus brought to a standard corresponding to that developed by Chamberlin in his studies of glacial formations in eastern Wisconsin.

The State Geological and Natural History Survey of Minnesota was organized in 1872 under the direction of N. H. Winchell, State geologist, and the work was carried through vigorously to its completion in 1900. The northeastern part of the State was studied with considerable care by N. H. Winchell and U. S. Grant. The rock formations received the major part of their attention and that of their assistants, A. H. Elftman, J. E. Spurr, and H. V. Winchell, and of Alexander Winchell, who spent some months in the region. The principal moraines, the high shore lines, and the bearing of glacial striae were studied in the field and briefly discussed in the reports. Warren Upham made a more special study and prepared a comprehensive outline of the glacial and lake features of northeastern Minnesota for the annual report for 1893, and Grant and Elftman prepared papers for the American Geologist dealing with special features of the drift in that part of the State. A. C. Lawson ran several lines of levels back from the Lake Superior shore to determine the height of the old lake levels. The

results appear in the Twentieth Annual Report of the Minnesota Survey for 1891. It seems that Lawson did not reach the highest limits of lake action with these levels, except in the vicinity of Duluth, and did not trace the beaches across the intervals between the lines of levels sufficiently to establish their correlations. His results, therefore, throw but little light upon the amount of uplift any particular beach has suffered. In 1901 N. H. Winchell prepared a special paper on the glacial lakes of Minnesota, which was published in the Bulletin of the Geological Society of America and describes the relation of lakes to the retreating ice border. Most of the material embraced in this paper had been presented in his official reports some years earlier.

The moraines and ice lobes are graphically delineated in Chamberlin's volume 1 of the Wisconsin Geological Survey for the region bordering Lake Superior and also in his paper on the terminal moraine of the second glacial epoch published in the Third Annual Report of the United States Geological Survey, for 1881-82. The relation of the Superior basin to the lobation of the ice is particularly set forth. Though Chamberlin's conclusions were correct in the main, it now appears that the Superior lobe had its greatest extension westward into Minnesota prior to the ice invasion from Manitoba which brought in the gray drift; also that the movement through Keweenaw Bay did not have sufficient strength to extend to the Chippewa Valley, the Chippewa lobe being fed by ice carried from the part of the basin west of the Keweenaw Peninsula.

Several papers dealing with shore lines of this region have been brought out by F. B. Taylor. The earliest was one on the highest shore of Mackinac Island, published in the American Journal of Science in 1892, and others in the next five years came out in that journal and the American Geologist. It was through Taylor's studies that the Nipissing Great Lakes and North Bay outlet became clearly differentiated from Lake Algonquin, and much of the know ledge of the Algonquin beach in the Huron and Superior Basins has been furnished by him, largely through studies carried on at his own expense.

Although much work has been done by J. W. Spencer on the shore lines of the Huron, Erie, and Ontario Basins, he seems to have done but little within the region embraced in this report, and this region is mentioned by him only in papers giving a comprehensive discussion of the Great Lakes region. Similarly studies of this region by Warren Upham have been confined to the Minnesota border of the Lake Superior Basin, but in several comprehensive papers he has considered the whole basin and the basins of the other Great Lakes.

The surface geology of this region was written up by Lawrence Martin for Van Hise and Leith's report (Monograph 52 of the United States Geological Survey) after a very rapid reconnaissance covering but a few weeks' time. It is not surprising that under these circumstances some of the interpretations are either poorly sustained by field observation or based too largely on outgrown ideas culled from old reports. Instances of such errors and defects are given in connection with the discussion of features in the body of the present report. A paper on the physical geography of Wisconsin, by Martin, issued as Bulletin 36 of the Wisconsin Geological Survey, embodies much of the same material.

Among the latest contributions to the surface geology of the region are several bulletins issued by the Wisconsin Geological and Natural History Survey on soil surveys in charge of A. R. Whitson. The bulletins touching the area embraced in the present report are Bulletin 31, on the Bayfield area; Bulletin 32, on the northern part of northwestern Wisconsin; Bulletin 43, on Vilas County and portions of adjoining counties; and Bulletin 47, on northeastern Wisconsin. On the last-named area there is also a report by the Bureau of Soils of the United States Department of Agriculture, forming part of the report on field operations in 1913. The Bureau of Soils has also issued a report on the area around Superior, Wis., and one on the area around Carlton, Minn. The scale of the maps in these reports, being usually about 3 miles to the inch and in some maps still larger, has proved adequate to bring out most of the detail of soil variations. As the soil variations bear a close relation to the geologic deposits, the distribution of moraines, till plains, and outwash gravel plains can be determined from the soil maps to a large degree.

The agricultural conditions and surface features of the entire northern peninsula of Michigan are described in a report by the present writer published in 1911 by the Michigan Geological and Biological Survey. A strip along the southern border of the northern peninsula was studied by I. C. Russell in 1904 and 1905, and two reports on surface geology prepared by him have been published by the State Survey. A report on the agricultural conditions of northeastern Minnesota prepared by F. W. Sardeson and the present writer has been recently published as a bulletin by the Minnesota Geological Survey. It is the second of a series of three reports (bulletins 12, 13, and 14) covering the surface geology of the entire State of Minnesota. The Michigan and Minnesota bulletins deal more largely with soil classes than with geologic history, though an outline of geologic history is presented, and moraines, till plains, drumlins, eskers, and outwash plains are represented on the accompanying maps, which show also the character of the lake beds and the position of some of the shore lines. A complete tracing of shore lines was not attempted in the field because of the wooded condition and the extreme difficulty of tracing such features.

In his report on Isle Royal, published in volume 6 of the Michigan Geological Survey, A. C. Lane discussed the shore lines and cited evidence that the entire island has been covered by the lake waters since the ice sheet melted.

In reports to the Ontario Bureau of Mines, for the period between 1899 and 1907, A. P. Coleman has discussed high shore lines on the north side of Lake Superior and around Lake Nipigon, of which the highest are above the

limit of levels of shores on that coast seen by A. C. Lawson. Robert Bell briefly outlined the origin of the Great Lakes and the History of the Lake Superior Basin in a paper published in 1899 in the Transactions of the Canadian Institute.

The earth movements in the Great Lake region were studied by G. K. Gilbert and the results were presented in part 2 of the Eighteenth Annual Report of the United States Geological Survey, for 1896-97, and also in the National Geographic Magazine in 1897. George L. Collie has presented a paper in the Bulletin of the Geological Society of America citing evidence of the rising of water in recent time on the Wisconsin shore of Lake Superior.

Leveling to shore lines bordering the north end of Green Bay in Delta County, Mich., was done by W. H. Hobbs, and the results were published in Publication 5 of the Michigan Geological and Biological Survey. Similar leveling was done by F. B. Taylor and J. W. Goldthwait on Mackinac Island and neighboring parts of the northern peninsula and the results are presented in Monograph 53 of the United States Geological Survey.

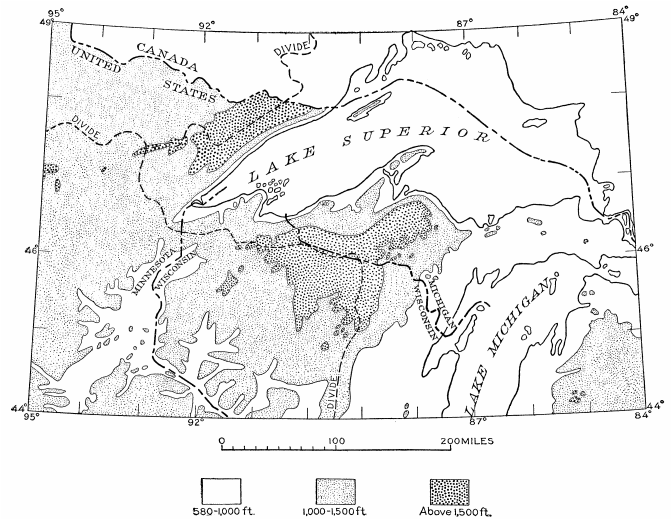


FIGURE 1.—Generalized topographic map of the Lake Superior region. Revised from Figure 4 of Monograph 52

TOPOGRAPHY AND DRAINAGE

TOPOGRAPHIC CONTROL OF THE SUPERIOR ICE LOBE

THE LAKE SUPERIOR BASIN

The Lake Superior Basin is the dominating feature of this region, for it induced a lobation of the continental ice sheet and also held the waters of glacial lakes that antedated the present Lake Superior. The mean water level of Lake Superior is about 602 feet above sea level, but the lowest part of the bed of the lake is nearly 400 feet below sea level, the maximum measured water depth being 978 feet. The contours of the basin below present lake waters are indicated on a map (pl. 3) taken from Monograph 52, and another map (fig. 1) shows the features outside of Lake Superior. It appears that the principal deeps of Lake Superior lie near the north side, opposite Isle Royal and between the Apostle Islands and the north shore. There is also an extensive branching deep portion east of Keweenaw Peninsula, where one arm runs toward Michipicoten Island and the other toward the south shore near Grand Marais, and another deep portion east of the Apostle Islands, extending northeastward between Isle Royal and the Keweenaw Peninsula. These deep parts, with the exception of that lying southeast of the Keweenaw Peninsula, all trend westward or southwestward, in the direction taken by the Labrador ice sheet in its passage through the Lake Superior Basin. It is very probable that in the eastern part of the basin the ice moved southward as well as westward, and that the Lake Michigan Basin was filled by ice flowing through this deep eastern part of the Lake Superior Basin. The Keweenaw Peninsula and the Huron Mountains are separated only by a shallow depression and thus form a great obstacle of either southward or westward movement. It is because of these prominences that the edge of the drift at the limit of the Driftless Area (see pl. 1) lies so far northeast in north-central Wisconsin. The relief map (pl. 3) also serves to make evident a fact that had been determined independently by field studies—that the Chippewa drainage basin is likely to have been covered by ice moving into it from the deep part of the Lake Superior Basin between Keweenaw Peninsula and the Apostle Islands instead of through the shallow basin in Keweenaw Bay, as was suggested by Chamberlin.

The west end of the Lake Superior Basin has features well suited to the development of a double ice lobe, with a reentrant at the Bayfield Peninsula and Apostle Islands, arid it did induce such lobation in the late part of the Wisconsin glacial stage, which is under consideration in this report. The latest striae on the north shore in the vicinity of Duluth bear west or north of west in such a manner as to show an ice movement from the basin up over the high bordering rim. A study of the rock constituents of the drift, however, shows that there was at some earlier time a southward or southeastward movement past the west end of the basin into northwestern Wisconsin, for the upper Huronian slate is very plentiful in the drift there, and rocks from the Mesabi iron range are also present. The writer's investigations have served to make it clear that this movement occurred prior to the westward movement through the basin. This is shown by the distribution of the moraines and of the outwash from the Superior ice lobe, as well as by the direction of the striae. It is also shown by the relation of the Superior lobe to the ponded waters or glacial lakes formed between it and the divide between the Superior and Mississippi drainage basins.

As the highlands next to Lake Superior in Minnesota were 1,500 to 2,000 feet above sea level, the Superior ice lobe could extend only a few miles over them. Its limits were reached on the south side of Cloquet River,

so that outwash from it extended down that river valley. At the time of the greatest expansion of this ice lobe the south front of the Patrician ice, which had previously extended from the west end of the Lake Superior Basin as far south as St. Paul, had already been melted back so far that it formed a junction with the Superior ice lobe in Lake County, as shown on page 20.

The prominence of the uplands on the south side of the Lake Superior Basin, on the Douglas copper range and the Bayfield Peninsula (altitude 1,200 feet), the Penokee iron range (1,600 to 1,800 feet), the Porcupine Mountains (1,400 to 2,000 feet), the Keweenaw copper range and Keweenaw Peninsula (1,200 to 1,400 feet), and the Huron Mountains and highlands to the south (1,500 to 1,800 feet), served to prevent the Superior lobe from extending far beyond the rim of the basin in that direction. Its limits in northern Wisconsin are only about 30 miles south of the edge of the lake. There was a marked reentrant in the ice border on the Bayfield Peninsula and a great checking of movement in the passage over prominences farther east, so that in the lee of the Huron Mountains the ice reached only to the vicinity of Crystal Falls, Mich. But still farther east the land on the south side of the basin is low, much of it less than 800 feet above sea level, and the ice extended with but little hindrance across the northern peninsula of Michigan into the Lake Michigan Basin. The lake beaches in this eastern part of the Lake Superior Basin show an uplift of about 400 feet since the ice disappeared; so at the time of the ice movement from the Lake Superior to the Lake Michigan Basin the checking effect of the northern peninsula was probably much less than it would be under present conditions of altitude.

TOPOGRAPHIC PECULIARITIES AROUND THE BASIN

Although the relief of this region is great enough to have exerted a marked control over the ice movement, the highest tracts on the border of the Lake Superior Basin show only a moderate depth of dissection or valley cutting. This dissection is not of a narrow, youthful sort, but the slopes are gentle and the valleys wide open. The valleys were excavated in early geologic time and then filled by Cambrian and later sediments. This filling was then largely removed by the action of streams prior to the glacial epoch, and what has been termed a fossil topography was uncovered. Broad lowlands such as border the Bayfield and Keweenaw Peninsulas and the lowland at the head of the lake were not so markedly reexcavated, and thus they retain the Cambrian sediments. These sediments are trenched by small valleys, which became filled with glacial deposits and are now traceable mainly by borings, for the present streams follow them to only a slight degree. On the south shore of Lake Superior these filled valleys have rock beds much below the level of the lake. Near the head, at Superior, Wis., the drift extends 550 feet below the lake level.

In the eastern part of the northern peninsula of Michigan the Cambrian and later rock formations form what are termed belted lowlands, in which resistant formations present steep escarpments at their outer edges and softer formations occur in the intervening troughs and fade out at their edges. From St. Marys River westward to the Manistique drainage basin the escarpments face northward. Thence they curve around to the southwest and run into eastern Wisconsin. Where the trend is west the ice was obliged to rise over these escarpments. But in the southwestward-trending part the latest axial movement of the ice seems to have been in line with the troughs and escarpments. The trough occupied by Green Bay thus had an ice lobe distinct from that in the Lake Michigan Basin. The highest escarpments rose 200 to 400 feet above the troughs. They are now largely buried under the glacial deposits and their preglacial relief is made known only by borings. The Keweenaw Peninsula and Isle Royal present a series of sharp ridges of resistant rocks separated by narrow troughs with softer strata. Those on Isle Royal are nearly in the line of the ice movement, though Lane reports a slight difference in course. The latest ice movement in the eastern part of the Keweenaw Peninsula was in the same general direction as the troughs and ridges and there was but slight deposition in the trough or on the ridge. But in the remainder of the peninsula the westward ice movement crossed over ridges and troughs and filled the troughs with the glacial material.

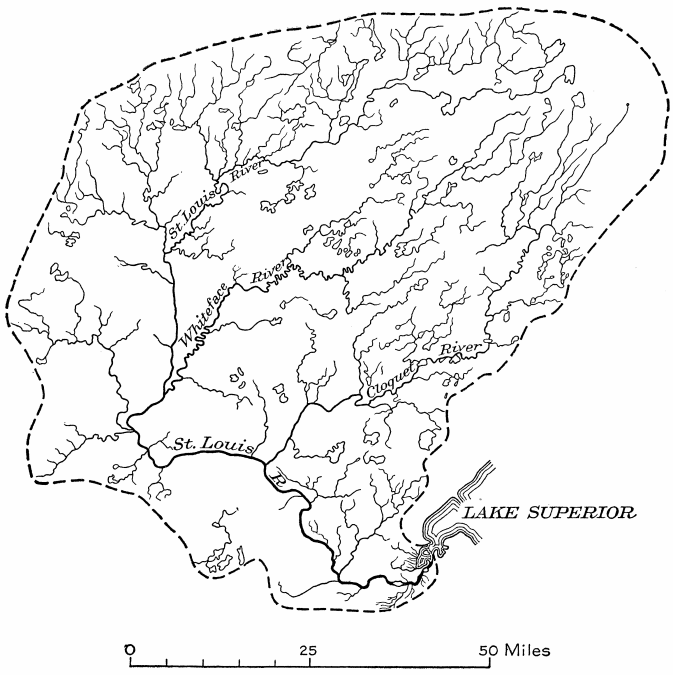


FIGURE 2.—Map of St. Louis River drainage basin, Minnesota and Wisconsin

DRAINAGE

LAKE SUPERIOR TRIBUTARIES

The tributaries of Lake Superior in Minnesota, Wisconsin, and Michigan are nearly all small streams. The largest is St. Louis River, with a drainage area of about 3,500 square miles, and the second in size the Ontonagon, with a drainage area of 1,400 square miles. Only one other, Bad River, has even 1,000 square miles of drainage area, and most of them have less than 250 square miles. The divide between Lake Superior and the Hudson Bay drainage system in northeastern Minnesota lies only a few miles back from the shore of the lake, and the divide between Lake Superior and the Mississippi drainage system is also close by the lake in northeastern Minnesota and northern Wisconsin. The divide between the Lake Superior and Lake Michigan drainage basins is nearer to Lake Superior than to Lake Michigan in the northern peninsula of Michigan. A considerable part of the drainage basin of St. Louis River lies outside the limits of the Lake Superior ice lobe, but with this exception the streams that drain to Lake Superior in these three States lie within the limits of this ice lobe.

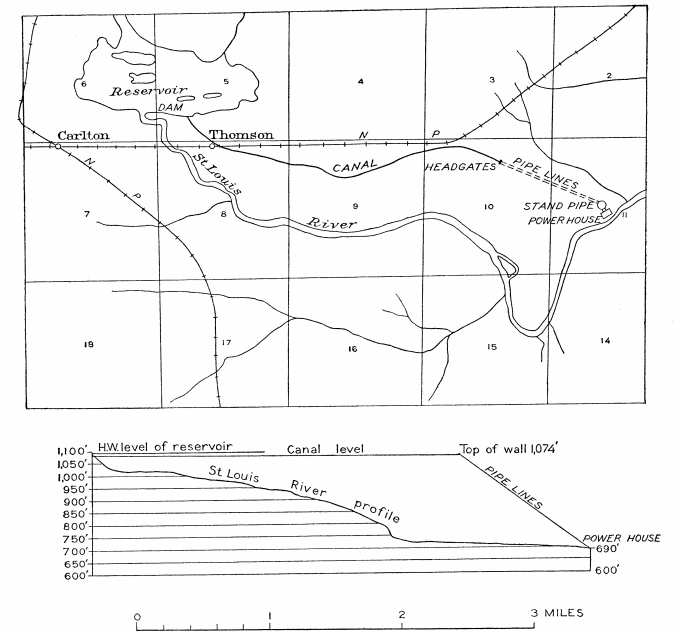


FIGURE 3.—Map and profile of canal of Great Northern Power Co., St. Louis River

In much of the Lake Superior Basin the present streams are controlled but slightly by preglacial valleys. Those valleys were so completely filled by drift back of the ranges, as well as next to the lake, that they not only have failed to control the courses of the postglacial streams but are known only by means of borings. In crossing rock ranges the streams form numerous rapids and cascades. In Minnesota and parts of Michigan where rock ranges are close to the lake shore cascades occur on many streams near the mouths, and thus are especially favorable for the development of water power, for at such a site nearly the entire flow of the drainage basin can be utilized. Surveys have been made of several of the minor tributaries in Minnesota and of St. Louis River, and some of the results are given below. The altitude of the land close to the lake is greater in Minnesota than in Wisconsin and in much of Michigan, and thus some of the small Minnesota streams have a descent of 1,000 feet or more in their short courses to the lake. On interstream areas in northeastern Minnesota there is usually a rise of 400 feet, and in places nearly 1,000 feet, within a mile of the lake.

On the headwaters of many of the streams that flow to Lake Superior in the three States there are a large number of lakes, which serve as storage reservoirs to supply a flow through dry seasons of the year and thus add to the water-power value of the streams.

St. Louis River heads in western Lake County, Minn., and has a general southwestward course for about 60 miles (by direct line), southward 25 miles to Mirbat, thence eastward, southeastward, and finally northeastward into Lake Superior. (See fig. 2.) Only the part of its course below Mirbat lies in the area covered by the Superior ice lobe. A considerable part of the basin above Mirbat was covered by ice that came in from the northwest and deposited a sheet of clayey calcareous till. But the headwaters are outside the limits of this drift, as well as of the drift of the Superior lobe, and they were covered by ice coming in from the north, which left a very stony drift deposit. The limits of the drainage basin on the north are in general at the Mesabi iron range, but it receives one tributary, Embarrass River, which brings in drainage from territory north of the range. Of the 3,500 square miles in the drainage basin only 60 square miles lies in Wisconsin. The greater part of the basin is a plain which is between 1,200 and 1,500 feet above sea level, or 600 to 900 feet above Lake Superior, but the altitude of the extreme headwaters on the ranges is nearly 1,800 feet. St. Louis River reaches Cloquet at an altitude of 1,172 feet and within a mile makes a descent of 67 feet, which is divided between two dams at the city. The stream falls about 500 feet between Cloquet and Fond du Lac, a distance of about 14 miles. The Great Northern Power Co. has diverted a considerable part of the flow into a canal near Thomson, 5 miles below Cloquet (see fig. 3), and has developed a head of 378 feet where the canal is returned to the river. There is still a fall of 90 feet unutilized below the tailrace of the power plant. The stream reaches lake level at Fond du Lac, several miles above its mouth, for a northward differential uplift has caused the lake to rise on its south shore and flood tributary valleys. Although the stream makes a descent of about 470 feet in 9 miles below Thomson, it does not have rock cascades such as are characteristic of the lower ends of the minor streams. It cuts very little into the rock but has eroded deep channels in the glacial deposits, which are banked here against the south face of the rock range that forms the north border of the Lake Superior Basin. Its course does not run through a preglacial valley, either here or across the rock range, for the range seems to have no break in

this vicinity, continuing at an altitude of 1,100 feet or more from the west end of Lake Superior some distance beyond Thomson, the place where St. Louis River leaves it.

Martin,[2] in maps as well as in discussion, makes it appear that a small stream having the present course of St Louis River below Thomson worked headward across the rock range above Thomson and captured a large drainage system that had been flowing to the Mississippi. The present writer's investigations, however, and indeed those by Winchell many years ago have shown that the St. Louis River basin carried a lake outside the limits of the Superior lobe, which was held up by that ice lobe until it had shrunk to a position between Cloquet and Thomson, near Scanlon, when it was drained southwestward into Kettle River. With the further shrinking of the Superior ice lobe the drainage led down the present course of the river about to Thomson, where it entered a lake (Lake Duluth) that stood about 500 feet above the level of Lake Superior. As the lake level dropped, the river lengthened its lower course, and it has come to its present condition without any such piracy as was pictured by Martin. The idea that such piracy may have occurred in preglacial time is also unsupported by any evidence thus far obtained, for, as indicated above, no break in the rock range such as a preglacial drainage line should have made has been brought to light.

A survey of St. Louis River for a distance of 149.4 miles from Scanlon to the Duluth & Iron Range Railroad crossing near Skibo was made by the State drainage commission in 1910 to determine chiefly the power possibilities of the river. The results are given in Plates 76 to 82 of an atlas accompanying the commission's report of water-resources investigations for 1909-1912. Recommendations as to the placing of dams or the location of the best power sites are presented on pages 500-502 of that report. Surveys made by the State drainage commission also cover parts of certain tributaries of St. Louis River, Embarrass River having been surveyed for 21 miles from its mouth, and Cloquet River as far up as Brimson, where it is crossed by the Duluth & Iron Range Railroad. (See pls. 15-18 of the atlas.) The feasible power sites on these tributaries are also discussed on pages 502 and 516-518. These surveys show a very moderate rate of fall in the sections covered, compared with the fall between Thomson and Fond du Lac (52 feet to the mile), in the lower course of St. Louis River. The fall on St. Louis River in the 146 miles downstream from the Duluth & Iron Range Railroad crossing to Cloquet is only about 400 feet, or less than 3 feet to the mile. Cloquet River falls about 260 feet in the 70 miles from the Duluth & Iron Range Railroad crossing to its mouth. Another large tributary, Whiteface River, falls 384 feet in 80 miles from the Duluth & Iron Range Railroad crossing to its mouth.

[2]Martin, Lawrence, U. S. Geol. Survey Mon. 52, figs. 9, 10, 1911; Wisconsin Geol. Survey Bull. 36, fig. 176, 1916.

The minor tributaries of Lake Superior entering from Minnesota have a rapid fall from source to mouth, except for very short sections through lakes or swamps. The data on the fall in the lower courses of several of these streams presented below are taken from the report of the State drainage commission for 1909-1912. There is a striking contrast between the gradient of Pigeon River, a stream that forms the international boundary for much of its course, and the minor streams entering Lake Superior between the Canadian line and the head of the lake at Duluth. Pigeon River has a drainage basin of 628 square miles, or more than double that of any of the other minor streams. This difference may account for a part of the difference in gradient, but not a large part. Unlike the other streams, it has a comparatively gentle slope from the general plateau level in its lower course, and a distance of 30 miles is embraced in a fall no greater than is made in one-third that distance on some of the other streams. The chief cause for the lower gradient seems to be found in the location of Pigeon River along somewhat weaker strata than those encountered by the other streams. Pigeon River has scoured practically to lake level up to a distance of 11/2 miles from its mouth, but the other streams descend over rock beds to points within a few rods of the lake.

Drainage areas and descent of minor tributaries of Lake Superior

River	Drainage area	Altitude at source	Character of drainage basin
	Square miles	*Feet*	
Pigeon	628	1, 650	Flows through lakes; has three notable falls.
Brule	282	1, 850	Sources of main stream and of tributaries are in lakes.
Devil Track	75	1, 920	Heads in small lake and flows through larger one (Devil Track) with area of 3 square miles.
Cascade	84	1, 950	Receives overflow from Devil Track Lake at high lake stages; other reservoirs in smaller lakes in upper course.
Poplar	144	(?)	Many lakes within its drainage area give good reservoir effect.
Temperance	198	1, 850	Divides the discharge from Brule Lake with Brule River, nearly equally, and flows through a chain of small lakes.
Cross	32	(?)	Descends nearly 800 feet in lower 6 miles.
Manitou	71	(?)	Has few lakes large enough for good reservoirs.
Baptism	135	1, 850	Do.
Beaver Bay	120	1, 700	Has few lakes or reservoir sites. Large tributary enters near mouth. Has numerous other tributaries.
Gooseberry	85	1, 700	Has numerous tributaries, but not good reservoir sites.
Lester	55	(?)	Has cascades in lower course and swamps in upper.

At two of the heaviest falls on Pigeon River log chutes have been constructed.

Data from survey of Lake Superior tributaries in Minnesota

Gooseberry River, Lake County

Distance from mouth	Location	Altitude above Lake Superior
Miles		*Feet*
0. 75	Foot of rapids	7
. 95	Head of rapids	120
1. 8	Foot of rapids	168
1. 85	Head of rapids	215
2. 7	Forks in sec. 21	241

Beaver Bay River, Lake County

0. 02	Foot of falls	3
. 3	Head of falls	114
1. 0	Head of rapids	303
2. 5	Highway bridge	313
3. 9	Foot of rapids	335
4. 1	Head of rapids	400
5. 0		424
6. 0		485
6. 6	Highway bridge, sec. 17, T. 55, R. 8 W.	486

Baptism River, Lake County

0. 1	Foot of rapids	1
. 85	Foot of falls	68
1. 0	Crest of falls	125
1. 3	Foot of rapids	128
1. 8	Head of rapids	241
3. 0		373
4. 0		442
5. 8	Highway bridge	505
6. 6		575
8. 0		704
8. 9	Highway bridge	733

Manitou River, Lake County

0. 05	Foot of falls	0
. 1	Crest of falls	54
1. 0		204
2. 0		285
3. 0		371
4. 0		482
5. 0		703

Temperance River, Cook County

0. 05	Foot of rapids	0
. 5	Head of rapids	162
1. 0		203
2. 0		284
3. 0		345
4. 0		425
5. 0		450
6. 0		463

Cross River, Cook County

0. 3	Foot of rapids	17
. 35	Head of rapids	113
1. 2	Foot of rapids	236
1. 5	Head of rapids	391
2. 7		592
4. 0		678
5. 0		738
6. 0		781
7. 2	Foot of log dam	848
7. 2	Crest of dam	858
7. 5	Upper end of pond	858
8. 2	End of survey	867

Data from survey of Lake Superior tributaries in Minnesota—Con.

Poplar River, Cook County

Distance from mouth	Location	Altitude above Lake Superior
Miles		*Feet*
0. 3	Highway bridge	71
1. 0		197
2. 0		353
2. 5	Foot of rapids	423
2. 8	Foot of logging dam	608
2. 8	Crest of dam	619
4. 0		620
5. 1	Highway bridge	634
5. 6	Foot of logging dam	648
5. 6	Crest of dam	650
6. 2	End of survey	652

Cascade River, Cook County

0. 15	Foot of falls	8
. 35	Crest of falls	132
1. 0		226
2. 0		398
3. 0		556
4. 0		688
5. 0		735
6. 0		817
6. 8	End of survey	840

Brule River, Cook County

0. 5	Highway bridge	18
1. 0		74
2. 0		228
3. 0		320
4. 0		415
5. 0		554
6. 0		681
7. 0		763
7. 2	End of survey	768

Pigeon River, on international boundary

0. 0	Head of Pigeon Bay	0
1. 5	Foot of rapids	3
1. 7	Foot of Big Falls	17
1. 7	Crest of Big Falls on low dam	111
2. 0	Upper end of pond	111
2. 4	Head of rapids	152
3. 45	Foot of rapids	163
3. 5	Head of rapids	190
5. 0		198
6. 05	Foot of rapids	223
6. 1	Head of rapids	241
8. 15	East boundary of Indian reservation	271
9. 2		288
10. 5		322
11. 5	Arrow River	331
14. 95	Foot of rapids	379
17. 45	Foot of falls	519
17. 45	Crest of falls on low dam	652
19. 1	Upper end of pond	652
19. 8	Foot of Partridge Falls	664
19. 8	Crest of falls	714
21. 95	West boundary of Indian reservation	714
24. 45	Missaich River	725
27. 85	Portage Brook	746
28. 8	Stump River	748
29. 7	Foot of dam	762
29. 7	Crest of dam	782
30. 05	Foot of dam	791
30. 05	Crest of dam	808
30. 4	Foot of dam at South Fowl Lake	828
30. 4	Crest of dam	834

The streams entering Lake Superior from Wisconsin are shown in Figure 4. They are very irregularly distributed, being numerous and nearly parallel in part of the area and relatively scarce and more winding in other parts. This difference is due largely to differences in the character of the deposits, there being many streams in clay areas and relatively few in the loose-textured drift. On the Bayfield Peninsula the drift is very loose textured and wide areas of it have no surface streams. The character of the erosion in the clay areas is well shown in the topographic map of the Superior quadrangle. This map also shows a short section of the Douglas copper range and south of it an area of loose-textured drift with relatively few streams. This map also shows by contours the highest waterfall in Wisconsin (pl. 4), that made by Black River in descending from the copper range at Manitou Falls, in sec. 21, T. 47 N., R. 14 W., where the river drops about 160 feet, from a point above the 960-foot contour nearly down to the 800-foot contour. Before leaving section 21 the river gets below the 700-foot contour, thus making a descent of more than 260 feet in passing through a single section. The

river has a 31-foot fall above Manitou Falls, where it cuts the copper range in the SE. ¼ sec. 28.

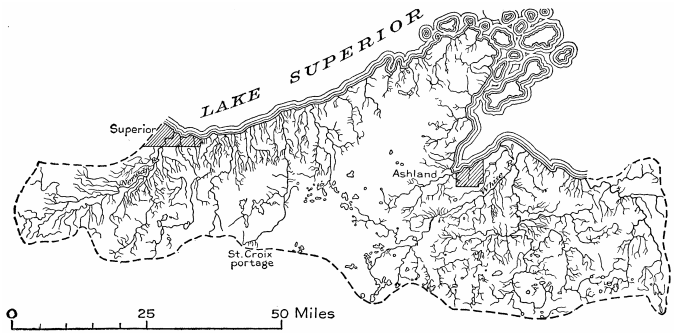


FIGURE 4.—Map showing streams entering Lake Superior in northern Wisconsin

The westernmost stream entering the lake in Wisconsin is Nemadji River, of which Black River is a southern tributary. It has a drainage basin of about 400 square miles, of which 60 per cent is in Minnesota and 40 per cent in Wisconsin. Nemadji River drains the part of the Lake Superior Basin lying southwest of the head of the lake. The river and its northern tributaries and the lower courses of its southern tributaries are in a clay plain in which no rock ledges are encountered. The southern tributaries head on or south of the Douglas copper range and descend from the range to the clay plain over low cascades and rock rapids.

Nemadji River is only about 20 feet above Lake Superior at the mouth of Black River, 10 miles from the lake by direct line and probably 30 miles by the meanders of the stream. Its gradient here has been greatly reduced as a result of the northward differential uplift which has affected this region and which has caused estuarine conditions on the lower course of St. Louis River. The bottom lands are marshy for several miles up the Nemadji Valley, and the river has built along its immediate banks natural levees that stand above the remainder of the valley bottom. The Nemadji River Basin held a small glacial lake in its headwaters in Carlton County, Minn., called Lake Nemadji, which discharged westward to Moose Horn River at Moose Lake village, and thence southward by way of Kettle and St. Croix Rivers to Mississippi River, as described on pages 55 and 56. The portion of its drainage system included in this glacial-lake bed is younger than that on the highest areas bordering it, which was in operation during the existence of the lake.

Between the Nemadji drainage basin and the Bayfield Peninsula there are several small streams classed as rivers, though none of them have drainage areas of 200 square miles. Some of them cross the copper range and have cascades on its slope, but several head near the base of the range and flow almost wholly on the clay plain bordering Lake Superior. Bois Brule River is the largest of these streams, the area of its drainage basin being estimated at 162 square miles. Its headwater portion is of exceptional interest, for it carries the outlet of the glacial Lake Duluth, which covered at its greatest expansion the whole west end of the Lake Superior Basin from points as far east as the Huron Mountains. This headwater portion of Bois Brule River flows in a broad swampy channel that opens at its south end into St. Croix Lake, which discharges through St. Croix River to the Mississippi. Immediately south of the copper range there was in the drainage basin of this stream a small lake, here named glacial Lak Brule, which antedated Lake Duluth and through which Lake Duluth discharged after the ice lobe had shrunk away from the copper range far enough to let its water pass into this small glacial lake.

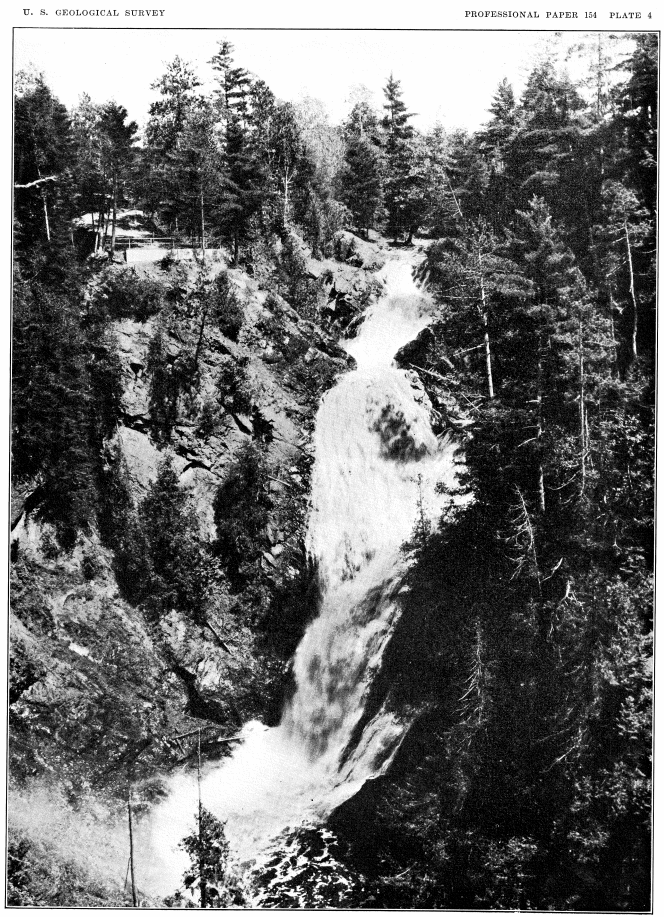
RELIEF MAP OF THE LAKE SUPERIOR REGION

East of the Bayfield peninsula is the Bad River drainage system, in which White River is a large tributary. The entire drainage system embraces about 1,000 square miles, of which fully 350 square miles is drained by White River. A large part of the drainage basin is in a clay plain, which borders Chequamegon Bay of Lake Superior and which was covered by the waters of Lake Duluth. The headwater streams head among or south of high rock ranges, the most prominent of which is the Penokee iron range, but there are others nearer the lake. Several cascades occur where the streams cross these ranges and also in their courses between the ranges. But after the several tributaries unite to form Bad River the stream flows in a clay plain without encountering rock ledges. White River is in the clay plain except in its headwaters.

There was a small glacial lake, Lake Ashland, which antedated Lake Duluth in occupying part of the drainage basin of Bad and White Rivers and which discharged across the Bayfield Peninsula into glacial Lake Brule through a channel passing just south of the site of Iron River village. With the recession of the ice border from the Bayfield Peninsula, Lake Duluth gained access to the Bad River drainage basin. Its altitude was but little lower than Lake Ashland, perhaps 20 feet lower.

Montreal River, which forms part of the boundary between Wisconsin and Michigan, has a drainage area of 280 square miles, of which nearly 200 square miles is in Wisconsin and only 85 square miles in Michigan. The main stream is about 50 miles long and heads on a table-land south of the Penokee iron range at an altitude

of about 1,600 feet. It makes scarcely one-fourth of the 1,000 feet fall to Lake Superior in three-fourths of its course, the great descent being in the remaining lower fourth, where there are several waterfalls, including one of 35 feet only a quarter of a mile from its mouth. Gogshungun River, a branch of the Montreal, has a length of about 30 miles and a descent of 500 feet. It breaks through the Penokee iron range in sec. 27, T. 46 N., R. 2 E., and has falls in that part of its course, but the headwaters are sluggish.



THE HIGHEST WATERFALL IN WISCONSIN
Manitou Falls, on Black River

There are two streams of considerable size in the western part of the northern peninsula of Michigan—Black River, with a drainage area of 250 square miles and Presque Isle River, with 390 square miles. Each heads in the north edge of Wisconsin and traverses the entire width of the peninsula. A considerable part of the drainage area of each stream is south of the Penokee-Gogebic iron range, and in that part the streams are rather sluggish. In crossing the range and the copper range, farther down, the streams have rapids and cascades that promise to be of much value in water-power development, as they occur so near the mouth of the river. The area drained by these streams lies west of the Porcupine Mountains and of Lake Gogebic.

The Porcupine Mountains are drained largely through Carp River, which flows into the lake at their western base. Its sources are at the base of knobs in this group of steep hills and ridges, at an altitude 600 to 700 feet above the lake. The highest knob stands about 1,400 feet above lake level, and others reach an altitude of 1,000 feet or more above the lake. This group of hills stands very close to the shore of Lake Superior. From the Porcupine Mountains westward into Wisconsin the copper range lies so close to the shore of Lake Superior that the clay plain is reduced to a strip only 1 or 2 miles wide. This strip is crossed by a multitude of short streams running directly to the lake. From the Porcupine Mountains eastward past the Ontonagon Valley to the Keweenaw Peninsula a clay plain several miles in width lies between the lake and the copper range, and, like the plain west of the Porcupine Mountains, is crossed by numerous small streams running directly down the slope to the lake. These streams have cut sharp deep trenches in the plain, which make the east-west roads difficult to construct. The existing roads, therefore, nearly all follow north-south lines or lines parallel to the streams instead of crossing them. A single main road runs from east to west close to the lake shore, where the trenching by the streams is shallow.

Ontonagon River has a drainage system embracing about 1,400 square miles and is the largest of the Lake Superior tributaries entering in Michigan. The extreme headwaters drain about 50 square miles in Wisconsin. Several streams 30 to 50 miles or more in length are brought together in a single river at the outer or south border of the copper range, about 2 miles south of Rockland, Mich., and 15 miles in direct line from the shore of Lake Superior at Ontonagon. Gogebic Lake lies in the course of the westernmost tributary and has a length of fully 15 miles. Its trend is toward Lake Superior, but its outlet runs for more than 20 miles eastward, parallel with the lake shore, along the south base of the copper range and receives the main south branch of the river midway of this course. It is probable that Gogebic Lake lies in a preglacial valley whose continuation extends northward from the lake to Lake Superior, beneath a moraine that here fills a gap in the copper range and through a plain north of the moraine, now drained by Iron River. The main south branch may have passed through the copper range at a break about 5 miles farther west than the one now utilized by Ontonagon River and have traversed the part of the clay plain now drained by Portage River, northward from the copper range. The middle branch of Ontonagon River finds a direct continuation along the present lower course, and the east branch seems likely to have had a preglacial drainage similar to that of the present stream and to have joined the middle branch just south of the copper range. As there are only a few places where this drainage system encounters rock ledges, rapids and falls are less numerous and conspicuous here than on some of the smaller drainage systems farther west. At the gap in the copper range south of Rockland the drainage is so concentrated as to give a large flow, and the valley there is sufficiently narrow to be easily dammed to a considerable height. The banks or bluffs

consist of clay, which is so compact that it would allow hardly any leakage.

There are a number of small rivers both east and west of the Ontonagon which head in the copper range and flow across a clay plain to Lake Superior. The longest are about 25 miles in length, but most of them are only 10 to 15 miles. Few of them cut deeply enough to reach rock. Montreal River drains the interior of the eastern part of the Keweenaw Peninsula and flows through a trough between rock ranges to a point near its mouth, where it turns southward and falls rapidly over rock ledges just before entering the lake. Eagle River and other small streams drain the slopes of this peninsula and have falls where they cross rock ridges.

Sturgeon River has a drainage basin of about 725 square miles on the southeastern slope of the Keweenaw Peninsula and on the highlands south of Keweenaw Bay. It does not discharge directly into Lake Superior but into Portage Lake, from which there is an outlet discharging into Keweenaw Bay. More than 200 square miles of the Keweenaw Peninsula aside from the Sturgeon River drainage basin is tributary to Portage Lake. The lake and its outlet are at the level of Lake Superior, as are also Torch Lake and an inlet to Portage Lake which leads southeastward across the peninsula past Hancock and Houghton. A ship canal now connects the head of this inlet with Lake Superior by a cut about 30 feet deep across a gravel bar of Nipissing age.

The lower course of Sturgeon River for a distance of about 15 miles has almost no fall, for differential uplift has converted this part into a marshy estuary, through which the stream now flows in a meandering channel. The stream flows in a relatively low clay plain for about 15 miles before it enters this marsh. The headwater part of the river is on a tract of hills standing 1,600 to 1,800 feet above sea level; thus the descent is fully 1,000 feet from source to mouth. At least 80 per cent of this fall is made in the upper half of the course. The headwater tributaries encounter a few rock ledges and have rapids and low cascades, and some of the western tributaries to the lower part of the river come in over rock ledges, but the main stream is nearly free from rapids for the greater part of its course.

The area from the head of Keweenaw Bay eastward to the Huron Mountains is drained through several small streams, of which Silver, Slate, and Huron Rivers are the largest. They rise about 1,000 feet above the lake and consequently have a rapid descent with numerous cascades. They are much like the small streams on the Minnesota shore of Lake Superior, but their lower courses lead through a lowland several miles wide, which was covered by the waters of glacial Lake Duluth.

From the Huron Mountains eastward to Whitefish Bay, at the southeast end of Lake Superior, there are about 20 small streams called rivers, as well as numerous creeks, which make a rapid descent to the lake, with numerous cascades. At several places a head of 100 feet or more could be easily developed for water power. The largest of these streams drains less than 200 square miles and most of them less than 100 square miles each. They are thus of little value for water power except where a great head can be developed. Those having cascades lie west of Grand Marais, for the streams east of that village flow through a region containing heavy deposits of drift. There are cascades in nearly every stream entering the lake west of Grand Marais. Anna River, however, which enters at Munising, at the head of a bay, seems to follow a preglacial drainage line, for its course leads through thick deposits of drift. Some of its eastern tributaries cascade over rock ledges to reach the main stream. The lower course of Au Train River is controlled by a succession of Nipissing Lake beaches, which cause the stream to swing back and forth between ridges and flow several miles to reach a distance of only 1 mile by direct course. This river has a series of falls just north of the Munising railroad bridge, with a descent of about 100 feet, above which there is a drainage area of about 80 square miles. These falls, as well as many others in the Lake Superior region, have not yet cut back into the rock bluff so as to have a rock gorge below them and are therefore in an extremely youthful stage. Dead River, which enters Lake Superior in the northern part of the city of Marquette, has a 96-foot fall a few miles above the mouth, in sec. 9, T. 48 N., R. 26 W., and a descent of about 600 feet below this fall over numerous small cascades. It is thus far from being a “dead” stream. Its drainage basin is about 150 square miles and there has been considerable development of its water power.

Whitefish Bay receives the discharge from Taquamenaw River, which drains about 800 square miles in the eastern part of the peninsula. There are two waterfalls a few miles from its mouth, the upper with about 40 feet and the lower with about 20 feet fall. At the foot of the lower fall the stream reaches the level of Lake Superior, though 15 miles from its mouth. The slack water thus produced is due to the northward differential uplift that has caused a rise of the water along the south shore of the lake. The main stream and also an eastern branch lead through swamps from points near their sources down to the upper fall. In a distance of 70 miles above the fall the main stream has an average gradient of only 6 inches to the mile. This low gradient and swampy condition is due, to some extent, to differential uplift, for the stream is flowing northeastward into the uplifted area, and the ledges of the upper fall have risen more as a result of this uplift than the headwater part of the stream. The swamps are largely underlain by clay or clayey till of closer texture than that on the bordering dry land, but sand is present under a considerable part of the swamp land.

ST. MARYS DRAINAGE BASIN

The main function of St. Marys River is to serve as the outlet for Lake Superior. Its tributaries, both in Michigan and on the Canadian side, are small and add very little to its volume. The falls or rapids at the head of this river

give a descent of about 18 feet and furnish water power of great value, which is already largely utilized. In comparatively recent time, perhaps since the beginning of the Christian era, the ledges at the rapids on St. Marys River have risen above the level of the water of the Lake Huron Basin, through northward differential uplift. Before this occurred a strait connected Lake Superior with Lake Huron along the course of this stream. Whether this uplift is still in progress has not been determined. If it is, the fall at Sault Ste. Marie will increase to correspond to the uplift of this outlet.

The preglacial line of connection between the Lake Superior and Lake Huron Basins was not along the course of St. Marys River but a few miles farther west. It led south from Whitefish Bay past Rudyard to Pine River and thence to Lake Huron. Wells along this line have reached depths about 200 feet lower than the surface of Lake Superior without striking rock. The rock floor of the valley is thus known to be less than 400 feet above sea level, and it may be considerably lower. The tilting of the Algonquin beach shows that an uplift of 400 feet has occurred at Sault Ste. Marie since the beginning of that glacial-lake stage. The rock bed of this preglacial channel was at that time below sea level. It probably stood considerably above sea level in preglacial time, and it may now have recovered only part of its preglacial altitude.

The principal tributary of St. Marys River in Michigan is Munuscong River, which has a drainage basin of 225 square miles, chiefly in a low clay plain lying north of what is known as the Niagara escarpment. It is a widely branching system, but nearly all the streams in it are rather sluggish. Other tributaries are Charlotte River, to the north of the Munuscong, and Gogomain River to the south. The Charlotte drains a fertile farming district; the Gogomain is largely in cedar swamp.

LAKE HURON DRAINAGE BASIN

Two streams, Pine River and Carp River, lead into Lake Huron from the northern peninsula of Michigan. Both of these discharge into St. Martin Bay, at the extreme head of the lake. The drainage basin of Pine River covers about 280 square miles and is chiefly a lowland tract north of the Niagara escarpment. The river flows south through a gap in the escarpment, which, as already indicated, appears to have been in the pre-glacial line of discharge from the Lake Superior to the Lake Huron Basin. Pine River, so far as known to the writer, has but one rock outcrop along its bed, about 5 miles south of Rudyard. The stream is not regular in flow, for much of the basin is clay, which sheds water rapidly, and thus it has but little discharge in dry seasons.

Carp River drains an area of about 200 square miles immediately south and west of the Pine River drainage basin, much of which is underlain by limestone thinly coated with glacial deposits. Several rock rapids occur along the main stream and some of its tributaries. There are, however, extensive swamps among the limestone ridges through which these streams flow.

LAKE MICHIGAN DRAINAGE BASIN

From Manistique eastward the drainage into Lake Michigan from the northern peninsula goes through small streams, none of which has a drainage area of 100 square miles. The streams head near the Niagara escarpment and flow down the dip slope of the limestone, which stands 200 to 300 feet or more above the lake, but several of them run through strips of swampy land before reaching the lake. Some of the swamps are high among the limestone ridges, but the lower land near the lake is occupied by sand ridges and is relatively dry. A considerable number of the swamps have a subsoil of clay or of till thickly set with limestone pebbles.

Manistique River, which enters Lake Michigan at the city of Manistique, is one of the largest streams in the northern peninsula, its drainage area being about 1,400 square miles. Some of the largest lakes in the northern peninsula are tributary to this river, Manistique Lake having an area of about 16 square miles, Whitefish Lake 7 square miles, and Indian Lake 13 square miles. It has a widely branching system, of which several streams head in a high moraine on the upland south of Lake Superior, their sources being but 5 to 10 miles from the edge of that lake. These streams lead down in converging courses through a great sandy swamp and marsh that covers much of Schoolcraft County and connects at the east with the Taquamenaw Swamp, which is drained to Lake Superior. There are narrow strips along parts of the streams which are fairly well drained, but the interstream areas are practically undrained and are covered with water throughout much of the year. The sandy condition of this swamp area makes drainage less needful than if it were a better soil. There appears to be sufficient southward slope in it to give good conditions for extensive drainage. The fall can not be less than 2 feet to the mile and in places may reach 5 feet. A valuable water power has been developed at the mouth of this river, where the water is held by dams to a height of about 20 feet above Lake Michigan. There are also dams in the outlet of Indian Lake. A large area west of Indian Lake has underground drainage which feeds springs that discharge into the lake in great volume.

GREEN BAY DRAINAGE SYSTEM

Big Bay de Noc, at the extreme northeast end of Green Bay, receives several small streams—Garden and Valentine Creeks from the east and Fishdam, Little Fishdam, Sturgeon, and Ogontz Rivers from the north. Sturgeon River drains about 200 square miles, or more territory than all the others combined, and has a length, disregarding the river meanders, of about 50 miles. It rises in Sixteenmile Lake, on the outer border of a moraine that runs along the south shore of Lake Superior, at an altitude of about 300 feet above that lake.

It encounters rock ledges and has rapids in the southern part of T. 42 N., R. 19 W., and at other points nearer its mouth, but its headwater portion is in a sandy region with thick drift. Fishdam, Little Fishdam, and Ogontz Rivers, and Valentine Creek drain large swamps and encounter few rock ledges. Garden Creek drains a good farming district on the Garden Peninsula, with clay-loam soil.

Little Bay de Noc, at the north end of Green Bay, receives Whitefish, Rapid, and Tacoosh Rivers at its head and Days and Escanaba Rivers on the west. The largest of these streams are Whitefish and Escanaba Rivers, the others being very small. Whitefish River, which drains about 350 square miles, has its source on the "Calciferous" escarpment near Lawson, at an altitude of nearly 1,100 feet. It has a rapid fall from source to mouth, much of the way over a rock bed in which rapids are numerous, though no cascades of note occur.

Rapid River heads in a swamp near Helena station, at an altitude of about 1,100 feet, and drains a narrow strip along the southwest edge of the Whitefish drainage basin, the drainage area being about 140 square miles. It has rapids at short intervals, as its name suggests, from a point near its source to its mouth, and there is a cascade of about 20 feet near the county-road bridge, in sec. 19, T. 42 N., R. 21 W.

Tacoosh River heads near Maple Ridge station, at an altitude of about 950 feet, and for 15 miles or more runs southeastward parallel with the Chicago & North western Railway. It then turns eastward and enters Little Bay de Noc just west of Rapid River. Its drainage area is less than 2 miles in average width and is estimated to embrace less than 50 square miles.

Days River also has its source near Maple Ridge, at an altitude of less than 1,000 feet, and drains a narrow strip along the west side of the Chicago & Northwestern Railway to Brampton station, where it crosses the railroad and runs eastward into Little Bay de Noc, about 2 miles south of Rapid River. The drainage area is between 50 and 60 square miles.

Escanaba River drains nearly 1,000 square miles in Marquette, Dickinson, and Delta Counties, its headwaters being in the pre-Cambrian hills of western Marquette County at an altitude of about 1,600 feet. The estimated length of the stream, disregarding minor meanders, is about 100 miles, and its descent from source to mouth is fully 1,000 feet, thus giving an average fall by direct line of about 10 feet to the mile. The river has numerous rapids and small cascades in its course and a large cascade near the Princeton mine, where there is an available head of 100 feet.

Ford River drains a narrow strip on the southwest side of the Escanaba drainage basin. Its headwaters are near Floodwood and Channing, in northern Dickinson County, and its mouth just below Escanaba. As the altitude at the source is 1,400 to 1,450 feet, the stream has a descent of more than 800 feet. There are numerous rapids in its bed but no large cascades-Limestone bluffs set in near Northland and are present at numerous points below.

The remaining streams of Michigan tributary to Green Bay include Cedar River, a small stream in Menominee County, that enters Green Bay midway between Escanaba and Menominee, and Menominee River, which through much of its course forms the boundary between Michigan and Wisconsin and enters the bay at the city of Menominee. Menominee River has numerous cascades which furnish valuable water power. A report upon its water power appears in volume 17 of the Tenth Census of the United States. Its drainage basin is estimated to be 4,100 square miles, of which 1,450 square miles is in Michigan and the remainder in Wisconsin. The river is formed by the junction of Brule and Paint Rivers near Crystal Falls, Mich.

The entire drainage basin of Brule River in Michigan and Wisconsin is outside the limits of the Superior lobe of the Labrador ice field. So also are the streams from the south which are tributary to Paint River above Crystal Falls. The drift of this part of Michigan is referred to an ice movement that was much more extensive and definitely earlier than that of the Superior lobe. The direction of striae and the trend of drumlinoid hills show that the movement was west of south over this outlying area, whereas the striae and the moraines of the Superior lobe show that the ice in this later movement was converging toward this area from the west and north and east. Paint River follows a curving course immediately outside the drift of the Superior lobe, its headwaters flowing northeastward, its middle course eastward, and its lower course southward. The sources of the river are at an altitude of more than 1,600 feet, and so are the sources of several northern tributaries that head within the area covered by the Superior ice lobe. The altitude at the junction of Paint and Brule Rivers is below 1,200 feet. The largest cascades are on the main Paint River near Crystal Falls. Above Crystal Falls this river and its several tributaries are in an area with thick drift and few and small outcrops of rock, but below Crystal Falls rock ledges are prominent and widely exposed, and they continue to be numerous down the Menominee and cause several notable cascades.

Menominee River was shifted several times to correspond to changes in the position of the ice border and came to its present course only when the Green Bay ice lobe had shrunk to a position east of its lower portion. When this lower course was covered by the ice lobe the river turned southward along or near the ice border and followed it to the end of the lobe or to some drainage way that led southward. These temporary courses ran through the sandy outwash plains which lie between moraines in Marinette County and eastern Florence County, Wis. These plains occur at lower and lower levels down the valley, and it is evident that the stream shifted from higher to lower plains as such plains came within its reach by the ice recession.

Michigamme River, which enters the Menominee just below the junction of Brule and Paint Rivers, drains a

large area that falls within the limits of the Superior lobe. Its headwaters gather into Lake Michigamme, one of the largest lakes in the northern peninsula. Its course extends through a region in which rock outcrops are numerous and the drift deposits more scanty than in bordering districts both to the east and to the west.

Sturgeon River is another large tributary of the Menominee which drains a considerable part of Dickinson County and along which rock ranges are prominent. It has a remarkably winding course caused by its following swales or depressions that lie between the ridges of rock or of glacial material, which have deflected it some miles to the right or left of a direct course. Because of this use of swales, it has but few rock rapids or cascades.

The Menominee receives two streams in Menominee County, Little Cedar River and Little River, each of which flows through a chain of swamps between drumlin ridges, which are numerous in that county. Almost the entire course of Little River is in swamps, and the highest part of this chain of swamps is little if any above the highest level of glacial Lake Algonquin. They may therefore have been prevented from developing a drainage line until the Lake Algonquin waters were drawn away. There was also a flooding of the lower course of Menominee River throughout the Lake Algonquin stage,

LAKES

The great glacial lakes that occupied the Superior, Michigan, and Huron Basins and stood at levels considerably higher than the surface of the three upper Great Lakes are discussed at some length below, and their relations to the present Great Lakes are set forth. In the present section reference is made to the many small lakes that are still filling basins and depressions in the drift deposits or among the rock hills. Almost all these small lakes are represented on the glacial map (pl. 1), only those that are too small to appear on a map of this scale being omitted. It is obvious that although these lakes are widely scattered over the region embraced in this report, they are particularly numerous in certain places and relatively rare elsewhere, also that there are very few of them on the smooth clay plains which were covered by the great glacial lakes. They are very numerous among the rock hills and ridges and on the prominent moraines of northeastern Minnesota. They also abound along the moraines that form the divide between the Lake Superior drainage system and that of Mississippi River in northern Wisconsin and the south edge of the west end of the northern peninsula of Michigan. There are probably more than a thousand of these small lakes within the area here discussed. Of these only two have an area so great as 20 square miles—Gogebic Lake in Gogebic and Ontonagon Counties, and the combined Portage and Torch Lakes, practically a single lake, in Keweenaw Peninsula. There are about 40 with an area of 2 square miles or more, and at least 100 exceeding 1 square mile. The aggregate area of the small lakes exceeding 2 square miles does not amount to 200 square miles, and the area of all these lakes in the region appears to be between 500 and 600 square miles.

Many of the lakes are bordered by swamps in which thick deposits of peat have accumulated. The base of the peat is very generally below the level of the lake surface, and its growth evidently has reduced the areas of the lakes to a large degree. Many lakes have been entirely converted into peaty swamps by this growth of organic matter. There has been more extinction of lakes by this process than by the draining away of the water through the cutting down of their outlets. Many of the lakes have no outlet except through swamps that connect them, and careful leveling has been found necessary to determine the direction of flow across some of the swamps. The drainage of not a few swamps and of some open lakes takes widely divergent courses. Thus Brule Lake, in Cook County, Minn., divided its waters between Brule River and Temperance River. On some lakes dams or even high-water stages cause a discharge by a course different from that of the low-water flow. It is because of the presence of these connecting swamps that the Indians and explorers and also geologic students have been able to make their way by canoes through the greater part of northern Minnesota and adjacent parts of Canada. Such traverses are also possible at several places in passing from waters tributary to Lake Superior to those tributary to the Mississippi or to Hudson Bay. Some of the swamps are in the beds of the outlets of glacial lakes or in the line of discharge of water from the melting ice sheet.

These small lakes have considerable variation in depth, but as yet soundings in them are incomplete. Some of them are said to reach a depth of 100 feet or more, but the usual depth is much less, and it is doubtful if many of them are more than 50 feet deep.

The lakes have great value in water-power development by holding back the discharge after freshets or rainy seasons and giving a steady flow through dry seasons. Many of them are fed by springs, another important factor in producing good flow in the dry seasons. One of the most remarkable springs that has come to the writer's attention discharges into Indian Lake a few miles west of Manistique, Mich. It wells up near the west edge of the lake in sec. 25, T. 42 N., R. 17 W. It is several yards across, and its depth is said to be fully 60 feet. The stream flowing from it is large enough to be navigated from the lake to the spring by small gasoline launches. An area of several square miles to the west of this spring is free from surface streams, and water goes into underground courses through sink holes in the limestone. This spring, therefore, probably affords an outlet for an underground drainage system embracing a considerable part of this limestone tract.

GLACIAL FEATURES

OUTLINE OF THE GLACIAL FORMATIONS

The Pleistocene glacial formations in America, as in Europe, include a complex series of deposits, there being on both continents four distinct sheets of boulder clay of widely different age, separated by soils and nonglacial deposits formed during stages of deglaciation. Aside from the four distinctly recognized drifts there is in Iowa and part of bordering States a glacial deposit of debatable rank and age which has been termed Iowan drift. It has been interpreted as having been deposited between the third or Illinoian drift and the latest or Wisconsin drift. But some geologists, including the present writer, are now inclined to refer part of it to the Wisconsin drift and part of it to the Illinoian. Others are disposed to place it between these drifts with a rank as high as is given to them.

The States bordering the upper Mississippi Valley have an especially full exhibit of the deposits and are thus classic ground for their study. The exhibit is not so full and clear in the relatively rugged area adjoining Lake Superior, though in places deposits of early glacial stages as well as those of the latest or Wisconsin stage are preserved.

The several drift sheets of the region bordering the Great Lakes and the Atlantic seaboard are named from States in which they are well displayed or in which a drift was clearly differentiated at an early date. The oldest drift on the Atlantic seaboard thus differentiated was named Jerseyan, from New Jersey, where it was clearly recognized in the 1890's. The oldest drift of the North Central States has been given the distinctive name Nebraskan, though it is very poorly displayed in Nebraska. In order from older to younger the drift sheets of the Great Lakes and Mississippi Valley region are as follows:

1. Nebraskan drift.
2. Kansan drift.
3. Illinoian drift.
4. Iowan drift (a deposit of debatable rank and age).
5. Wisconsin drift, separable into early, middle, and late Wisconsin.

The first and second drift sheets are best displayed on the west side of the Mississippi Valley, but one of them, probably the Kansan, has been recognized as far north as the north side of the Lake Superior Basin, in the Kaministikwia drainage basin back of Fort William, Ontario. These drift sheets have been covered by the Illinoian drift to a large degree in Illinois, Wisconsin, Michigan, Indiana, and Ohio. The distribution of the drift sheets in the north-central part of the United States, with the exception of the Nebraskan drift, which is almost wholly covered by Kansan drift and loess, is shown in Figure 5, together with the main subdivisions of the Wisconsin drift.

The latest or Wisconsin drift is the uppermost deposit over fully 90 per cent of the glaciated area of North America and is thus more widely open to inspection than the earlier drifts. A study of the distribution of its moraines and of the material embodied in it has served to show that the outline or shape of the ice field and the direction of ice movement were subject to wide variation. In the early part of this glacial stage (substages 1 and 2, fig. 5) the ice appears to have moved southwestward from Labrador across the Great Lakes into central Illinois. At that time it may not have extended into the region north and west of the Driftless Area in Wisconsin, Minnesota, Iowa, and the Dakotas. But later the ice sheet appears to have gradually extended westward, so that in the midst of this stage of glaciation (substage 3, fig. 5) its highest part, or center of radiation, was in the district of Patricia, in Ontario, north of the Great Lakes. The ice then moved southward across the eastern part of the Lake Superior Basin and through the basin of Lake Michigan into Indiana and Illinois. At the same time it moved slightly west of south across the west end of the Lake Superior Basin into western Wisconsin and eastern Minnesota. It deposited the sheet of young red drift of that region, called in this report the Patrician drift.[3] The prominent morainic system on the border of the Green Bay and Chippewa lobes in Wisconsin and of a large lobe to the west, in western Wisconsin and eastern Minnesota, was formed at this time. (See pl. 1.)

[3]A late readvance of ice from the Patrician center of radiation south of Hudson Bay was brought to notice by J. B. Tyrrell in 1913 at the International Geological Congress at Toronto, Canada, and a brief abstract is published in the proceedings of that congress. There is clear evidence that a much earlier radiation from the Patrician district reached its culmination prior to the culmination of the Keewatin center of radiation in the middle part of the Wisconsin stage of glaciation.

After the Patrician drift was deposited there appears to have been less snowfall in the region north of the Great Lakes and a corresponding shrinking of the ice in the Lake region; but the snowfall appears to have become greater in central Canada, in what is known as the Keewatin center of glaciation, and ice moved from that center southward across Manitoba and through western Minnesota and eastern North and South Dakota into Iowa. The main movement was through the Red River Valley into the Minnesota River Valley and thence into the Des Moines River Valley, down which it passed to the site of the city of Des Moines. There were two minor lobes in eastern Minnesota, branching off from the main lobe. One of them crossed the Mesabi range and filled the middle part of the St. Louis River drainage basin, and the other extended from the Mississippi Valley above St. Paul northeastward to the St. Croix Valley, which it covered between Grantsburg and Osceola, Wis.

It was at about this time (substage 4, fig. 5) that the lobe in the Lake Superior Basin, which forms the theme of the present report, reached its fullest extension. The ice at this time moved much farther southwest through the deep basin of Lake Superior than it did over the relatively high land lying northwest of the Lake, in northern Minnesota. The ice there appears to have had a movement west of south and to have reached a little beyond Vermilion Lake and Lake of the Woods. This ice

coalesced with that in the Lake Superior Basin from eastern Lake County, Minn., northeastward into Canada. It probably also coalesced with that moving south from central Canada in the district west of Lake of the Woods. Later (substage 5, fig. 5) the ice from central Canada extended past this line of coalescence in Manitoba and northern Minnesota.

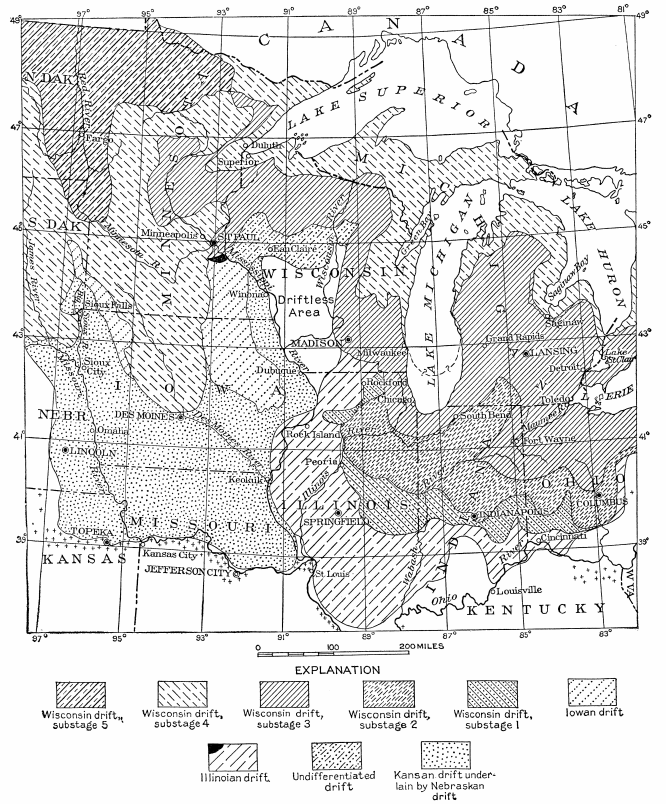


FIGURE 5.—Map of drifts in the northern United States, showing subdivisions of the Wisconsin drift. Crosses indicate outlying erratic boulders and patches of till. A small area of Illinoian drift south of St. Paul is indicated in solid black

The ice movement from central Canada brought in a clayey, calcareous blue-gray drift similar to that of the Kansan and pre-Kansan drifts of Minnesota but much fresher in appearance. It is known as the Young Gray drift. It is strikingly different from the very stony Patrician drift, which it overlaps. In the St. Louis River drainage basin, however, this calcareous drift contains so much iron gathered from the formations of the Mesabi range that it presents a red color, but it is easily distinguished from the underlying Patrician drift, being much less stony and having a more clayey matrix.

LIMITS OF THE SUPERIOR ICE LOBE

The extent of the Superior lobe of late Wisconsin time was first worked out in 1913 in Minnesota by F. W. Sardeson and in Wisconsin and Michigan by the present writer. The general glacial map (pl. 1) shows the extent of this lobe in the three States.

A variety of features have been taken into account in determining the limits of this ice lobe. The most conspicuous of these features are the moraines that loop around the west end of the basin and shed their outwash into the outlying districts. These moraines ride over moraines of Patrician red drift at various angles and in such a way as to make it clear that they were formed by a different ice lobe and at a later time. This discordance with the earlier moraines is found in northern Wisconsin and in the western part of the northern peninsula of Michigan as well as in Minnesota.

A second feature is that of difference in drift constitution. The drift of the Superior lobe along the northwest side of the Lake Superior Basin includes many rocks that were gathered near the Lake Superior shore and carried westward beyond their belt of outcrop, which falls within the limits of the Superior ice lobe. The Patrician ice, moving southward, would have carried them into and across the basin and could not have transported them so far westward. This Patrician ice movement carried rocks from formations such as the upper Huronian slates, iron ores, and associated rocks, which crop out farther west, in a southward course past the west end of the Lake Superior Basin and dropped them in the district later invaded by the Superior ice lobe.

A third feature is that of glacial striae. Those formed by the Superior lobe at this latest advance radiate from the basin toward its rim, their bearing on the north side of the basin being westward or considerably north of west, and on the south side of this part of the basin generally south westward. The striae of the Patrician ice movement trend nearly south throughout northeastern Minnesota, or about at a right angle to those of the Superior lobe. This discordance in trend is shown on Plate 1. It is found as far east as Iron County, Mich., where the earlier movement was about south-southwestward, and that of the Superior lobe was east-southeastward in the northwestern part of the county, southward in the northern part, and south westward or even westward in the eastern part. There is also in the Iron County district a difference in the rock constituents of the earlier and later drift. The later movement carried rocks from the Gogebic iron ranges to the east of their outcrop, but the earlier movement did not.

FEATURES OF THE BORDER OF THE SUPERIOR ICE LOBE

The Superior lobe seems to have held almost its maximum extent in northern Wisconsin and on much of the border northwest of Lake Superior while it was melting back considerably at the west end of the lobe. There are several small moraines at this west end which are the equivalents of a single massive morainic belt farther east.

On the northwest shore of Lake Superior, in Lake and St. Louis Counties, Minn., as far west as Duluth, the Superior ice lobe extended only 12 to 15 miles beyond the limits of the lake, the district farther back having been covered by ice that came in from the highlands of Canada on the north. The morainic system that runs westward across central Lake County and thence west-

northwestward in St. Louis County past the south side of Vermilion Lake marks a contemporary position of the ice that came in from the north. This ice coalesced with that which came into the Lake Superior Basin from the northeast. The junction was in eastern Lake County, where an interlobate spur of great prominence was developed, its altitude being about 2,000 feet above sea level, or, 1,400 feet above Lake Superior. Northeast of this interlobate spur eskers are a conspicuous feature, and they seem to have been formed at the junction of the ice lobes.

At the west end of the Lake Superior Basin the Superior ice lobe extended about 60 miles beyond the present limits of the lake, its terminus as worked out by Sardeson being in southeastern Aitkin County, Minn., near the sources of Rice and Snake Rivers, about 10 miles east of Mille Lacs Lake. The south edge of the lobe crossed northern Pine County, 4 to 8 miles from its north line. The north edge crossed the northwestern part of Carlton County and came to St. Louis River in southwestern St. Louis County. It crossed the St. Louis River Valley just below the mouth of Cloquet River and kept south of that stream its entire length in St. Louis and Lake Counties.

In Douglas County, Wis., the Superior ice lobe extended 20 to 25 miles south of the shore of Lake Superior but fell short several miles of reaching St. Croix River and encroached but slightly on the headwaters of its northern tributaries. In Bayfield County an interlobate moraine was developed on the Bayfield Peninsula, there being a lobe of ice on the east that projected southward from Ashland or Chequamegon Bay and a lobe on the west that filled the west end of the Lake Superior Basin. The ice extended 25 to 30 miles south from Chequamegon Bay, or far enough to embrace Long Lake and Namakagon Lake, in southern Bayfield County. It passed a few miles beyond the Penokee iron range in Ashland and Iron Counties. The border follows or its moraine constitutes the divide between the Lake Superior drainage basin and that of large tributaries of the Mississippi, such as St. Croix and Chippewa Rivers, in much of its course across Douglas, Bayfield, and Ashland Counties, but it lies in places a few miles south of that divide in Iron and Vilas Counties. The border runs nearly due east from southeastern Bayfield County across Ashland, Iron, and Vilas Counties, Wis., and southeastern Gogebic County, Mich. As the Lake Superior shore there bears north of east, the distance from the lake to the border of the Superior ice lobe increases eastward and is 45 to 50 miles where the border passes from Wisconsin into Michigan.

In Michigan the border of the Superior lobe continued eastward past the north side of Lac Vieux Desert about to the line between Gogebic and Iron Counties. Thence it took a northeastward course for 10 to 12 miles and then turned eastward and followed the north side of Paint River in an eastward and southward course to the mouth of the stream, a few miles south of Crystal Falls. It then passed into Wisconsin and maintained a course nearly due south for 36 miles across Florence County to central Marinette County, forming the west edge of the Green Bay lobe of that time. From Marinette County southward the Writer, in company for part of the way with Samuel Weidman, made a reconnaissance trip through Oconto, Shawano, Waupaca, Waushara, and Winnebago Counties, during which the tentative interpretation was reached that this readvance of the ice in the Lake Superior Basin is to be correlated with a readvance in the Green Bay and Lake Michigan Basins, which, as shown by Alden, developed red-clay moraines and worked upon a sheet of red clay that overlies the earlier deposits in that region. This advance that developed the red-clay moraines in Wisconsin, as shown by the writer in Monograph 53, seems to be correctable with the advance in the Huron Basin to the Port Huron morainic system. It thus appears to be part of a widespread readvance in the Great Lakes region.

RANGE IN ALTITUDE ALONG THE BORDER

In eastern Lake County, Minn., where the Superior lobe coalesced with ice coming in from the north, the altitude is about 2,000 feet above sea level. There are a few hills and ridges still higher to the northeast, in Cook County, the highest being about 2,300 feet. The altitude along the border of the Superior lobe declines gradually toward the southwest, being about 1,700 feet at the line between Lake and St. Louis Counties and 1,200 to 1,300 feet at the west end of the lobe in Aitkin County and southwestern St. Louis County. It falls below 1,100 feet for a few miles in northwestern Pine County but rises eastward to about 1,300 feet at the Wisconsin-Minnesota line. It is below 1,100 feet at the outlet of glacial Lake Duluth but rises gradually eastward, reaching 1,400 feet on the east side of Long Lake and 1,500 feet east of Namakagon Lake, 1,600 feet in eastern Ashland County, and 1,700 to 1,800 feet in eastern Iron County and northern Vilas County, Wis., and southern Gogebic County, Mich. It is generally above 1,500 feet and in places reaches 1,700 feet in Iron County, Mich., but drops below 1,400 feet at the Michigan-Wisconsin line. For a few miles into Wisconsin it is up to 1,500 feet or more, but then it begins a gradual descent southward and is below 900 feet at the south end of the Green Bay lobe, south of Lake Winnebago. It falls within the limits and below the level of Lake Michigan (580 feet) at the south end of the lobe in the Lake Michigan Basin. The highest point covered by the Superior lobe in the northern peninsula of Michigan is about 2,000 feet above sea level and is near the Lake Superior shore in the Porcupine Mountains of western Ontonagon County. This lobe thus covered the highest points in Minnesota and Michigan and very high points in Wisconsin.

OUTER BORDER FEATURES

The features on the outer border of the Superior ice lobe furnish evidence as to the limits of this lobe. A series of

outwash plains and heads of glacial drainage lines show clearly the position of the edge of the ice.

The outwash plains are conspicuous along Cloquet River throughout much of its length and in places reach a width of 3 or 4 miles. Locally no outwash was deposited because of high altitude in the outer border district, but there were numerous places in this district where the water found escape from the ice and spread out gravel.

For a few miles west from the mouth of Cloquet River conditions were unfavorable for outwash, but around the end of the lobe there is a sandy plain covering about 20 square miles from which drainage now leads both to the northwest, down Rice River, and to the south, down Snake River. The sand contains few pebbles, and the outwash seems to have been rather sluggish, probably because of the gentleness of the slope.

On the south border of the lobe near its west end there is a sandy area drained to Kettle River. This area, however, seems to have been covered to some extent by the ice and to have had boulders incorporated in the sand, and there was also some disturbance of the deposits which seems referable to glacial action on them.

From Kettle River eastward into Wisconsin there was remarkably little outwash, perhaps because a free discharge was not offered across the rather broken tract outside the ice. But in the reentrant angle on the Bayfield Peninsula between the Ashland lobe and the lobe in the west end of the Lake Superior Basin an extensive plain of sandy gravel was formed which covers more than 100 square miles in Douglas County and fully 50 square miles in Bayfield County. The interlobate moraine to the north of this plain is made up largely of waterworn material of rather coarse texture. Most of the surface of this outwash plain is more than 1,100 feet above sea level, or nearly 100 feet higher than the Brule-St. Croix outlet of glacial Lake Duluth, which runs along its northwest edge. The plain stands above 1,200 feet in the head of the recess between the lobes in western Bayfield County.

The Namakagon Valley appears to have been a line of strong glacial drainage from the Superior lobe from a point near Cable. Above Cable the stream flows in a narrow valley, and the Superior ice lobe probably covered part of its course between Namakagon Lake and Cable. Below Cable a sandy gravelly plain 1 to 2 miles wide follows down the river.

In western Ashland County a sandy plain stands just outside the outer moraine of the Superior lobe at the head of one of the headwaters of Chippewa River. It has a general width of more than a mile in its course across T. 43 N., R. 4 W., from the edge of the moraine to the Chippewa Lakes but is somewhat narrower below (south of) the lakes. From the Chippewa Valley eastward for several miles considerable swampy land occurs along the border of the outer moraine of the Superior lobe, and there was probably some ponding of water there. Still farther east are the extensive Manitowish marshes, occupying a strip 1 to 3 miles wide and 12 to 15 miles long on the outer border of the moraines of the Superior lobe. Farther east there are small sandy and gravelly outwash plains in Vilas County.

At the head of Wisconsin River, around Lac Vieux Desert, there is an extensive sandy gravel plain formed by outwash from the Superior lobe. It lies partly in Gogebic County, Mich., and partly in Vilas County, Wis. The altitude of its northern edge at State line station on the Chicago & Northwestern Railway is 1,712 feet. The outwash plain or glacial gravel fill along Wisconsin River is 1,670 feet above sea level at Conover, about 8 miles south of the State line, and 1,635 feet at Eagle River, 10 miles farther south.

In Iron County, Mich., there was glacial drainage all along Paint River from the ice border along the north side of the valley to its mouth. The outwash did not continue down Menominee River, because the ice was at that time covering the Menominee Valley nearly up to the mouth of Paint River. It passed southward across Florence County, Wis., through a district just outside the Green Bay lobe of that time. It received accessions from that ice lobe from point to point in Florence and Marinette Counties, Wis.

MORAINES OF THE SUPERIOR ICE LOBE IN MINNESOTA[4]

The moraines of the Superior lobe are markedly discordant with the moraines formed by the ice coming in from the north, that of the Patrician ice sheet. The Superior moraines either cross over the Patrician moraines because of difference in trend, or they face in the opposite direction where the courses are more nearly similar. The moraines of the Superior lobe are less bulky than some of the outlying and also underlying moraines formed by ice from the north. They belong to a rather thin till sheet. The knolls and ridges consist to some extent of crumpled and disturbed Patrician drift, over which there is in places only a thin veneer of the brighter-colored drift of the Superior lobe.

On the north side of the Superior ice lobe, north of Lake Superior in Lake and St. Louis Counties, Minn., a great system of moraines, referred to in earlier reports of the Minnesota Geological Survey as the Highland morainic system, lies immediately within the border of this drift sheet. (See fig. 6.) This morainic system is formed by the converging and coalescence at the side of the lobe of moraines, which are distinct and separate toward the west end of the lobe. The moraines are likewise combined on the south side of the lobe in northern Wisconsin but are split up toward the west and there appear as distinct moraines.

On the south side of the lobe hi Pine and Carlton Counties, Minn., there are two morainic systems, the Kerrick and the Nickerson, which are the equivalent of six more or less distinct moraines on the north side in Aitkin and Carlton Counties and southern St. Louis

County—namely, the Wright, Cromwell, Draco, Cloquet, Thomson, and Fond du Lac moraines. The Wright and Cromwell moraines are regarded as the equivalent of the Kerrick morainic system, and the other moraines as the equivalent of the Nickerson morainic system; the entire series of moraines enumerated above are equivalent to the Highland morainic system.

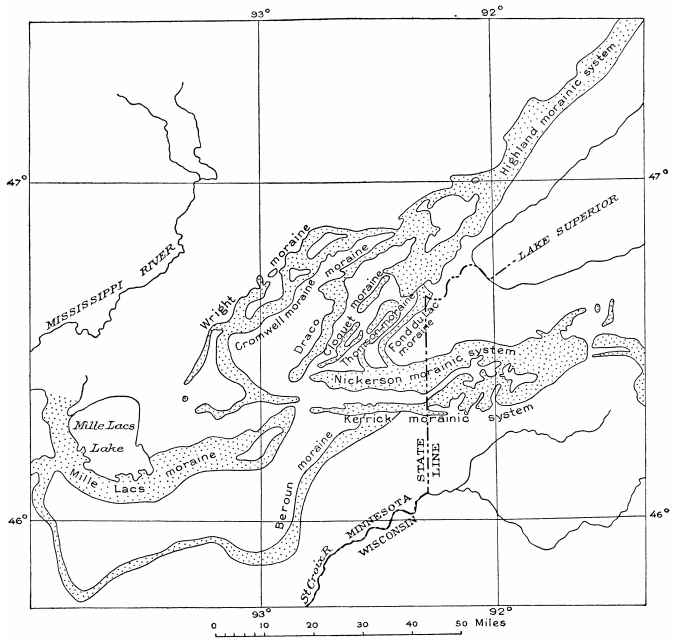


FIGURE 6.—Map showing moraines of Lake Superior lobe in northeastern Minnesota and the Mille Lacs and Beroun moraines of the Patrician ice sheet

The time relations of the moraines of the Superior I lobe as well as those of the Patrician ice sheet in this area are shown below.

Superior lobe (Highland morainic system).	Fond du Lac moraine (deposited in water).	Nickerson morainic system.
	Thomson moraine.	
	Cloquet moraine.	
	Draco moraine.	Kerrick morainic system.
	Cromwell moraine.	
	Wright moraine (oldest).	
Patrician ice sheet.	Mille Lacs moraine.	
	Beroun moraine.	

[4]Prepared largely from notes and manuscript by F. W. Sardeson.

KERRICK MORAINIC SYSTEM AND ASSOCIATED GLACIAL FEATURES

THE MORAINES

The subdivision of the Highland morainic system of the north side of the Superior lobe into distinct constituent morainic ridges begins near the crossing of the St. Louis River Valley just below Brookston. To the northeast there is no distinct separation, but to the west there are two moraines of nearly equal strength, the Wright moraine and the Cromwell moraine, here named by the writer for villages on them in northwestern Carlton County, Minn. The Wright moraine bears away from St. Louis River near Paupori and passes by Prairie Lake to Wright station on the Northern Pacific Railway and thence runs along the south side of the railroad into Aitkin County, where it turns southward and runs about 4 miles west of Lawler and dies out in a sandy outwash plain near the sources of Rice and Snake Rivers, about 10 miles east of the northeast edge of Mille Lacs Lake. The Cromwell moraine runs southwestward from Brookston past Cromwell to Lawler and there turns abruptly south and marks the end of the Superior lobe of that time. Its position is several miles east of the Wright moraine at the end of the lobe. On the south side of the lobe the two moraines are separated only for a few miles in Aitkin County. In Pine County they are united into a single morainic system, which passes through or near Denham, Kerrick, and Belden and is here named the Kerrick morainic system. Near the Wisconsin line the Kerrick morainic system becomes coalesced with a later one, which is here designated the Nickerson morainic system, from the village of Nickerson.

The Kerrick morainic system has a general width of about 3 miles from Belden to Kerrick but is only about 2 miles wide in the vicinity of Denham. It widens a little to the west of Denham. The Wright and Cromwell moraines are each about 2 miles wide.

The Kerrick morainic system consists at Kerrick of closely distributed small knolls 10 to 20 feet high. Near Belden its knolls are 5 to 15 feet high and separated by much swampy land, probably half the surface being bog. For 5 miles west from the State line the proportion of bog is still higher, so that the morainic knolls are scattered widely. Midway between Belden and Kerrick the morainic expression becomes strong again, the morainic system crosses obliquely over the Beroun moraine, of the Patrician ice sheet, here named by the writer for Beroun, Minn., and for 3 miles there is the combined strength of the two systems. There is much less swamp west of the crossing of the Beroun moraine, although near Kerrick the moraine is interrupted by a swamp half a mile to a mile wide. A few miles west of Kerrick the moraine is weak in expression and consists of slightly disturbed outwash gravel and sand in a strip along Moose and Kettle Rivers. To the west of this outwash plain the moraine becomes strong again. It overrides the Mille Lacs moraine, of the Patrician drift (here named by the writer from its position on the borders of Mille Lacs Lake), and some outwash was spread over the lower places in that moraine in northwestern Pine County. In secs. 15, 22, and 27 and also in secs. 25 and 36, T. 45 N., R. 20 W., it rides obliquely over prominent ridges of the older moraine and caps them with its own small knolls. In the vicinity of Denham the Kerrick morainic system lies partly on a rock ridge and partly in a valley south of the ridge.

After separation into two distinct parts or members, the Wright and Cromwell moraines, the knolls become more scattered than in much of the united belt and in places are so diffuse as to be difficult to map. They run through a region of bogs and consist of groups of knolls or of

short ridges for stretches of 1 to 3 miles, which are separated by wide swamps. As these bogs have a peaty filling of 5 to 20 feet, low knolls may be completely overgrown and concealed under them.

In a few places the Kerrick morainic system consists of heavy clay till, but for the greater part it is loose textured or sandy, with numerous pebbles of Keweenawan diabase and red rock, greenstone, red sandstone, quartz, and chert and rarely a limestone pebble. Sandstone is most common on the south and west sides of the lobe but is also found on the north side as far north as the crossing of St. Louis River near Brookston.

At Kerrick the till is a light clay of bright red color with many pebbles of sandstone and basic volcanic rocks. Heavy clay is found west and north of Denham but the drift is loose textured between Kettle River and Denham, in parts of the morainic system south of Arthyde, and from Solana to Snake River. This loose-textured till is, however, in places only a few feet thick and lies on heavier till of the Patrician drift. The clay is heavier in many places in Carlton County.

An isolated gravel hill or kame of the Wright moraine, standing nearly 100 feet above the surrounding land, rises from an outwash plain on Snake River in the NW. ¼ sec. 5, T. 44 N., R. 24 W. It covers about 40 acres. It is at the apex of the Superior lobe. Boulders and till occur at the surface, but the hill appears to consist of gravel below.

OUTWASH DEPOSITS

Glacial drainage from the part of this lobe in Minnesota occurred at several points but was of slight extent and relatively weak. On the south side out-wash is present on Willow River. At the apex of the lobe it extends down Snake River and on the north side it occurs at Cromwell and Brookston and along Cloquet River. Nearly all the outwash at Willow River appears to pertain to the Mille Lacs moraine of the Patrician ice sheet. The Kerrick morainic system passes across this outwash, but a part of the deposit seems to belong with the Kerrick system. The narrow strip of terraced gravel along the south fork of Willow River could not have been formed earlier. The outwash on Snake River lies in strips and patches, as if deposited slowly during the entire time in which the Wright moraine was forming. It takes the place of the moraine for 6 miles in length and is spread over a belt 2 to 4 miles wide at the end of the lobe. There is a little gravelly outwash along Split Rock Creek connected with the Cromwell moraine. It forms a terrace where the stream enters the moraine from the southwest in sec. 5, T. 45 N., R. 22 W. Outwash occurs in connection with both of the moraines near Cromwell, but the largest deposit lies near the inner one. The outwash occupies an area of about 5 square miles west of the village, along the Northern Pacific Railway. That north of the railroad is outside the moraine, but that on the south is partly within the moraine. The outwash at Brookston is opposite the mouth of Cloquet River and seems to be the west end of a strip that comes down that river from Burnett. It is of especial interest at Brookston, for it was there carried up St. Louis River from the mouth of Cloquet River instead of down the valley, the part of the valley below the mouth of Cloquet River being covered by the ice of the Superior lobe. About half a mile south of Brookston are exposures showing outwash involved in the morainic material by a forward thrust of the ice. There appears also to have been some invading of the outwash by forward ice movement in other places between Brookston and Burnett.

TILL PLAIN OR GROUND MORAINE

The till plain between the Wright and Cromwell moraines is narrow in southern St. Louis County and northwestern Carlton County, Minn., its width being about the same as that of either moraine. In Aitkin County north of Solana, however, it widens to 7 miles. The drainage in this plain is rather imperfect and is effected by several small streams that start in the plain or in neighboring moraines. The altitude is relatively high, as may be inferred from the fact that the plain is the starting point of drainage lines.

The plain that lies between the Cromwell moraine of the Kerrick morainic system and the succeeding Draco moraine of the Nickerson morainic system is somewhat wider than that between the Cromwell and Wright moraines. Though only 3 to 5 miles wide on the south side of the lobe, it widens to about 20 miles near the end of the lobe, in western Carlton County. It is narrow also on the north side of the lobe in St. Louis County. It is partly occupied by outwash in its narrow parts north of St. Louis River and on the borders of Willow River. This plain drains partly to St. Louis River, of the St. Lawrence drainage system, and partly to Kettle River, of the Mississippi drainage system, but the divide here between the two systems is mostly flat and ill drained. The plain is composed largely of clayey till, which is so thick that rock exposures are rare. There are slate outcrops, however, in secs. 14, 15, 22, and 23, T. 46 N., R. 21 W., and sec. 9, T. 45 N., R. 20 W. A diabase ridge that is cut through by the Minneapolis, St. Paul & Sault Ste. Marie Railway (Soo Line) 2 miles south of Harris runs across T. 45 N., R. 16 W., from sec. 12 to sec. 31.

NICKERSON MORAINIC SYSTEM AND ASSOCIATED GLACIAL FEATURES

THE MORAINES

On the north side of the Superior lobe the Nickerson morainic system becomes distinct from the Kerrick morainic system near Grand Lake, Minn. Its outer member, here designated by the writer the Draco moraine, branches off in that locality, and the others branch off a few miles farther east. The Draco moraine passes in a southwesterly direction to St. Louis River at Draco. Across the river in Carlton County it runs to Big Lake, thence southward by Sawyer station to Park Lake near Mahtowa, thence southwestward to Kettle River west of Moose Lake.

The middle member, or Cloquet moraine, comes to St. Louis River at Cloquet from the north-northeast and thence takes a southwesterly course at Atkinson, Barnum, and Moose Lake, where it meets the Draco moraine and turns east with it to form the undifferentiated Nickerson morainic system.

The inner member, or Thomson moraine, is interrupted by a wide gap at St. Louis River immediately north of Thomson and is closely associated with the Cloquet moraine northeast of this river. From Carlton and Thomson it runs southwestward to Nemadji, turns to the south and east, and within a short distance coalesces with the other parts of this morainic system. For a few miles from Carlton it is a double ridge with a narrow gravelly strip between its members.

On the south side of the lobe from a point near Nickerson eastward there is a single massive morainic belt that forms the equivalent of the three moraines just described. It leaves the State of Minnesota at the corner of Pine and Carlton Counties and, in combination with the Kerrick morainic system, continues eastward into Wisconsin. From the State line westward to Nickerson, for 10 miles, its border lies about 2 miles south of the Pine-Carlton county line, but it nearly follows the county line from Moose Horn River to Kettle River. The apex of the lobe was a mile west of Kettle River at Split Rock Creek.

The united morainic belt along the Pine-Carlton county line is about 4 miles in width. Where the members are separate the Draco, Cloquet, and Thomson moraines are each 1 to 2 miles wide, but near the apex of the lobe the Draco moraine spreads out to nearly 5 miles. The Cloquet moraine spreads out near Barnum to a width of 3 miles, and the Thomson moraine is of similar breadth just south of Carlton if the gravelly plain between its two members is included.

The Nickerson morainic system presents throughout a knolly and ridged surface of moderate strength. Where a moraine of this system overrides or crosses the Mille Lacs moraine of the Patrician drift, as the Draco moraine does near Moose Horn Lake, its knolls are less prominent than the ridges of the older moraine. From Moose Lake eastward to the State line the morainic system lies on a high divide and is thus prominent as well as compactly morainic. In the turn at the apex of the lobe west of Moose Lake the knolls and ridges are more scattered than to the east. Northwest of Moose Lake the moraine is broken by swamps and also by drainage channels but still is well defined. It has especially rugged features near Big Lake and Perch Lake.

The middle or Cloquet moraine is cut through by the outlet of glacial Lake Nemadji east of Moose Lake village, at the place where it makes the turn at the apex of the lobe. This outlet is, however, only about one-sixth of a mile in average width. From Moose Lake nearly to Atkinson the Cloquet moraine lies high on the ridges of the Mille Lacs moraine. Between Atkinson and Cloquet it is broken by swamps, drainage courses, and outwash. North of Cloquet it includes some very prominent knolls and a short gravel ridge of esker type.

The Thomson moraine is closely associated with its outwash plain for several miles west from Nickerson and is rather inconspicuous there and around the end of the lobe, for it was laid down for a few miles in the water of Lake Nemadji. A short distance beyond the point where it rises to the north from Lake Nemadji, about 5 miles northeast of Nemadji station of the Soo Line, it runs over the Mille Lacs moraine and thus attains exceptional prominence. Its course north of St. Louis River is also over highlands and along the ridges of a Patrician moraine.

The prevailing type of drift in the Nickerson morainic system is clayey rather than sandy. From the State boundary westward to Kettle River it is chiefly heavy clay and has relatively few large stones embedded in it, and in places even small stones are scarce. It may include considerable material derived from lake beds which the ice passed over as it moved out from the Lake Superior Basin. On the northwest side of the Superior lobe from Kettle River northeastward there is a considerable amount of gravelly and loose-textured drift. From Otter Creek to Cloquet it is very largely gravelly. The till has a larger proportion of clayey drift northeast of St. Louis River than for a few miles southwest of that stream. Yet gravel knolls and ridges are not rare. In places where the morainic ridges of Patrician drift are overridden there are many exposures of the older drift in cuts of moderate depth, for the Superior drift is a relatively thin deposit. Though each drift is classed as red drift, there is a perceptible difference in color due presumably to a difference in the rock constituents.

The rock striations in this morainic system were partly produced by the Patrician ice and partly by ice of the Superior lobe. In some places striae of both ages are present on a single rock outcrop. In a cut on the Soo Line a mile south of Harris, near the outer edge of the Nickerson morainic belt, the younger set bear S. 62° W. (magnetic) and the older set S. 20°-30° W. Outside the moraine 2 miles south of Harlis only the older set is present with magnetic bearing S. 20°-32° W. Near Moose Lake striae produced by the Superior lobe bear nearly due west, and in Duluth and westward past Carlton those formed by the Superior lobe in high ranges bear west or slightly north of west. Lower down along the slope toward the Lake Superior Basin they commonly bear a little south of west. North of Atkinson near Park Lake are striae bearing about N. 60° W., including heavy furrows an inch in depth.

OUTWASH DEPOSITS

Outwash deposits of considerable extent are found in many places in connection with the Nickerson morainic system. On the south side of the lobe there is an area of about 10 square miles south of Willow River lying between the Kerrick and Nickerson morainic belts which is occupied by rather sandy gravel. Another plain of

sandy gravel covering several square miles lies on the north side of the most prominent moraine of this system and is probably a dependency of the Thomson moraine. It stands higher than the land to the north, which was covered by ice at the time this outwash was laid down and later by the waters of Lake Duluth.

At the end of the Superior lobe and the outer border of the Nickerson morainic system there are small areas of sandy gravel outwash, one east of Kettle River Station on the Soo Line and one east of Glassy Brook.

Outwash of coarser grade is found near Barnum, outside the Cloquet moraine. It extends south about to Moose Lake and extensive gravel pits have been opened in it by the Minneapolis, St. Paul & Sault Ste. Marie Railway Co. Another deposit inside the Cloquet moraine south of Atkinson covers about 3 square miles, and east of Atkinson is an area of about 10 square miles of gravelly outwash lying outside the Thomson moraine.

An area of undulating gravelly land covering about 3 square miles lies northwest of Park Lake, and farther north there are ridges of gravel in the vicinity of Sawyer station and northward to Big Lake. Although these areas are not outwash plains, they seem to have been developed by water action along the ice border, where conditions were not favorable for spreading out the gravel. The ice probably overlay much of these areas, for surface boulders are not uncommon on the gravel. Between Big Lake and Cloquet plains of out-wash gravel occur in steplike succession from higher to lower toward Carlton either from Big Lake or from Cloquet. In each of these steps the tread is an outwash plain or glacial drainage line, and the steep slope down to the next step marks the correlative position of the ice border. In some places boulders and till or cobbly drift are to be seen in these steep slopes.

A conspicuous channel known as the Scanlon channel leaves St. Louis River at Scanlon and runs south-westward to Atkinson. There it branches; one branch is followed by the Northern Pacific Railway to Moose Lake and the other passes southward and turns west on the inner side of the Cloquet moraine. The southern branch is a slightly lower channel and was probably utilized as a line of glacial drainage after the one now followed by the Northern Pacific Railway had been abandoned. The Scanlon channel seems to have carried a volume of water considerably greater than the present St. Louis River and to have been a line of glacial drainage for a large area on the northwest side of the Superior lobe, and possibly it carried water from the melting of ice that came in from the northwest, whose southeast edge at this time seems to have been but a short distance from the northwest edge of the Superior lobe.

The glacial drainage of the Nickerson morainic system seems to have increased in strength with the development of each moraine. The drainage on the south down Willow River was weak and the streams do not seem to have been large at the time the morainic system was being started. There was also drainage of a similar sort in the west side of the lobe, through the meadows and swamps that extend southwestward from Big Lake to Kettle River. On Glassy Brook more vigorous drainage seems to have been in operation. In northern Carlton County and the region north of St. Louis River there seems to have been westward flow through low passages and swampy tracts, but the line of escape of the waters has not been worked out. While the Cloquet moraine was being formed the drainage on the northwest border of the Superior lobe became vigorous. The glacial streams flowed down the course now taken by the Northern Pacific Railway from Atkinson to Moose Lake, the ice at that time being present in the part of the Scanlon channel east of Atkinson. This drainage was fed from points as far northeast as Cloquet through the outwash strips noted above. The Scanlon channel and the channel leading south from Atkinson were formed as a result of drainage during the recession of the ice sheet to the Thomson moraine and the development of that moraine, and eventually the glacial stream flowed into Lake Nemadji and discharged through the Cloquet moraine past Moose Lake.

TILL PLAINS OR GROUND MORAINE

On the south side of the Superior lobe the Nickerson morainic system is not separated into distinct members with intervening plains. On the northwest side, where there are separate moraines, the intervening areas are partly occupied by outwash gravel and sand, partly by channels of glacial drainage, and partly by till plains. Between the Draco and Cloquet moraines a small till plain is found in parts of secs. 9, 16, 17, and 19, T. 46 N., R. 19 W., north and west of Moose Lake. The material is undulating till at the south, but this gives place toward the northeast to bare slate in sections 2, 3, and 10. Another till plain lies west of Mahtowa in secs. 6 and 7, T. 47 N., R. 18 W., and secs. 1, 11, 12, 13, and 14, T. 47 N., R. 19 W. Farther north, nearly west of Atkinson, is a narrow till plain that spreads out to a width of almost 3 miles and trends northward to the Northern Pacific Railway between Iverson and Sawyer station. An area of till plain nearly surrounded by outwash runs from the Draco moraine at the north end of Big Lake for 4 miles eastward and is about a mile wide. Above Cloquet on each side of St. Louis River there is a till plain which covers several sections in T. 49 N., R. 17 W., and the southeastern part of T. 50 N., R. 17 W., an area of about 12 square miles, of which 5 square miles is west and 7 east of the river. There is a small area of till plain between the Thomson and Cloquet moraines northeast of St. Louis River, though these moraines generally are close together there. Parts of secs. 7, 8, 9, 10, 11, 16, 17, 18, 20, and 29, T. 49 N., R. 16 W., may perhaps be better classed as till plain than as moraine. To the southwest from St. Louis River as far as the edge of Lake Nemadji the interval between the Cloquet and Thomson moraines is nearly all occupied by outwash plains and glacial drainage channels.

FOND DU LAC MORAINE (DEPOSITED IN WATER)

The Fond du Lac moraine, here named by the writer from Fond du Lac, Minn., is water-laid so far as it stands out separately from the morainic systems with which it connects at its two ends. It leaves the Highland morainic system that lies north of the west end of Lake Superior in the southwestern part of Duluth and crosses St. Louis River at Fond du Lac. Its inner slope is on the Wisconsin side of the State line opposite Fond du Lac but its outer border is in Minnesota. It leads southwestward through T. 48 N., R. 16 W., the northwestern part of T. 47 N., R. 16 W., and the southeastern part of T. 47 N., R. 17 W., and thence swings around to the southeast and east through the northeastern part of T. 46 N., R. 17 W., and the central part of T. 46 N., R. 16 W., and becomes merged with the Nickerson morainic system on the south side of the Superior lobe, near the State line. The part of this moraine running southwest from Fond du Lac has a relief of 75 to 100 feet on the inner border in much of its course but has scarcely any relief on the outer border. It rises less prominently on the inner border at the end of the lobe and on its south side. Ravines and railroad cuts in the prominent part southwest of Fond du Lac show a large amount of fine sand and nearly pebbleless clay capped by a few feet of boulder clay. The glacial material thus seems to be banked against and spread lightly over a thick deposit of water-bedded material. As the entire moraine lies within the limits of the highest shore line of glacial Lake Duluth and is below the level of that shore line, the ice lobe was probably bordered by ponded waters and dropped its boulders and till in deposits laid down by these waters.

The portion of the bed of Lake Duluth to the north of this moraine is generally covered with sandy deposits, but around the end of the lobe and on its south border the sand is much less conspicuous and red clay usually occurs at or near the surface. The district lying inside the moraine in Carlton County, Minn., is almost entirely a plain of red clay. In this red clay are embedded a few stones which suggest glacial derivation. It is a widespread deposit in northern Wisconsin and Michigan, as well as in Carlton County, Minn., and occurs in a narrow strip along the north side of Lake Superior from Duluth northeastward into Canada within the limits of Lake Duluth or of smaller lakes that preceded Lake Duluth. Its characteristics and probable relation to the Superior glacial lobe and to glacial lakes are considered more fully below.

HIGHLAND MORAINIC SYSTEM AND ASSOCIATED GLACIAL FEATURES

MORAINAL DEPOSITS

The Highland morainic system takes its name from Highland station on the Duluth & Iron Range Railroad, in the southwestern part of Lake County, Minn. It is the equivalent of the entire series of moraines just described, from the Wright to the Fond du Lac, both inclusive. Northwest of Duluth it is separable into two great morainic belts, between which there is a till plain that surrounds Wild Rice Lake and occupies an area of about 50 square miles; but from the east side of Duluth northeastward for more than 60 miles it is a single massive morainic system from 4 to 6 miles in general width but in places reaching 7 to 8 miles. Its inner border is only 1 to 2 miles from Lake Superior back of Duluth, but thence bears inland and is 9 to 12 miles from the lake in Lake County. In the vicinity of Duluth its highest points are about 1,500 feet above sea level, or 900 feet above Lake Superior, and it covers the slope toward Lake Superior to a level below 1,200 feet. It increases gradually in altitude toward the northeast and reaches about 2,000 feet in eastern Lake County. In this highest part, in T. 59 N., Rs. 7 and 8 W., this morainic system meets a correlative morainic system formed by the southward-moving Patrician ice sheet, and its great prominence is due in some degree to the heaping up of drift at the junction of the two ice sheets. Some of the drift ridges there are 100 feet or more in height. The morainic system changes to a series of eskers or gravelly ridges near the corner of Tps. 59 and 60N., Rs. 6 and 7 W., and these ridges continue northeastward into the western edge of Cook County and appear to mark the line of junction of the Superior lobe with the Patrician ice sheet.

The Highland morainic system is prevailingly of the strong knob and basin type, with knobs or ridges of drift rising abruptly to heights ranging from 25 to 75 feet or more above the intervening basins and low ground. Some of the basins and low swampy tracts are completely surrounded by higher land and have no drainage over the surface. Others are winding depressions through which drainage courses run. The lakes interspersed with the drift knolls and ridges of this morainic system are not so many nor so large as those found among the rock hills and ridges farther north, in Cook, Lake, and St. Louis Counties. Wild Rice Lake has an area of but little more than 2 square miles, and no others reach 2 square miles. The drift is generally loose textured and contains many cobblestones and small boulders. There is, however, enough fine material in the matrix to produce a rather loamy soil. The diabase of Beaver Bay, which forms a notable constituent of the drift, seems to have contributed material that weathers into a loamy rather than sandy soil. The soil is therefore classifiable as stony loam. This moraine has been brought under cultivation with good results in the vicinity of Duluth, but elsewhere it is largely undeveloped, and much of it is still in hardwood forest.

OUTWASH DEPOSITS

Outwash deposits are conspicuous on the border of the Highland morainic system for most of its course in Lake and St. Louis Counties, and Cloquet River now flows through the outwash district. The outwash is present for a few miles farther northeast than the head of the Cloquet River, but the line of discharge from the ice was down that valley. The outwash ranges in width from less

than a mile to 4 or 5 miles. It consists in many places of rather coarse cobble and gravel, and little of it is fine and sandy. There were numerous points of discharge of water from the ice lobe, and at such places the material is exceptionally coarse. The ice in some places readvanced into the outwash area and introduced boulders and other morainic material and roughened the surface to some extent. Such disturbances were noted as far down as Brookston.

INNER BORDER TILL PLAIN

A strip of land 11/2 to 3 miles or more in width having a gently undulating surface such as is characteristic of till plains lies on the inner or southeast border of the Highland morainic system in Lake County and the southeastern part of St. Louis County. Its soil is somewhat better than that of the moraine, and a considerable part of it has already been brought under cultivation.

LATER MORAINES IN NORTHEASTERN MINNESOTA

A narrow morainic strip, scarcely more than a mile in average width, was traced from Baptism River west of Finland southwestward for nearly 50 miles, or to a point within 8 or 10 miles of Duluth. Its drift is more knolly and of looser texture than that in the till plain back of it just described. This moraine may continue to the northeast beyond Baptism River, but rock knobs are so conspicuous there as to make its identification rather difficult and to break it up into isolated knolly spots or strips.

A later moraine than that just noted sets in on the Lake and Cook County line, only 2 or 3 miles from the shore of Lake Superior, and leads northeastward beyond the meridian of Grand Marais, Minn. It is generally 6 to 10 miles back from the lake shore and has a width of 1 to 2 miles. It passes along the north side of Devil Track Lake and was traced northeastward about 8 miles beyond this lake to Brule River. To the north of Brule River there is a rough rocky region in which it may be difficult to identify the moraine. This moraine lies back of the Sawtooth Range, in a district where the drift is heavy enough for the morainic features to stand out with some clearness. The drift is stony and loose textured and the area contains swamps of considerable extent and therefore has not been developed for agriculture.

A still later moraine was traced from a point near the mouth of Cascade River northeastward for several miles. This is thought to continue across Cook County to the Canadian border, crossing Brule River in the southwestern part of T. 63 N., R. 3 E., and passing west of Toms Lake and coming to Pigeon River in T. 64 N., R. 4 E. After passing Devil Track River it follows the eastern edge of a prominent rocky area and marks the west limit of a district with considerable drift and much swamp land. Immediately above the place where, according to Elftman,[5] the moraine reaches the Canadian border there is a lowland extending back several miles west from Pigeon River, nearly across T. 64 N., R. 3 W., in which the drift deposits are heavy. This lowland has a nearly smooth surface and is thus in contrast with the knolly moraine to the east and with the rock ridges to the north and south.

To the east of this moraine, in eastern Cook County, about half the surface is in rock ridges and the other half is in swamps and drift deposits of ground-moraine rather than terminal-moraine type. North of Grand Portage is an area in which lake clay occupies the low areas between the rock ranges, for it stands below the level of glacial Lake Duluth.

[5]Elftman, A. H., Am. Geologist, vol. 21, pl. 11, 1898.

MORAINES OF NORTHERN WISCONSIN

OUTER MORAINIC SYSTEM

From a point near the Minnesota-Wisconsin State line eastward across northern Wisconsin the several moraines that have been traced around the end of the Superior lobe in Minnesota are combined into a massive system 8 to 15 miles in width whose members are distinct at only a few places where narrow strips of till plain and swamps or small outwash plains separate them. The outer or southern edge of this morainic system enters Wisconsin about 28 miles south of Superior, in the northern part of T. 44 N., R. 15 W.; the inner edge is 10 to 12 miles farther north, in the northern part of T. 46 N., R. 15 W. In its course across Douglas County the moraine lies mainly on the north or Great Lakes side of the divide, but in places it extends a short distance into the drainage area tributary to the Mississippi. Its general course is slightly north of east and its constituent ridges trend mainly in the same direction. In this respect they differ from the ridges in the district outside of this morainic system, which trend more nearly south. The drift is also somewhat different in character from that of the outlying district, containing more red clay. On the soil map of the northern part of northwestern Wisconsin that accompanies Bulletin 32 of the Wisconsin Geological and Natural History Survey the soil in the outlying district in western Douglas County is classed as Millen silt loam and that in the moraine is termed Millen loam. According to that map, the boundary between these two classes of soil follows very closely the southern edge of this morainic system for 8 or 9 miles east from the State line, but not farther east. It is the present writer's opinion, however, that distinctions in texture continue eastward to the Brule-St. Croix channel, though perhaps in less marked degree than in the part represented on the map cited.

In Bayfield County the prominent Bayfield Peninsula is occupied by an interlobate moraine belt for its entire length, and morainic features also appear on Oak Island, of the Apostle group. This morainic belt was formed between a sublobe that occupied the extreme west end of the Lake Superior Basin and another that projected into the lowland east of the peninsula, at the south end

of the Chequamegon Bay. This interlobate belt consists of sandy and somewhat stony drift, which is classed, on the soil map of the Wisconsin Geological and Natural History Survey under three names—Vilas sand, Plainfield sand, and Superior sandy loam. Depressions extending back into this morainic system in the northeastern part of the peninsula contain a much heavier clayey drift, which is classed on the soil map as Superior clay. These depressions were almost entirely covered by glacial Lake Duluth, whereas only a small part of the loose-textured moraine was thus submerged. In the midst of this interlobate morainic belt there are strips of outwash plain filling the space between the ridges and knolls, but the greater part of the interlobate belt is characterized by sharp knobs and deep basins. The general width of this interlobate morainic system with its included outwash plain is about 12 miles. A great outwash plain extends from its south end to St. Croix River and to Eau Claire River a small eastern tributary of the St. Croix that drains the Eau Claire Lakes. This outwash plain fills a great recess at the junction of the two sublobes just noted and slopes southwestward from the edge of the morainic system.

From this interlobate area the morainic system continues southeastward into western Ashland County and thence eastward across Ashland and Iron Counties and northern Vilas County into Gogebic County, Mich. It covers the Penokee iron range as well as lower land both north and south of it in western Ashland County, but from Bad River eastward it lies mainly south of the iron range. Slender moraines north of the range in these counties were formed as the ice border was receding from the range into the Lake Superior Basin. One of these smaller moraines is merged with the main morainic system from Bad River westward but lies some miles north of it in the district east of Bad River.

The Millen loam is mapped by the Wisconsin Geological and Natural History Survey as the most extensive soil class in this morainic system in southeastern Bayfield County and Ashland County, but the soil in the vicinity of Long Lake is represented on the map as the Vilas sand. The morainic system there includes a few kames and gravelly ridges. In the district outside this morainic system the soil is classed mainly as the Vilas sand from Cable eastward into Ashland County and as the Kennan loam in the vicinity of Glidden.

Rock knobs and ridges of the Penokee iron range and also Keweenaw rocks crop out at many places in this morainic system from the north side of Namakagon Lake eastward to the vicinity of Mellen. East of Mellen the moraine lies mainly south of the ranges, and rock outcrops are rather rare.

On the soil map of Vilas County this morainic system is shown as consisting largely of the Kennan fine sandy loam, and in the district outside of it the main soil classes are the Vilas sand and the Plainfield sands. The change from the Kennan to the Vilas and Plainfield soils is made directly at the border of this morainic system or within a mile or so of it from the west border of the area included in the soil map (the line of T. 43 N., Rs. 2 and 3 E.) eastward to Donaldson, in sec. 33, T. 43 N., R. 10 E., or for a distance of 40 miles. A large outwash plain east of Donaldson covers the district north and west of Lac Vieux Desert on the border of this morainic system, in Gogebic County, Mich. The Vilas County soil map represents the Kennan series of soils as covering large areas south and east of Lac Vieux Desert outside the limits of this morainic system. The soil distinction between the morainic area and the outlying districts, which is so marked to the west, therefore seems not to be maintained east of Lac Vieux Desert, but in that region there is a noticeable difference in the constitution of the drift of the morainic system and that outside. The morainic system contains abundant Keweenawan rocks, which were brought in from the northwest, but in the outlying district such rocks are rare and the drift consists largely of materials from formations that crop out to the north or northeast.

This morainic system is a pronounced feature throughout its course across northern Wisconsin. Although many of its knolls are but 10 to 15 feet high, they are closely aggregated and form an intricate network that is in striking contrast with the greater part of the outlying district, in which slopes are smoother or less hummocky, even where the ridges are prominent. Some knolls of the morainic system are 75 to 100 feet high, and knolls 30 to 40 feet high are to be seen in nearly every township it traverses. The interlobate moraine of Bayfield County includes many large knolls, and they abound around Long Lake and in northern Vilas County along the Wisconsin-Michigan State line. In that area the swamps and lakes are 100 feet lower than the most prominent drift ridges and knolls on their borders.

To the west of the interlobate moraine that extends

across western Bayfield County and Douglas County the morainic system includes some large swamps, in which a few low drift knolls are present. There is relatively less swamp land to the east of this interlobate tract within the morainic system itself, but very extensive swamps lie just outside of it in Vilas County and part of Iron County. A swamp covering 18 to 20 square miles on the inner border extends immediately south of the Duluth, South Shore & Atlantic Railway for several miles west from Bibon Junction.

Lakes are especially numerous in the morainic system in northern Vilas County, Wis., and the adjacent part of Gogebic County, Mich. Surrounded by wooded hills and well stocked with fish, they constitute attractive and popular resorts for summer tourists or persons seeking relaxation.

The drift throughout the Wisconsin portion of the morainic system is of reddish color, because it includes Keweenawan rocks of red tinge, as well as a liberal amount of the red sandstone of the Lake Superior region. Iron ore from the Mesabi range and slate from the western part of the Lake Superior Basin are well represented in the drift in Douglas County, but, as noted

above, these constituents seem to have been brought in by an earlier ice movement than that which formed this morainic system and were worked over and incorporated in its drift. Limestone pebbles, which occur sparingly in the drift of this morainic system, as well as in that of the plain bordering the west end of Lake Superior, are not so easily traced to their source or interpreted in terms of ice movement. It is not yet known whether they have come from formations in Manitoba or from those bordering James Bay. Nor has it been determined to what extent limestone of Paleozoic age has covered the western part of the Lake Superior Basin. The presence of limestone formations near the head of Keweenaw Bay in Baraga County, Mich., and the widespread presence of chert from limestone formations in the region south of Lake Superior, give some support to the view that limestone formations may at one time have extended much farther west than their present known limits in this basin.

LATER MORAINES

The moraines in Wisconsin between the outer morainic system and the shore of Lake Superior are weak and fragmentary. A few isolated areas of rolling drift, surrounded by smooth plains of lower altitude, occur in the district west of the interlobate morainic belt on the Bayfield Peninsula, and a smaller number on the east slope of the peninsula. There are also long morainic spurs projecting out into the plain that borders Lake Superior. One of these spurs runs eastward through Mason about to the east line of Bayfield County, or fully 12 miles from the point where it connects with the great interlobate moraine east of Pike River station. It is only about 2 miles wide and stands only about 3 miles north of the inner edge of the main morainic system in eastern Bayfield County.

In the vicinity of Saxon there are two moraines separated by a narrow valley that served as a line of glacial drainage outside the inner or north moraine. The outer of these moraines runs southwestward to Bad River, about 3 miles north of Millen, and a short distance beyond that stream it becomes merged with the main morainic system. It has a general width of less than 2 miles, and its knolls are generally only 10 to 20 feet high, but they are closely aggregated. The inner moraine bears directly away from the outer one just west of Saxon and runs to the Lake Superior shore at Point Clinton, about 18 miles east of Ashland. Probably at the time this moraine was being formed, the ice extended over the Apostle Islands, and it may have covered the northeast end of the Bayfield Peninsula, but it appears not to have reached the present shore of Lake Superior between Point Clinton and Ashland. At that time there seems to have been a glacial lake, discussed below as Lake Ashland, which covered the low country in Ashland County and eastern Bayfield County and was drained across the Bayfield Peninsula near Pike River. It is thought that the lake outlet may have been forced to take this line of discharge because the ice was still resting on the north end of the Bayfield Peninsula, and that upon the opening of a passage around the north end of the peninsula the lake waters were drawn down a few feet, or to the level of the lake that occupied the part of the Lake Superior Basin west of the peninsula.

MORAINES OF THE WESTERN PART OF THE NORTHERN PENINSULA OF MICHIGAN

OUTER MORAINIC SYSTEM

The outer morainic system is more diffuse and complex in the western part of the northern peninsula of Michigan than in northern Wisconsin. It curves around from an eastward to a southward course in Iron County and neighboring parts of Houghton, Baraga, Marquette, and Dickinson Counties. In places it is spread over a width of 30 miles, in which narrow strips of till plain and gravel plain lie between morainic ridges.

The outer border comes into Michigan near State Line station of the Chicago & Northwestern Railway, in southeastern Gogebic County, and has a general eastward course across T. 44 N., Rs. 39 and 38 W., to the Iron County line, following the edge of the plain of outwash that lies northwest of Lac Vieux Desert in R. 39 W., but crossing over ridges of till northeast of that lake in R. 38 W. Upon entering Iron County the border turns abruptly to a north-northeast course which it follows for about 10 miles, keeping on the northwest side of a gravel outwash plain drained by headwaters of Paint River in Tps. 44 and 45 N., R. 37 W. It then turns eastward near the corner of Tps. 45 and 46 N., Rs. 37 and 36 W., and follows the course of Paint River eastward and southeastward to Brule River at the Wisconsin State line. In a few places its knolls lie on the south side of the stream, but generally the stream is in an outwash plain a mile or more outside the morainic border. There are also till ridges between this moraine border and Paint River in the southern part of T. 45 N. and northern part of T. 44 N., Rs. 34 and 35 W. Outwash strips from the morainic system fill the low places between the till ridges and connect with the outwash along Paint River in these townships. West of Crystal Falls the morainic border for a few miles is close to Paint River and in places south of it. South of Crystal Falls there are a few knolls in the outwash plain west of Paint River that may belong in this morainic system. The outwash greatly interrupts the continuity of the morainic border both east and west of Paint River from Crystal Falls southward to the Wisconsin State line. In places above Crystal Falls strips of outwash come through the outer portion of the morainic system from its middle part and thus break the continuity of the moraine.

In Gogebic County there are two prominent moraines in this morainic system which are separated by a strip of till plain 2 to 4 miles wide for a distance of 25 miles, from the eastern part of T. 45 N., R. 45 W., to the eastern part of T. 45 N., R. 41 W. Farther east, across T. 45 N., Rs. 40 and 39 W., the moraines are separated in places by strips of sandy outwash. The outer of these has a

general width of about 8 miles and lies partly in Wisconsin. The inner moraine has a width of 2 to 5 miles or more and lies almost entirely in T. 46 N., Rs. 40 to 45 W. Its inner border passes the south end of Gogebic Lake. The village of Watersmeet, Mich., stands between the two moraines in the outwash plain just noted. The inner moraine for a few miles in the vicinity of Watersmeet covers the northern part of T. 45 N., Rs. 39 and 40 W.

In eastern Gogebic County, southeastern Ontonagon County, and northwestern Iron County the morainic system has exceptional width and prominence and is not so clearly separable into distinct moraines as in western Gogebic County. The inner border is irregular, with spurs of moraine projecting 2 to 4 miles into a plain in Ontonagon County and southwestern Houghton County. One of these spurs extends into the southeastern part of T. 48 N., R. 39 W. Still farther north, in eastern Ontonagon County, isolated morainic areas surrounded by plains lie between this morainic system and the later ones described below.

The morainic system again becomes divided into two strong moraines with an intervening outwash plain in northern Iron County and southern Houghton and Baraga Counties. The outer moraine of these two lies entirely in Iron County; nearly all of the inner one lies in Houghton and Baraga Counties. The intervening outwash plain lies along the borders of the three counties and occupies an area of 60 to 70 square miles. It is widest immediately outside the inner moraine, in southern Houghton County and southwestern Baraga County. (See pl. 5.) The outer moraine has a width ranging from 3 or 4 miles to fully 10 miles in northern Iron County and as far southeast as Crystal Falls, but east and south of that town it is poorly developed and buried in outwash. The inner moraine lies 1 to 3 miles south of the Duluth, South Shore & Atlantic Railway for the entire width of Houghton and Baraga Counties and runs to the west shore of Michigamme Lake in western Marquette County. It then bears southeastward across southwestern Marquette County and south ward along the line of Iron and Dickinson Counties to Menominee River above Iron Mountain.

In southern Marquette County and northern Dickinson County the ice moving southwestward from the vicinity of Marquette was opposed by the westward spreading of the Green Bay lobe. Several townships in the area of converging and conflicting ice movements have morainic features, and these should perhaps be included in the great morainic system under discussion. Among the morainic ridges there is a network of glacial drainage channels, now largely of swampy character but carrying deposits of sand or gravel in the drier parts. There are also narrow strips of clayey till plain, chiefly in the western half of Dickinson County. Areas with nearly bare rock surface are also present, including one that covers several square miles around the corner of Tps. 43 and 44 N.; Rs. 28 and 29 W., and a still larger area in the southern part of the county, extending from Sturgeon River westward to Me-nominee River. A network of glacial drainage lines runs through both of these rocky areas and continues southward across Menominee River toward the end of the Green Bay lobe.

A part of this morainic system falls within the Perch Lake, Ned Lake, Witbeck, Iron River, Crystal Falls, and Sagola quadrangles and the Menominee special area, which are covered by contour maps of the United States Geological Survey. Although these maps are not up to the present standards of mapping by the Geological Survey, they show fairly well the amount of swampy land and the closeness or diffuseness of grouping of the drift knolls and ridges. The ruggedness of parts of the Menominee special area is due to rock ridges, and so are the hills near Mansfield, but elsewhere the rock ridges inside this morainic system are usually inconspicuous and less prominent than the morainic knolls. Few of the knolls exceed 50 feet in height, and most of them are 25 feet or less. They are generally without system in arrangement. In places they stand close together in groups, but as a rule they are rather diffusely scattered over swampy and nearly level tracts. In the outwash plains basins are numerous, some of which are well represented on the Perch Lake topographic map. (See pl. 5.)

The highest parts of this morainic system in the northern peninsula are more than 1,800 feet above sea level, and a considerable part is above 1,600 feet, as may be seen by reference to Plate 2. The high altitude is due to the prominence of the underlying rock, for the drift is estimated to have an average thickness of less than 100 feet. There are records of a thickness of 200 feet or more, but these are at places where borings have been sunk in preglacial valleys, and in such places the present surface is usually lower than on the interfluvial preglacial ridges. Were the drift to be stripped off this region it would show more difference between ridges and valleys than now appears. Thus in southern Baraga County, where the rock ridges reach an altitude of 1,800 feet above sea level, the rock beds of valleys near them lie at about 1,400 feet, or 200 feet lower than the present valley bottoms. The altitude of the rock surface decreases southward from Baraga County across eastern Iron County and neighboring parts of Marquette and Dickinson Counties. The inner or eastern part of the morainic system in Marquette and Dickinson Counties is also considerably lower than the outer part, the altitude being 1,400 to 1,500 feet in the outer part and 1,000 to 1,100 feet in the inner part in Dickinson County. In consequence of this eastward decline in altitude, the lines of ice-border drainage shifted eastward with the recession of the ice and so developed the complex network of channels referred to above. The southward descent along these lines of glacial drainage is more gentle than the eastward descent across the morainic system, but on account of the presence of the ice in the lower country to the east the only lines of escape for the glacial streams led southward. When the ice that then covered the Green Bay lowland disappeared the

streams naturally took southeastward courses to Green Bay in the direction of steepest slope.

The drift of this morainic system throughout its course in the northern peninsula of Michigan is very largely of loose texture and very stony, especially in the morainic knolls and ridges. It is strikingly different from the drift in the plains to the north, which is in large part a heavy clay. It contains enough material from iron-bearing formations and from the red sandstones to give it a red tinge. There are a few short eskers in the midst of the morainic system, most of them not more than 25 feet high nor more than a mile in length. They are found mainly in the swampy strips that cross the moraines or wind about among the knolls and ridges.

OUTWASH DEPOSITS AND GLACIAL DRAINAGE

The outwash plain around the head of Wisconsin River and Lac Vieux Desert is mentioned above. This river served as the line of discharge for several miles of the ice border when the outer part of the morainic system was being formed. As the ice melted back to the inner part of the morainic system there was some outwash into low areas on its border, but the deposit is of sandy rather than gravelly character, and probably the discharge was not so free as that from the outer border. The sandy deposits are to be seen along or near the Chicago & Northwestern Railway from Watersmeet westward nearly to the south end of Gogebic Lake.

The Paint River Valley afforded a line of discharge for glacial waters from the outer part of the morainic system in Iron County, Mich. There is a gravelly plain 1 to 2 miles wide along the stream in the western part of the county and another plain fully as wide below Crystal Falls. But in central Iron County Paint River cuts across some outlying till ridges with north-northeasterly trend and also the troughs or swales that lie between the ridges. At the ridges the valley is narrow, but at the troughs it widens out, in some places to 2 or 3 miles or more. These low tracts seem to have been flooded and thus coated with deposits of sand at the time the morainic system to the north was being formed. Part of the sand and gravel in these troughs may have been laid down during the recession of the ice border prior to the development of this morainic system. In support of this view there are basins and also surface boulders in these strips of sandy gravel so far outside the border of the morainic system that they probably have no connection with it.

The portion of an outwash gravel plain that lies in the northwestern part of the Perch Lake quadrangle and the moraine north of it are shown in Plate 5. This plain is north of the present divide between the Lake Superior and Lake Michigan Basins, but as its altitude is a little higher than that of swampy channels which lead south and southeast across the divide, discharge through the channels probably took place during the development of this outwash plain and the moraine north of it. One channel leads southward past Marten Lake to Golden Creek, a tributary of Faint River 2 miles southwest of Perch Lake. It is slightly more than 1,520 feet above sea level, whereas the altitude of the outwash plain is 1,540 to 1,560 feet or more. Another channel that leads eastward from Perch River to Ned River about 2 miles south of the Baraga-Iron County line is less than 1,520 feet above sea level and probably carried part of the discharge from this outwash plain.

From southwestern Marquette County and western Dickinson County the Michigamme Valley afforded a southward line of discharge to the Menominee after the ice border had shrunk too far to the east to find a southward outlet down Paint River. Still later the Sturgeon River Valley served as a line of discharge, though the glacial drainage departed in places from the present course of that stream.

LATER MORAINES

The later moraines of the western part of the northern peninsula of Michigan form a system whose members are in places separated and in places combined into a single broad morainic belt. On the whole, the moraines are more distinctly separated than those in the outer morainic system. They have courses that were controlled to some degree by the topography and by the outline of the shore on the south side of the Lake Superior Basin. Thus the Porcupine Mountains held the ice in check sufficiently to give the moraines a northward turn both on the west and on the east of them. On the Keweenaw Peninsula a massive morainic belt was developed. Around Keweenaw Bay also the moraines are exceptionally strong. At the Huron Mountains and in the High area in eastern Baraga County the ice movement was held in check, so the moraines make a northward detour in passing over these highlands. Between the Huron Mountains and Marquette the moraines are split up into several more or less distinct members and are spread over a width of 15 to 20 miles. Because of the prominence of rock hills they are interrupted and have less continuity than in smoother districts to the west.

The two nearly parallel moraines in the extreme west end of the peninsula, from the Wisconsin line eastward to Presque Isle River, are clearly differentiated from the till plain between them and from the lake plain north of the inner one and also from a till plain south of the outer one. They are each about a mile in general width, but range from half a mile to nearly 2 miles. The hummocks or knolls rise rather steeply to heights of 15 to 20 feet or locally to 40 or 50 feet above the inclosed basins and irregular depressions. The border plains have a more gently undulating surface. Along or near the outer border of each of the moraines are channels marking the line of westward discharge of glacial waters on the border of the ice lobe. The Duluth, South Shore & Atlantic Railway runs in one of these channels for much of the way from Thomaston, Mich., to Saxon, Wis. This line of drainage served as the outlet for the glacial Lake Ontonagon, as shown below. A swampy strip outside

the inner moraine marks the course of glacial drainage for much of the way from Black River to the Wisconsin line. A few of the morainic knolls contain beds or pockets of gravel, but till is the prevailing material in the moraines as well as in the bordering till plains. It is rather stony and ranges from close-textured clay matrix to a loose-textured till. In a few places rock hills rise above the general level of these moraines, but in general they are no more prominent than the drift knolls, and most of them carry a cover of drift of moderate thickness.

In the vicinity of Presque Isle River the moraines are in a more broken country than to the west, and this condition extends northeastward past the Porcupine Mountains. The ice moved southeastward or southward into this broken district on the west side of the Porcupine Mountains but southwestward on the east side, and the moraines have courses in harmony with these movements. In this broken country rock hills rise above the level of the morainic knolls or are but partly covered by the drift. The morainic features are prominent in a strip 2 or 3 miles wide extending southwestward to Presque Isle River and southeast to the north end of Gogebic Lake, thus occupying as wide a strip as the two moraines to the west would cover if combined. Directly north of Gogebic Lake the moraine fills a gap in the copper range 2 or 3 miles in width, lying partly in R. 41 W., and partly in R. 42 W. The moraine there is so high, however, that Gogebic Lake does not discharge through it but drains eastward along the south edge of the copper range. On each side of this gap the rock hills rise to a height of 50 to 100 feet above the level of the moraine, and thus the moraine filling is insufficient to conceal this break in the range. This gap seems to mark the place where the preglacial drainage of western Ontonagon County and eastern Gogebic County passed through this range to the Lake Superior Basin.

From Gogebic Lake northeastward across Ontonagon County the moraine follows the course of the copper range. It is strongly developed in low places on the range, but morainic knolls are scarce on the prominent parts. The altitude of the moraine here is higher than that of the country immediately south of it, and during the development of the moraine this lower country was covered by a lake which occupies a considerable part of the Ontonagon drainage basin and has therefore been named Lake Ontonagon. This lake and its outlet, which led westward from Gogebic Lake, are discussed below. The moraine is composed of stony till of rather loose texture, but the plain outside covered by Lake Ontonagon has a stiff clay subsoil. So also has a plain to the north, which became a lake bed (Lake Duluth) when the ice melted away from it.

Near Mass City the morainic belt that follows the copper range across Ontonagon County meets a strong morainic system, which encircles Keweenaw Bay, and the two are banked against each other from Mass City northward past the Winona mine to Misery River. Farther north the morainic belt seems to have been formed mainly by the Keweenaw Bay sublobe, for the striae in its midst bear westward. The striae in Ontonagon County and as far northeast as the Winona mine bear southward and were formed by ice to the west of the Keweenaw Peninsula. This morainic belt is very prominent as far north as the hill called Wheal Kate, west of the village of South Range. It is well defined northward from that point to the shore of Lake Superior, which it strikes between Redridge and the north canal entrance to Portage Lake. Northward from Mill Mine Junction it has been covered by glacial Lake Duluth, yet its morainic topography has been but slightly toned down.

Where the two moraines are united for a few miles northeast of Mass City the width of the morainic system is about 12 miles. From Misery River northward, where it was formed mainly by the Keweenaw sublobe, its width is 5 to 8 miles. A considerable part of the moraine from Mass City to Mill Mine Junction is 600 to 800 feet above Lake Superior, and Wheal Kate is about 900 feet above the lake. This prominence is due to the high altitude of the rock formations, as I the drift is in general only about 100 feet thick. In this morainic belt there are rock hills that stand more than 700 feet above Lake Superior. From Mill Mine Junction northward the moraine is on a gentle downward slope west of the main rock ranges of the peninsula. There is, however, a conspicuous hill only a mile from Lake Superior near the corner of Tps. 55 and 56 N., Rs. 34 and 35 W., rising more than 400 feet above the lake.

The topography of the northern part of this moraine for about 16 miles south from the Portage Lake Ship Canal is shown on the contour map of the Houghton quadrangle. A comparison of the features to the north of Mill Mine Junction with those to the southwest (pl. 6) will make clear the difference between the part that was covered by lake waters and that which was not. In the part that was covered by the lake few of the knolls take more than one 20-foot contour, but in the part that was not covered many of them take two or three contours, and Wheal Kate takes 10 contours on its north slope and eight on other parts. This hill, 160 feet high, seems to be made up entirely of drift. As it occupies less than 40 acres, its slopes are exceptionally steep. Small lakes and marshy basins are inclosed among the knolls and ridges of this morainic belt, and the moraine has a strong expression for much of its length. The drift is stony, loose-textured till that includes much sand and gravel. There are very few places where it is a clayey till. The moraine is thus in striking contrast with the plain west of it, which is generally underlaid by a stiff clayey drift.

As the ice border was receding eastward across the Keweenaw Peninsula it formed moraines, but they are generally of weak expression, for they are very largely below the level of glacial Lake Duluth. Some of the knolls and ridges, however, have considerable sharpness of prominence. Groups of such drift knolls occur immediately west and northwest of Calumet, in secs. 10, 15, 16, 21, and 22 T. 56 N., R. 33 W. They are

brought out clearly in the contours of the Calumet, special map. Their highest points are about 60 feet lower than the upper limit of glacial Lake.Duluth, but lower beaches of Lake Duluth are found on their slopes. There is considerable drift between the ranges and on the southeast slope of the copper ranges from the Allouez Gap, near Mohawk, northeastward past Gratiot Lake, and in places it is knolly and ridged in morainic fashion. But for about 15 miles from the east end of the peninsula there is very little morainic drift. Southward from Mohawk past Torch and Portage Lakes and on each side of Sturgeon River to the edge of Baraga County the drift is morainic but shows very gentle swells. It is looser textured in the morainic strips than in the bordering clay plains but contains enough fine material to make farm land of fair quality.

The strong morainic belt that was traced northeastward from Mass City to the north end of the Portage Lake Canal continues southeastward from Mass City to Sturgeon River, below its great bend near the line of Houghton and Baraga Counties, in a belt 6 to 8 miles wide. This is at the end of the Keweenaw sublobe of the Superior ice lobe, which moved southwestward 25 to 30 miles beyond the limits of Keweenaw Bay. The moraine is bordered by extensive out-wash plains of sandy gravel. Pori station, on the Chicago, Milwaukee & St. Paul Railway, stands in the midst of one outwash plain. Another extends from Frost Junction southeastward to Sidnaw. From Sidnaw northeastward across Sturgeon River and for several miles on the north side of the westward flowing part of that stream there is a broad outwash tract along the outer edge of the morainic belt. This belt was partly covered by Lake Duluth after the ice had disappeared, but the outwash plains just mentioned and fully half the width of the moraine were too high to be covered by the lake waters. The portion that was submerged is nearly as strong in morainic expression as that above the lake level. It is strikingly in contrast with the smooth clay plain that lies between its inner border and the head of Keweenaw Bay. The morainic belt also consists of much looser textured drift than this clay plain. The outwash plains around Pori and from Frost Junction to Sidnaw extend down on the west to the clay plain that was covered by Lake Ontonagon, and that lake was contemporary with the outwash. The limits of westward and southwestward distribution of the outwash were probably determined to some degree by the presence of the lake, for the outwash slopes down at the edge about to the level of the lake shore.

Beyond Sturgeon River the morainic belt takes a north of east course and maintains it across Baraga County. It is banked on a steep slope south and southeast of Keweenaw Bay and its inner border is close to the bay for several miles on the east shore. The waters of Lake Duluth later covered this slope up to a height of about 600 feet above Keweenaw Bay. A considerable part of the morainic belt, however, stood above the lake level. The knolls and ridges of drift that were covered by the lake are in general not so sharp as those that were not covered. Notches on the lakeward side of the knolls and the filling of recesses on the shore by material cut from salient points mark the chief effects of the lake action. The drift in this part of the morainic system is generally very stony and loose textured, yet it carries enough loam to make a fair soil. It is thick enough to conceal a considerable part of the rock surface, but not a few prominent hills and ridges of rock rise above the surrounding drift knolls. The rock ridges and knolls are much more conspicuous and the land is of poorer quality for farming outside this moraine in central and eastern Baraga County than along it. But in western Baraga County, along the south side of Sturgeon River in the vicinity of Covington, the drift is less stony, and on the whole better suited for farming than along the moraine.

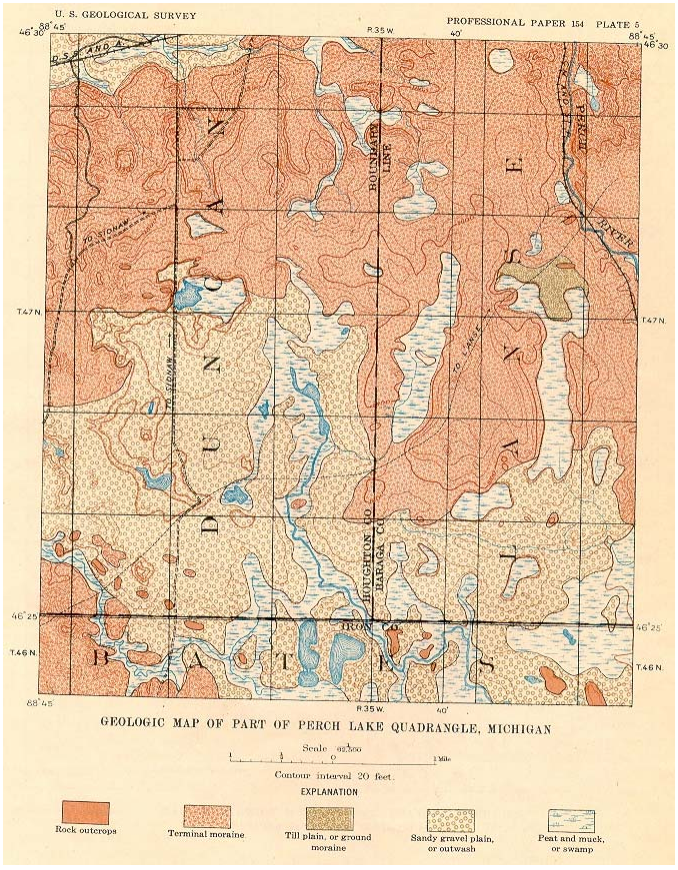
The relations of the ice border to Lake Duluth on the east side of Keweenaw Bay have not been fully deciphered. It is known that Lake Duluth extended eastward from the bay about to the Marquette County line, but traces of its shores have not been found farther east, nor any other evidence of submergence at altitudes corresponding to those covered by the lake in Baraga County. The ice therefore appears to have covered northern Marquette County until about the time the waters in the western part of the Lake Superior Basin were drawn down to lower levels, and it was the recession of the ice border in northern Marquette County that permitted an eastward discharge for the water in the western part of the Lake Superior Basin. When the ice stood high enough in Marquette County to close the eastern line of discharge it probably still covered lower districts in northern Baraga County along the borders of Huron Bay and Keweenaw Bay. An effort was made by the writer to find a moraine or other evidence of ice occupancy there that could be correlated with the moraine or ice border in Marquette County that shut out the waters of Lake Duluth. A strip of drift with slightly undulating surface was found leading westward from the Huron Mountains in Marquette County to Skanee, on the east shore of Huron Bay. It is a mile or more in width and lies 2 to 4 miles inland from the Lake Superior shore. Its knolls are only 10 to 15 feet high and have gentle slopes, but if it was formed in ponded waters its expression is fully as strong as can be expected. The number of boulders appears also to be somewhat greater in this undulating J strip than on bordering plains both north and south of it. The thickness of the drift probably averages not more than 20 feet. This slight thickness, however, seems not to preclude its marking an ice border, for in parts of the morainic system above the limits of Lake Duluth in eastern Baraga County and along the moraines in northern Marquette County the drift has an average thickness not much greater than 20 feet. On the whole, therefore, it seems probable that the ice sheet occupied northern Baraga County and if so a considerable part of Keweenaw Bay down to the time when the recession of the ice in northern Marquette County opened an eastward discharge for the waters of the western part of the Lake Superior Basin.

In Marquette County the members of the later set of moraines are more widely separated than in Baraga

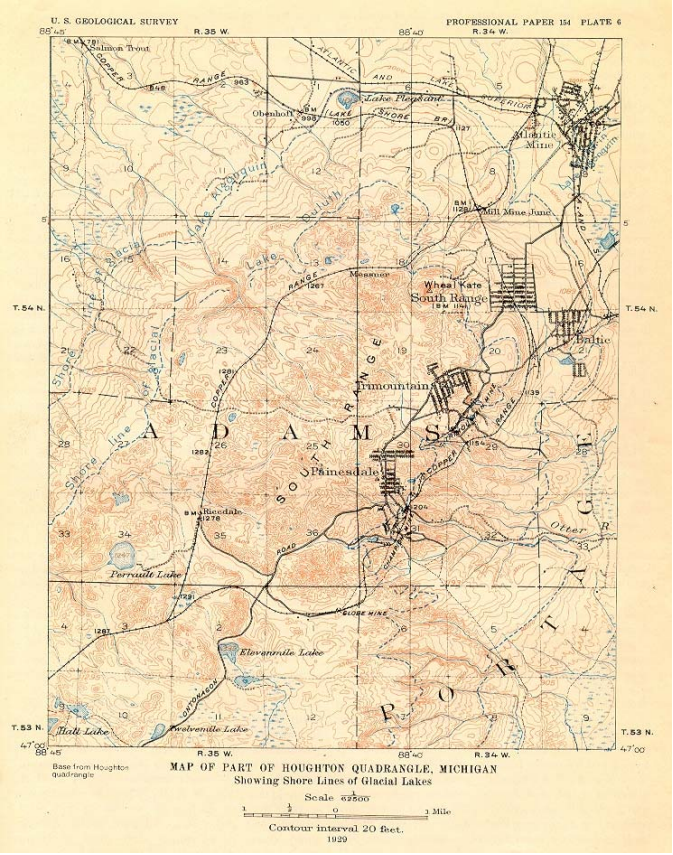
County and trend south of east and in places nearly south. The outermost member is not far from the headwaters of the streams that flow directly into Lake Superior, and glacial drainage from this moraine found passages across the divide into headwaters of Michigamme and Escanaba Rivers. This moraine is rather poorly developed from Silver Lake northwestward to the Baraga County line, but its knolls are present among rock hills and fill the space between Yellow Dog and Dead Rivers in the central and eastern parts of T. 50 N., R. 29 W. From Silver Lake the moraine takes a course but little east of south and is well defined all the way to Escanaba River, a distance of 20 miles. The Duluth, South Shore & Atlantic Railway crosses it near Greenwood. For about 13 miles in its course across Tps. 48 and 47 N., R. 28 W., it is on the divide between the Escanaba River and streams flowing to Lake Superior. It is 1 to 2 miles wide, and rock knobs are not conspicuous along its course. Its drift is of very loose texture and comprises gravelly knolls and ridges and sandy to stony loam soil. In the southern part of T. 48 N., and entirely across T. 47 N., R. 28 W., there is on its western border a strip of outwash gravel which reaches in places to Escanaba River. Considerable outwash is present farther north, in the vicinity of Silver Lake, and it is probable that some of the waters that formed this deposit discharged to Michigamme River through a swampy channel that crosses the divide between the Dead River and Michigamme drainage basins in sec. 22, T. 49 N., R. 29 W. The headwater part of the Escanaba also probably drained into the Michigamme, at that time one line of discharge being through a channel now followed by the Chicago & Northwestern Railway across T. 48 N., R. 29 W.

A moraine branches off from the one just described 5 or 6 miles northwest of Ishpeming and runs southeastward into the extreme southwestern part of that city. It is only about half a mile in average width, but has a strong expression, with steep slopes in the knolls and ridges. It consists of loose-textured material with some gravelly knolls. Outside this moraine, from the point where it parts from the other moraine to its southeast end at Ishpeming, there is an outwash plain of sandy gravel, which fills the space between it and the outer moraine.

The outer moraine ends at the south in a gravelly plain, which covers a wide area south of Escanaba River in T. 46 N., R. 27 W. A probable continuation of this outer moraine of the later system is found south of Escanaba River in a moraine that runs southeastward from the southern part of T. 46 N., R. 27 W., to the Princeton mine. The moraine is from 1 to 3 miles wide and is very prominent in the northeastern part of T. 45 N., R. 27 W., and the western part of T. 45 N., R. 26 W., its altitude there being about 1,500 feet above sea level, but it declines to about 1,200 feet near the Princeton mine. There is an outwash plain south of this moraine, in the southern part of T. 45 N., R. 26 W., and the southwestern part of T. 45 N., R. 25 W., which extends southward into T. 44 N., Rs. 25 and 26 W. In this outwash, as well as in the moraine, there is very little limestone material. It is thus in striking contrast with the drift in till plains and moraines lying immediately southwest of the outwash plain, for that drift contains a large amount of limestone. This moraine and its outwash were formed by ice that was moving southward or but slightly west of south, directly from the Lake Superior Basin, and which did not encounter the Paleozoic limestone formations of the eastern part of the northern peninsula of Michigan. But the till plains and moraines to the south are the products of ice which was spreading westward in passing across the peninsula from the Lake Superior Basin to the Green Bay Basin and which thus encountered the limestone formations. This moraine seems to be traceable no farther southeast than the Escanaba Valley at the Princeton mine, for on the east side of this valley the outwash from one of the later moraines comes in from the north and follows down that side of the river, as shown below. This moraine presents sharp ridges and knolls, but in the main immediately west of the Princeton mine there are gently undulating tracts alternating with sharp ridges or chains of knolls, and these are deeply indented by basins. A string of basins several miles long separates the south edge of the moraine from its outwash apron, forming a fosse of unusual length. Small lakes fill some of the basins. The morainic ridges north of this string of basins rise sharply to heights of 75 to 100 feet above the basins.



[PLATE 5. Map of part of Perch Lake quadrangle, Michigan, showing glacial features]



[PLATE 6. Map of part of Houghton quadrangle, Michigan, showing glacial and lake features]

There are some indications of an ice border running from Silver Lake southeastward to Ishpeming and Negaunee. For about 6 miles southeast from Silver Lake, along Dead River, the country is a combination of outwash and morainic knolls, in which the outwash plains are the more conspicuous. For the next 3 or 4 miles morainic features are well developed in a strip about 2 miles wide extending from sec. 36, T. 49 N., R. 28 W., to sec. 16, T. 48 N., R. 27 W. Among the morainic knolls and ridges are cedar and spruce swamps. The moraine here as well as to the northwest consists largely of loose-textured sandy drift. Rock hills are prominent in the line of this ice border in the southern part of T. 48 N., R. 27 W., but in section 34 morainic knolls become conspicuous, and a narrow moraine with an outwash plain of sandy gravel on its southern border leads southeastward through the northern part of Ishpeming into Negaunee. The outwash plain covers much of secs. 2 and 3, T. 47 N., R. 27 W. In the southern part of Negaunee rock hills become prominent, and this ice border was not identified beyond that point.

A moraine of more prominence than those just described enters Marquette County from Baraga County in the southwestern part of T. 51 N., R. 29 W., and extends slightly south of east for about 15 miles to the northeastern part of T. 50 N., R. 28 W. An outwash plain about 2 miles in average width and fully 12 miles in length lies between this moraine and Yellow Dog River. At the east end of the outwash plain, in secs. 14 and 23, T. 50 N., R. 28 W., the moraine crosses to the south side of Yellow Dog River, and thence it runs east of south for about 20 miles to Negaunee. It traverses the eastern part of T. 50 N., R. 28 W., and the adjacent part of T. 50 N., R. 27 W., and runs diagonally across T. 49 N., R. 27 W., from northwest to southeast. Near the center of the last-named township an outwash plain of sandy gravel covering about 2 square miles stands in the line of the moraine. The moraine crosses Dead River in the northwestern part of T. 48 N., R. 26 W., and its main part runs southeastward along the south side of the river and then turns south and comes to the Duluth, South Shore & Atlantic Railway at Eagle Mills. This railway is in a lowland, which seems to have been occupied by ice at that time as far west as Negaunee, or about 3 miles from Eagle Mills. At the west end of this lowland the moraine is strongly developed, and an outwash plain extends west from it to the east end of Teal Lake. There is also an outwash area covering several square miles in the recess in the moraine northeast of Negaunee.

The ice border probably crossed the hills south of Eagle Mills, but drift knolls are rare among these hills. At the south side of the hills the ice seems to have extended westward in a lowland about to Palmer. It formed a moraine on the south side of this lowland from Palmer eastward about 4 miles, through the south edge of T.47N., R. 26 W. Outwash plains of a later moraine here set in, and to the south there is a tract in which rock hills and ridges rise above a gravelly or stony drift deposit with nearly plane surface. A definite continuation of the moraine was not found in this tract, and possibly it was buried under the outwash of the later moraine to the east.

From the inner or eastern border of the moraine whose course has just been outlined a branch starts at the north side of Dead River and another south of Yellow Dog River. The latter was traced for only 5 or 6 miles southeastward as a rather indefinite moraine in a tract of rock ridges. The former is also ill defined and interrupted by rock ridges in its course through T. 48 N., Rs. 26 and 25 W., except in an area of 3 or 4 square miles in the northeastern part of T. 48 N., R. 26 W., where it has some prominence. It becomes a conspicuous feature where it passes out of the rock ridges in the northern part of T. 47 N., R. 25 W. A double moraine is traceable across this township. The outer or western moraine runs in a course slightly east of south across sections 5, 8, 9, 16, 17, 20, 21, 28, 29, 33, 34, and 35; the inner one covers the northeastern part of the township from sections 9, 15, 23, and 26 eastward. An extensive outwash plain lies outside the outer moraine. Between the moraines is another plain covering the greater part of sections 15, 16, 21, 22, 26, 27, and 28 of this town ship, and a narrow channel separates them in sections 35 and 36. They become united into a single bulky moraine near the corner of Tps. 46 and 47 N., Rs. 25 and 24 W. This moraine covers a width of 3 to 6 miles or more and runs south-southeastward through T. 46 N., Rs. 24 and 25 W., and T. 45 N., R. 24 W. It is bordered on the west through

this distance of 12 miles by an extensive outwash plain, which extends to Escanaba River. Immediately south of this plain, in T. 44 N., Rs. 23 and 24 W., the moraine turns to the southwest, and this marks the beginning of the Green Bay lobe. The continuation of this moraine is discussed below as a feature of that lobe.

The moraines in Marquette County whose courses have been outlined all stand above the level of glacial Lake Duluth and are not connected with the shifting of the discharge of the lake to an eastward course from the western part of the Lake Superior Basin. There was also but little ponding along the ice border in Marquette County outside these moraines for passages among the outlying hills were low enough and numerous enough to carry the discharge from the ice border into valleys that drained southward. When contour maps of this region are available it may be possible to work out details of drainage.

On the whole, the drift in these moraines in Marquette County is very loose textured and full of stones of all sizes, as is to be expected where ice has passed over so rugged an area. The drift is thick in some of the low places among the rock hills but is generally very scanty on the hills. Notwithstanding the filling of low areas, the region is still very rough and broken, and rock prominences are far more conspicuous than the drift knolls and ridges. The strips of moraine just outlined mark places where there is a closer aggregation of drift knolls and a somewhat thicker drift coating than on intervening strips, but in places there is very little difference between the morainic strips and the intervening strips not classed as moraine. The outlines of the courses of moraines given above, however, are thought to indicate the approximate positions held by the ice border from time to time in the course of its recession from this district.

Outside this series of moraines in western Marquette County and eastern Baraga County about to Lake Michigamme and the Duluth, South Shore & Atlantic Railway there is a very high district with a relatively light coating of glacial material, though the rock knobs are rubbed so smooth in places by glacial action that they glisten in the sunlight. From commanding points in this district can be seen many hills that seem nearly destitute of drift coating or even of soil. The depressions among the hills are swampy, and some of them seem to have functioned as lines of glacial drainage.

On the slope toward the Lake Superior Basin all the way from the Huron Mountains to Marquette morainic features are weak and the morainic lines are greatly interrupted by rock hills. In places there is a heavy drift deposit filling depressions among the hills and some knolls of morainic type, but ordinarily the filling is light and is lacking in morainic expression. The best development of moraines is at relatively low altitudes only a short distance back from the shore of Lake Superior. A moraine traverses the southwestern part of the Marquette quadrangle at an altitude between 1,000 and 1,100 feet above sea level in much of its course. It is generally only about a quarter of a mile wide and has a relief of about 20 feet on its outer side. It is best defined from Dead River in secs. 7 and 18, T. 48 N., R. 25 W., southeastward to the north base of Mount Mesnard, in the southern part of Marquette. A lower moraine sets in at the base of granite hills west of Granite Point and runs northward past Birch station to Yellow Dog point, east of Lake Independence, or a distance of about 15 miles. Its northward continuation would carry it inside the limits of Lake Superior. In most of its course between Yellow Dog Point and Granite Point it is near the shore of the lake. From Birch northward it is not banked against the granite hills so closely as to the south. Its general width is about a mile. The surface is gently undulating rather than sharply morainic, but it seems to have been developed along the ice border as a terminal moraine. This moraine is at a lower altitude than the highest shore of glacial Lake Algonquin, but immediately outside of it for part of its course the granite hills rise above the level of that lake. The waters of the western part of the Lake Superior Basin may therefore not have been drawn down fully to the level of Lake Algonquin until the ice border receded from this moraine.

When it became evident to the writer that the lowering of the waters of the western part of the Lake Superior Basin from the level of Lake Duluth to that of Lake Algonquin was dependent upon the recession of the ice from the hilly slope between the Huron Mountains and Marquette an attempt was made to trace lines of ice-border drainage through which this lowering took place. It was found that the topography of this border district is such that the streams in places became expanded and in other places flowed through narrow passages between hills. It is only in these narrow sections of the stream courses that cutting or aggrading was definite enough to be traceable. In the broad places there were pools which were not filled with fluvial material and whose borders are not marked by definite shore features. Short sections of graded stream beds were found that seem referable to this ice-border drainage, the highest at about 1,200 feet above sea level and others down to about 1,000 feet. When the waters had become lowered to this level there was ponding of water between the ice border and the hilly slope, and a faint shore line is traceable through the southwestern part of the Marquette quadrangle along or near the 1,000-foot contour. It is best defined on the inner slope of the moraine above noted from Dead River southeastward for 3 or 4 miles, through secs. 18, 20, and 28, T. 48 N., R. 25 W., and eastward through the southern part of Marquette. This shore line appears to be a little higher than the highest shore of Lake Algonquin east of Marquette and thus marks an interruption of the lowering from Lake Duluth to Lake Algonquin, which indicates that the ice dam was still blocking the discharge at some place east of Marquette not yet fully determined. As the district north of Dead River is largely occupied by granite hills at the level of this shore line, it was not traced far in that direction. It was, however, identified about to the

1,000-foot contour at the west side of the Marquette quadrangle.

CORRELATIVE MORAINIC SYSTEMS IN THE LAKE MICHIGAN AND LAKE HURON BASINS

PORT HURON MORAINIC SYSTEM

At the time the outer morainic system of the Superior lobe was forming the ice appears to have occupied the Lake Michigan Basin as far south as Milwaukee, Wis., and Muskegon, Mich., and to have completely occupied the Lake Huron Basin. The morainic system is described under the name Port Huron morainic system in Monograph 53 of the United States Geological Survey in the description of its course through the southern peninsula of Michigan, where it borders the Huron, Saginaw, and Michigan Basins. In eastern Wisconsin this morainic system is scarcely so prominent as in the southern peninsula of Michigan but is split up into several parallel moraines between which are narrow strips of gravel plain that were developed as lines of glacial drainage or as outwash on the border of the ice lobe.

RED DRIFT OF EASTERN WISCONSIN

The portion of the Port Huron morainic system lying in eastern Wisconsin from latitude 44° southward has been studied in some detail by W. C. Alden,[6] who shows that it marks the limit of a readvance of the ice that left in its path a red drift, which is different from the underlying and outlying drift of Wisconsin age. North of latitude 44° there has been only a small amount of detailed mapping of the moraines and associated gravel plains in eastern Wisconsin. Part of this district is sparsely settled and has few roads and much forest or brushy land difficult to work. Dr. Samuel Weidman and the present writer made some investigations there both jointly and individually, but the mapping is of the nature of rough reconnaissance and the correlations are tentative. Such data as have been obtained as to the position and course of moraines in that part of Wisconsin and the probable limit of the ice at this readvance are shown in Plate 1. Description is deferred to a time when more detailed studies have been made. The several moraines and their associated border drainage lines become successively lower from the western or outer one eastward to later ones. They also each individually increase in altitude from north to south toward the end of the ice lobe.

When the later system of moraines of the western part of the northern peninsula was being developed the ice apparently extended some distance beyond the eastern part of the peninsula, into the basins of Lake Michigan and Lake Huron. It reached at least to Escanaba and possibly to Menominee, on the west side of Green Bay. It probably covered the Beaver Islands and perhaps the Manitou Islands in Lake Michigan and rested on the edge of the southern peninsula as far south as Little Traverse Bay on the Lake Michigan side and some distance beyond Cheboygan on the Lake Huron side.

After it had receded from these lake basins the ice border made prolonged stands and developed strong moraines on the eastern part of the northern peninsula, and these give a clue to the general direction of recession toward the east end of the Lake Superior Basin. The ice appears to have persisted there after it had uncovered the east end of the peninsula and the part of Canada immediately east of St. Marys River.

[6]U. S. Geol. Survey Prof. Paper 106, 1918.

GREEN BAY LOBE

MORAINES OUTSIDE THE MENOMINEE DRUMLIN DISTRICT

The Green Bay lobe was developed principally to the west of the Green Bay Basin, though its axial movement seems to have been through the basin. This asymmetry is perhaps due to the crowding of the Lake Michigan lobe against it on the east side. In the northern part of the Green Bay lobe moraines were built up mainly on the western border, there being scarcely any morainic material along the line of junction of the Green Bay and Michigan lobes, either on the Garden Peninsula of Michigan or on the Door Peninsula of Wisconsin and the islands lying north of Sturgeon Bay between these two peninsulas. The interlobate moraine has its north end near latitude 44° 30'. There was, however, an extensive deposition of outwash and some morainic development at the junction of these ice lobes to the north of Green Bay in Delta, Alger, and Schoolcraft Counties, as shown below.

On the west side of the Green Bay lobe the striae have a westward to southwestward bearing. Locally they are deflected to a course north of west, as was noted near Norway, Mich., by Russell, and near Kate, just north of the Dickinson-Marquette County line, by the present writer. Near Mountain, in Oconto County, Wis., the striae bear about northwest. In Michigan westward-bearing striae are found as far west as eastern Iron County. In the axis of the lobe the movement was southward or slightly west of south. Near Escanaba the striae bear nearly due south. On the east side of the lobe there should theoretically have been a southeastward movement, and striae bearing southeast have been noted as far north as the Garden Peninsula, east of Big Bay de Noc.

The moraines of southern Marquette County and northern Dickinson County, Mich., were developed at the line of conflict between southward-moving ice from the Lake Superior Basin and westward-moving ice across the northern peninsula from the Lake Superior Basin into the Green Bay Basin. (See p. —.) The inner part of this morainic system continues southward from Dickinson County through the western edge of Menominee County

as far as the great bend of Menominee River near Koss, Mich., covering a strip 2 to 5 miles wide on the east side of the river. It crosses into Wisconsin immediately above Koss and continues in a course nearly parallel with the west shore of Green Bay and 20 to 25 miles distant from it through Marinette, Oconto, and Shawano Counties into Outagamie County, and is traceable as far as the north end of Lake Winnebago, near Neenah, Wis. There is considerable outwash on the western border of this inner moraine, as well as in connection with earlier members of this great morainic system. It is present along and west of Sturgeon River in Dickinson County and along Menominee River from the Dickinson County line southward to the bend a few miles west of Koss.

THE DRUMLIN DISTRICT AND ASSOCIATED FEATURES

The plain that lies between the great morainic system and the later moraines of the Green Bay Basin is diversified with drumlins, which are conspicuous over the greater part of Menominee County and adjacent parts of Dickinson, Marquette, and Delta Counties. It is about 50 miles long from north to south and about 20 miles in greatest width. The drumlins have been noted as far north as the central part of T. 43 N., R. 26 W., in southern Marquette County, and almost as far south as the south end of Menominee County. The eastern limit is near the ancient shore line of glacial Lake Algonquin from a point opposite Escanaba southward, in Delta and Menominee Counties. The western limit is near Sturgeon River in southeastern Dickinson County and near Menominee River farther south. A few drumlins were noted west of Menominee River in Marinette County, Wis., some 10 to 15 miles above the mouth of the river. I. C. Russell gave considerable attention to this drumlin district in the annual reports of the Michigan Geological Survey for 1904 and 1906.

The drumlins are somewhat unevenly distributed, some single square-mile sections containing several and others none. There are, however, only a few places where there is a space of more than a mile between drumlins. The number of drumlins is probably twice as great as the number of square miles in the district. A representative township in the drumlin district is shown in Figure 7.

The length of individual drumlins ranges from less than a quarter of a mile to fully 11/2 miles and the height from less than 10 feet to more than 100 feet. Neighboring drumlins differ markedly in height as well as in length. Russell stated that he found places where the tops of drumlins came up to a general level, but the present writer was not able to discover such a tendency, and the condition cited by Russell certainly is not widely prevalent in this district. The length is generally from three to five times and in a few drumlins ten times as great as the width. A few of the drumlins have an oval shape, much like one-half of an egg cut lengthwise, but the prevailing form is lenticular.

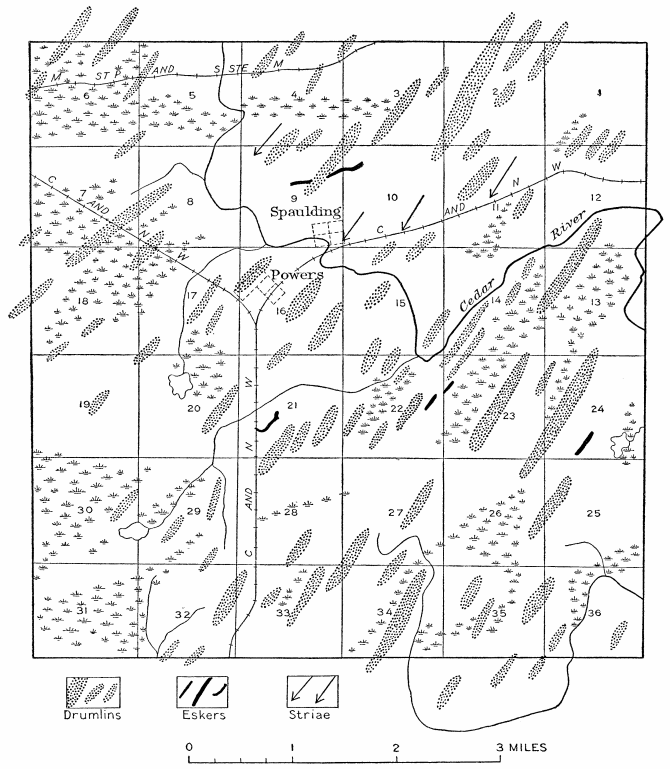


FIGURE 7.—Map showing drumlins, eskers, and striae in T. 38 N., R. 26 W., Menominee County, Mich.

The trend of the longer axis of each drumlin is in the direction of ice movement, being in rather close correspondence with the bearing of the glacial striae. (See fig. 7.) At the north end of the district the trend is westward, but toward the south end it shifts through southwestward to a course only a few degrees west of south.

The drumlins are composed of till of rather loose texture and of a red tinge. Russell states that some of them include lenses and beds of sand and gravel, but such inclusions appear to be rare.

It was thought by Russell that the till sheet which makes up the body of the drumlins was laid down by an earlier ice advance than the one which shaped them into drumlin form. Most of the drumlins have an arched surface and a slope in all directions from the culminating point. In a few there is a sculpturing or shaping of the sides or the lower part of the slope into the regular contours of the drumlin but the upper part is flat-topped or has a surface with irregularities not consistent with the drumlin form. Russel interpreted these as incompletely developed drumlins. He also cited the occurrence of chunks of copper and of iron ore in the drift of which the drumlins consist as evidence that this drift was laid down by ice moving southeastward toward the Lake Michigan Basin, or nearly at a right angle with the movement that shaped the drumlins. He thus referred it back to an ice movement that was pre-Illinoian as well as pre-Wisconsin. An early ice movement in the Kansan or pre-Kansan stage of glaciation carried the copper ores of the Superior region as far southeast as the Scioto Basin, in central Ohio. The deposits laid down at the early glacial

stage were, however, gathered up to a large degree and redeposited by the later ice movements in both Illinoian and Wisconsin time, and copper is now found in drift of undisputed Wisconsin age all over the southern peninsula of Michigan and in neighboring parts of Indiana and Ohio. The presence of copper and iron ore in the drumlins, therefore, does not prove that the drift sheet in which they occur is as old as the pre-Illinoian southeastward ice movement.

An examination of the degree of weathering, leaching, and other changes to which the drift forming the body of the drumlins has been subjected was made in 1919 by the present writer and no place was found in which it is essentially different in aspect, so far as weathering and leaching are concerned, from the drift of the morainic knolls and ridges of that region. In both classes of knolls and ridges it is the fresh Wisconsin drift. The till varies in texture in different drumlins or even within a single drumlin. The sandy or loose-textured till, however, greatly predominates over the clayey compact till. Little of the material is so clayey as to show any lamination. The coarse stones in the till are largely of local derivation from rock formations that crop out around the north end of Lake Michigan. This local material in places makes up 85 to 90 per cent of the coarse rock of the till. The limestone slabs and other coarse blocks seem to be embedded at various angles in the till, though in some exposures a tendency to lie with the broad side downward was noted; many of these blocks, however, stand on edge.

Eskers or gravel ridges are found in all parts of the district occupied by drumlins, but, they are far less numerous than the drumlins. Those that have been mapped in T. 38 N., R. 26 W., appear in Figure 7. They range in length from a fraction of a mile to 3 miles or more. Their trend is in the same general direction as the longer axis of the drumlins or the bearing of the striae, but in some eskers the trend differs a few degrees from that of neighboring drumlins. A few show marked changes in trend when followed from end to end. They are generally low, a height of more than 20 feet being exceptional, and the usual height is only 10 to 15 feet. They usually contain gravel of the sort needed in highway construction and thus are coming to be valuable assets in the region they occupy. In nearly all the eskers, however, sandy beds appear either between gravel beds or at the same horizon, for the coarseness of the material deposited depended upon the force of the current and the nature of the material that was undergoing transportation by the stream that formed the esker. This stream evidently was confined by ice walls and the material in the esker was derived from the melting of the dirt-laden ice along the path of the stream.

The relation of the eskers to the drumlins shows that some of them were formed after the drumlins had been built up or shaped. They commonly lie in the smooth troughs between the drumlins. These troughs appear to have been scoured by ice movement in connection with the development of the drumlins. Here and there the course of the stream that formed the esker led across a drumlin and a notch was cut in the drumlin by the stream. A good illustration of notching of this sort was noted by Russell in a drumlin north of Spaulding, in the NE. ¼ sec. 9, T. 38 N., R. 26 W. (Fig. 7.) That the stream which cut this notch was near the bottom of the ice sheet is evident from the fact that the crest of the drumlin across which it cut the channel is not more than 20 feet above the bordering till plain. The notch here is cut near the end of the drumlin. A notch was cut across the middle part of a drumlin immediately north of Harris, but here the esker is not so well developed as that near Spaulding. A low irregular-shaped gravelly ridge comes to the notch from the east but is not continued to the west of the drumlin.

In some places an esker is superimposed on a drumlin. Russell called attention to such an occurrence which he found south of Wilson. The esker lies on the crest of the drumlin and follows it for about a mile. The drumlin extends a little farther south than the esker. The top of the esker on the highest part of the drumlin is 70 to 80 feet above the bordering plain at the base of the drumlin.

On some drumlins there are irregular-shaped gravelly knolls which appear to have been deposited after the shaping of the drumlins had been completed. It is also not rare to find hummocks of drift in the shallow troughs between the drumlins. These features seem to indicate that the drumlins were developed and shaped while the ice was in active movement, but that the eskers and other drift deposits laid down on drumlins and in drumlin troughs may represent the work of the ice and the accompanying drainage at a time when the ice sheet had become relatively stagnant.

At a few places in the midst of the drumlin district drift hummocks are rather closely aggregated and are lined up in such a way as to suggest a moraine, but the writer was unable in the time given to this investigation to work out any definite ice-border lines in the drumlin district such as Alden has traced across drumlin districts in southern Wisconsin.

The drumlins, as above indicated, are usually present clear to the edge of the area later covered by glacial Lake Algonquin in southwestern Delta County and southern Menominee County, and there are several drumlins which stood as islands in Lake Algonquin in southwestern Delta County. However, for a distance of about 20 miles north from the mouth of Menominee River in southern Menominee County there is a strip of land 1 to 2 miles wide just outside the limits of Lake Algonquin which has a series of low ridges and swells that are not definitely shaped into drumlin form and which in places has a morainic aspect. This strip stands a little higher than the land immediately west of it, which is traversed by Little River. It may therefore represent a weak moraine or a brief stand of the ice border in the course of its retreat toward Green Bay. It seems to be a little older and also weaker than the moraine discussed below, which is traceable along the east side of the drumlin district about as far south as the mouth of Ford

River. It was identified no farther north than the vicinity of Hayward Lake, in T. 34 N., R. 26 W.

LATER MORAINES

In Marquette County a strong morainic belt was traced southeastward to the vicinity of Little Lake, as described above. Attention was also given to a broad outwash plain that lies outside the moraine which is traversed by the Chicago & Northwestern Railway from the vicinity of Cascade southeastward to Little Lake. Directly opposite Little Lake the moraine turns southwestward and forms the western border of the Green Bay lobe.

For a few miles there is a large amount of swamp land in the morainic belt, and the ridges and knolls rise like islands above the level surface of the swamp, conspicuously in T. 44 N., R. 24 W., but less so farther south. From the southwestern part of that township the moraine runs southward for about 10 miles along the east side of Escanaba River in a strip scarcely 2 miles in average width. The river there crosses to the inner edge of the moraine and both take a southward course into Delta County. The moraine comes to Ford River in the central part of T. 40 N., R. 24 W., and, crossing to the west side of the stream, follows it somewhat closely to its mouth. There are strips or small areas with morainic aspect east of the river in the southern part of T. 40 N., R. 23 W., and the northern part of T. 39 N., R. 23 W., which are regarded as spurs on the inner border of the morainic belt. The moraine is weak where it lies within the limits of glacial Lake Algonquin near the mouth of Ford River. It has not yet been determined whether the ice border passed within the limits of Green Bay a short distance south of the mouth of Ford River or continued farther south along the west side of the bay to embrace the strips of dry land that rise a few feet above the swamps in the bed of Lake Algonquin. Some of these dry strips consist of till, but others are sandy. It seems, on the whole, more probable that the ice border passed into Green Bay near the mouth of Ford River, and this is as far south as morainic features are definitely preserved.

The moraine is composed of till, with sufficient clay and pulverized limestone to make a soil of fair quality. Surface boulders are not so numerous as to render it difficult to cultivate the land. The swamps greatly interrupt the moraine for a few miles southwest from Little Lake, but elsewhere they are no more extensive than on the bordering till plains, so the greater part of the land is cultivable.

At the time this moraine was formed the Green Bay lobe seems to have covered the north end of Green Bay and the two arms known as Big Bay de Noc and Little Bay de Noc and to have extended as far as the Garden Peninsula, .east of Big Bay de Noc. Striae with southeastward bearing along the west side of that peninsula appear to be referable to the Green Bay lobe. The Michigan and Green Bay lobes may have been merged together at this time in the northern part of the Lake Michigan Basin. However, at a time somewhat later, when the end of the Green Bay lobe barely reached the northern part of Little Bay de Noc, the Green Bay and Michigan lobes were yet sufficiently differentiated to the north of the Garden Peninsula to give clear evidence as to the limits of each lobe.

A few miles north of the Garden Peninsula, in the northeast township of Delta County, there is a very high tract of moraine and outwash which appears to stand at the junction of the Green Bay and Michigan lobes. The outwash plain occupies the central and southeastern part of the township; the morainic tract borders it on the east, north, and west. The moraine on the west seems to be the product of the Green Bay lobe. It is traceable southward to the head of Big Bay de Noc. Sturgeon River crosses it in the southwestern part of T. 42 N., R. 19 W., and follows the east side of the moraine southward past St. Jacques to Big Bay de Noc. The part of the moraine south of Sturgeon River is below the level of Lake Algonquin and has a gently undulating surface, which in places is diversified by ridges of wind-blown sand. It stands 20 to 25 feet above the bordering plains and for several miles from its south end is scarcely a mile in average width. The part of the moraine northeast of Sturgeon River is mainly above the limits of Lake Algonquin and consists of sharp ridges and knolls, some of which are 50 feet or more in height. This prominent part of the moraine is made up largely of loose-textured sandy to very stony drift with scarcely any clayey material. The part that stands below the Lake Algonquin level contains some clayey till, as shown by wells in the vicinity of St. Jacques, but seems to be generally sandy. The ice when this moraine was formed may have covered much of Big Bay de Noc and Little Bay de Noc and the peninsula between these bays, but no definite limits appear to be traceable.

A sharply morainic tract directly north of the out-wash plain above noted, extending several miles northward into Schoolcraft County, seems to be a spur between the Green Bay and Lake Michigan lobes. It occupies nearly all of T. 43 N., R. 18 W., and the southern part of T. 44 N., R. 18 W. The knolls and ridges are sharp and some of them rise to heights of 50 to 60 feet or more. The material is very stony and gravelly drift, such as one would expect to find in an interlobate spur.

A moraine leads south westward from a point near the north end of this spur and seems to mark the position of the southeast side of the Green Bay lobe at a later time than the one above noted. This moraine is crossed by Sturgeon River just south of the Alger-Delta county line. It is only about a mile in width northeast of the river, but to the southwest it widens out and extends a spur westward along the county line to the east branch of Whitefish River. It again narrows about 3 miles south of the county line and lies a short distance east of Whitefish River from that point nearly to the head of Little Bay de Noc. It dies out in a high outwash plain that lies east of the northern part of this bay. Along much of its course it consists of sharp ridges and knolls of gravelly drift 20 to

50 feet or more in height. On the west side of Little Bay de Noc a high outwash plain fills the interval between the bay and Escanaba River. It seems not improbable that the ice lobe was occupying the north end of the bay while this outwash was being deposited at its borders. The outwash plains bordering Little Bay de Noc were built up about to the level of the highest stage of Lake Algonquin, which was nearly 150 feet above Green Bay opposite Gladstone. The material in the plain west of the bay is largely fine sand; in places search is required to find a pebble over a quarter of an inch in diameter. The sand has a depth that varies considerably because of the unevenness of underlying beds of till and clay, but in places it is 75 feet thick. Under it there are places where bouldery till has been exposed. There are also deposits of red laminated clay nearly free from pebbles that seem to have been laid down by the waters of Lake Algonquin before the sandy outwash was deposited by water issuing from the ice lobe. This clay has been noted on both sides of Little Bay de Noc and reaches an altitude 50 to 75 feet or more above the level of the bay.

The correlative moraine formed at the west side of the Green Bay lobe is well developed for a few miles northwest from the outwash plain and is especially strong in the vicinity of Perkins, where knolls 30 feet or more in height occur. In places between Perkins and Lathrop along or near the Chicago & Northwestern Railway small drift knolls abound and the surface appears morainic, but the writer's studies were not sufficiently detailed to determine whether a definite moraine is traceable all along the western border of the ice lobe.

TILL PLAIN IN THE AXIS OF THE GREEN BAY LOBE

In the northwestern part of Delta County, the southeastern part of Marquette County, and the western part of Alger County there is an extensive till plain across which the ice border receded after forming the moraines just discussed. It is about 18 miles wide from west to east and about 35 miles long. Its eastern limits are at the Au Train-Whitefish Valley and its western limits at the moraine that was traced through eastern Marquette County and western Delta County to the shore of Green Bay below the mouth of Ford River. It seems to lie entirely in the path of the Green Bay lobe. This plain has a loose-textured reddish till much like that of the drumlin district of Menominee County and southern Marquette County. There are only a few drumlins on it, and these are not in the part nearest the drumlin district, but in the vicinity of Chatham and Eben Junction. The percentage of swamp land in this plain is also not greatly different from that of the Menominee County drumlin district. The amount of limestone material incorporated in the till becomes less and less from south to north, for the northern part has only a calciferous sandstone from which such material can be derived, but the southern part is in a district in which relatively pure limestone formations are present, and the till contains a large percentage of material from these formations. Here and there are short eskers a fraction of a mile in length and low ridges with a large number of local rock slabs embedded in poorly assorted material. Many of the slabs show but little rounding by water action. The drumlins near Chatham and Eben Junction are steep-sided ridges 20 to 30 feet high and half a mile to a mile or more in length. Their trend is nearly south. They contain a large amount of slabs and flat pieces of the local rock in a rather loose textured matrix.

A short gravel ridge of the esker type is crossed by the highway about 5 miles south of Chatham, at the highest point on this road between Chatham and Trenary, 946 feet above sea level. This esker trends east-southeast and is thus directed toward the east side of the lobe and suggests that the axis of the lobe was farther west. Its length is less than a mile. About 2 miles southwest of this esker is a sandy ridge with easterly trend which is crossed by the Rapid River branch of the Soo line. Its altitude is about 950 feet above sea level, and it rises 10 to 15 feet above the bordering till plains. This may prove to be a wind-formed ridge rather than glacial, for the slight exposures found in it revealed only fine sand. It is about 90 feet higher than the highest shore of glacial Lake Algonquin, 4 miles to the east.

The strong morainic system bordering Lake Superior, described below, shows a slight lobation at the Au Train-Whitefish lowland, which marks, perhaps, the latest definite work of the Green Bay ice lobe. It seems more convenient, however, to consider it in connection with the remainder of the morainic system than to give it separate description here.

OUTWASH PLAINS EAST OF THE AU TRAIN WHITEFISH LOWLAND

Of the outwash plains connected with the moraines of the Green Bay lobe in northeastern Delta County and neighboring parts of Schoolcraft and Alger Counties the highest one and the earliest to be formed occupies a considerable part of the northeast township of Delta County. The ice on its north and east sides pertained to a lobe that covered the Manistique drainage basin and represented the closing phase of the Lake Michigan lobe; that on the west side pertained to the closing phase of the Green Bay lobe, as indicated above. This plain slopes southeastward and appears to have been built by outwash from both of these lobes.

Another outwash plain lies between the two moraines of the Green Bay lobe above described. It is east of Sturgeon River for a short distance north and south of the Alger-Delta county line, in Tps. 44 and 43 N., R. 19 W., but west of that stream from a point near the center of T. 43 N., R. 19 W., south westward to the east side of Little Bay de Noc, opposite Gladstone. It seems to be a little above the level of glacial Lake Algonquin in northern Delta County and southern Alger County, but farther south its level seems to be very nearly the same as the highest Algonquin water level. In much of its

course from the Soo Line near Ensign station northeastward to the center of T. 43 N., R. 19 W., its east edge appears to be at Lake Algonquin level, the ponded water being the limiting agent in the eastward transportation from the edge of the ice lobe. The plain was thus extended to a distance of 2 or 3 miles outside the moraine that marks the position of the ice border. There is along Sturgeon River a low strip 1 to 3 miles wide which probably because of this ponding was not filled by the outwash.

After the ice began to recede from the moraine that lies on the east side of Whitefish Valley in northern Delta County the slope toward the valley was shaped into steps that become lower and lower from the moraine down to the valley. It might be assumed that these steps are merely the work of the waves of Lake Algonquin and that they mark successively lower levels of the lake waters, but the tread or level part of each step carries basins and irregularities that are not consistent with the cutting into a slope by wave action, and the riser or bluff part has spurs and recesses such as are characteristic of the ice contact where the higher plain was built up outside the ice while the lower plain lay beneath it. There may have been some work by the waves of Lake Algonquin in connection with these steps, but it seems probable that the steps mark successive positions of the retreating ice border.

There is a very conspicuous outwash plain outside a strong moraine in Alger County from the Au Train-Whitefish Valley eastward which may have been formed in large part during the recession of the ice border across the area it occupies, for the plain has a general width of 6 or 7 miles. It is full of basins and irregular-shaped depressions, which seem to mark the places where detached masses of the ice sheet persisted after the active ice border had melted back beyond them. These depressions, with the great width of the outwash district, support the view that the outwash was largely built in the course of the ice recession.

The outwash on the west side of the Green Bay lobe in southern Marquette County and western Delta County is very meager compared with its extent on the east side in the same latitude and on the west side farther north in Marquette County. From Little Lake northward to a point within 5 or 6 miles of Marquette, as already shown, the outwash is very extensive. This tract, however, is above the place where the Green Bay lobe became differentiated from the ice of the Lake Superior Basin.

CLAY DISTRICTS

North of Big Bay de Noc there are small areas of clay. One lying east of the Sturgeon Valley embraces 30 to 40 square miles and comes to the border of Big Bay de Noc near Isabella. The clay is red, has very few pebbles embedded in it, and appears to be a water-laid rather than a glacial deposit. Parts of this area have a thin coating of sand on the clay, but in much of it the clay is so near the surface as to be within reach of the plow.

Another clay area lies west of Ogontz Bay and runs northward along the west side of Ogontz River beyond the Soo Line. It is about 10 miles long from north to south and about 3 miles in average width. These clay areas are low next to Big Bay de Noc but reach an altitude of 100 feet or more above the level of the bay in their northern parts. They lie much below the level of glacial Lake Algonquin. They seem to be in places where sandy and gravelly outwash from the Green Bay lobe did not reach. At the north ends of these clay areas there is a steep rise to the outwash plains.

AREAS OF VERY THIN DRIFT

On a considerable part of the peninsula between Big Bay de Noc and Little Bay de Noc and on the Garden Peninsula limestone lies near the surface and in places stands a few feet above the general level of the drift filling. These peninsulas were almost entirely covered by the waters of Lake Algonquin and show the effects of the submergence in the gravelly bars and in bare wave-washed ledges. The general thinness of the drift, however, seems to be due in larger degree to scanty deposition by the ice than to removal by subsequent wave action.

Along the lowest part of the Au Train-Whitefish depression there is a strip of nearly bare rock from the crossing of the Munising, Marquette & Southeastern Railway southward to the head of Little Bay de Noc. Here the rock may have been denuded of some of its drift cover by the passage of lake currents through the narrow strait that in Lake Algonquin time led from the Lake Superior Basin to the Green Bay Basin, as shown more fully in the discussion of Lake Algonquin (pp. 63 to 68).

LAKE MICHIGAN LOBE

The ice that formed the Lake Michigan lobe crossed the northern peninsula east of the meridian of Munising and covered it about as far east as the meridian of St. Ignace. At the time the outer morainic system of the western part of the northern peninsula was being formed by the Superior lobe the Port Huron morainic system seems to have been in process of development by the Lake Michigan and Huron lobes. The Port Huron morainic system has been described in Monograph 53. The full limit and fluctuation of the Lake Michigan lobe during the period in which the later sys tem of moraines of the west end of the northern peninsula was being formed can not be stated definitely, but it seems not unlikely that the ice for a part of that time reached the Manitou Islands and encroached slightly in the northern part of the southern peninsula. The Cheboygan moraine and a small moraine bordering Little Traverse Bay may be correlated with the outer member of this later system. These moraines also are described in Monograph 53. The Beaver Island group, in the northern part of the Michigan Basin, seems to have been buried under ice at that time, but was uncovered, perhaps, before the later

members of this younger morainic system were formed. By the time the moraines and outwash plains north of Big Bay de Noc were being developed the ice may have entirely disappeared from the Lake Michigan Basin. Its border then may have been at a moraine traversing the southern part of the peninsula, across Schoolcraft and Mackinac Counties. A slight protrusion of the ice southward over the great swamp in the Manistique River drainage area seems to be the successor of the Lake Michigan lobe when the ice no longer reached the Lake Michigan Basin.

HURON LOBE

ICE MOVEMENTS AND DRIFT CHARACTERISTICS

There appears to have been considerable complexity of ice movement over the east end of the northern peninsula. The striae indicate a west-southwestward movement across the high limestone ridges east of Trout Lake and Ozark and on the shore of Lake Michigan near Point Epoufette. They show a southeastward movement near Hessel and Les Cheneaux Islands and a southward movement across Drummond Island and neighboring parts of Canada. There was thus a wide divergence of ice movement in the part between Point Epoufette and Les Cheneaux Islands and a convergence in the district east of those islands. Whether these wide differences represent differences in direction of ice movement at the same time or at different times is not yet determined. The dominant direction of movement into the northern part of the Lake Huron Basin seems to have been southward, yet there is clear evidence of vigorous southeastward movement not only in the bearing of striae but also in the trend of drumlins on Les Cheneaux Islands and neighboring parts of the mainland. In other areas drumlins appear to have been formed where ice movement was vigorous, and the same thing seems likely to have taken place here. This southeastward movement seems also to be inconsistent with the direction of movement a few miles to the north of this drumlin area. Several moraines between the Cheneaux drumlin area and Sault Ste. Marie trend in nearly the same direction as the drumlins and thus appear to have been formed by a south-westward ice movement. The movement that produced these moraines extended up to and in places beyond the brow of what is known as the Niagara escarpment, the outermost of the moraines being in part on the top of the escarpment and in part on its southern slope. The southeastward-bearing striae and the drumlins are confined to low ground on the immediate border of Lake Huron. Possibly the depth of the Lake Huron Basin was sufficiently greater to the southeast from Les Cheneaux Islands than to the southwest to cause a local deflection southeastward, for the basin is relatively shallow to the southwest, in the vicinity of the Straits of Mackinac. The extent of the movement past the Cheneaux drumlin area into the Lake Huron Basin is not known. The ice may have reached the position marked by the Cheboygan moraine, which lies near the edge of the southern peninsula from Mackinaw City southeastward past Cheboygan. The Cheboygan moraine is described in Monograph 53, and attention is therefore given here only to the features on the northern peninsula.

In the Carp River drainage basin there is a large amount of swampland in which the rock is not far below the surface. The swamps seem to be underlain by sand rather than clay, and sandy ridges are found in them at short intervals. The high land within this drainage basin consists largely of bare limestone ridges and hills. They seem to have been swept clean in some places by the wave action of Lake Algonquin, to which they were exposed at nearly all levels in the course of the uplift which was in progress during Lake Algonquin time and which caused the water to take lower and lower positions on the slopes of these limestone hills.

Southwest of the headwaters of Carp River, along the border of Lake Michigan from Brevoort Lake westward for about 12 miles, there is a high tableland of sandy gravel, which is probably an outwash deposit from ice that was covering the Carp River drainage basin. The strip is 2 or 3 miles wide and stands about 700 feet above sea level, or 120 feet above Lake Michigan. As the height of this tableland is more than 100 feet below the highest level of Lake Algonquin, it was probably formed in deep water. There is, however, some likelihood that ice persisted in stagnant condition in the deep north end of the Lake Michigan Basin down to a time when the border of the moving ice had been melted back to some position on the northern peninsula. In that case the Lake Algonquin waters may not have had access to this area and the level to which it was filled may have been controlled by local conditions between ice masses on its borders.

In the Pine River drainage basin there is a large amount of clay land, and this borders the west side of St. Martin Bay for a few miles beyond the mouth of Pine River. The conditions are thus strikingly different from those in the Carp River drainage basin. Much of this clay seems to be lake sediment laid down by the waters of Lake Algonquin. Some clayey till, however, is found beneath the lake deposits.

On the east side of St. Martin Bay and on the islands in the bay there is a large amount of sand, and the hills consist of bare limestone. This condition extends to the edge of the drumlin district at Hessel.

Only a few small areas along the brow of the Niagara escarpment rose above the level of Lake Algonquin, but with two exceptions these areas have very little drift. One east of Trout Lake has an altitude of more than 100 feet above the highest Algonquin beach, yet there are only a few pebbles and boulders on it, and deep unfilled fissures occur in the limestone. Its appearance is that of a fiercely wave-swept tract. Possibly in the complexities of ice movement and melting the waters became locally ponded here to a height much higher than the limits of

Lake Algonquin. Another very prominent tract of bare limestone lies east of Pine River 6 to 8 miles southeast of Rudyard. On this tract also there are deep unfilled fissures in the limestone which make treacherous pitfalls for stock grazing on it. This tract is encircled by the highest beach at a level more than 50 feet below its highest point. Between these two prominences of bare rock ledges there is another prominent area fully 100 feet above Lake Algonquin which carries a deposit of drift heaped into morainic knolls and ridges. This deposit occupies several square miles east and northeast of Round Lake in T. 43 N., R. 4 W. It seems probable that the moraine was formed between ice lobes that protruded southward in the low lands on each side and converged on the high land that carries the moraine.

Another morainic area that stood above Lake Algonquin lies directly north of Hessel on the line of Tps. 42 and 43 N., R. 1 W. It embraces only 3 or 4 square miles and has a strong morainic expression. This moraine is traceable southeastward into the central part of T. 42 N., R. 1 E., at levels below the limits of Lake Algonquin. In that area it has a very subdued expression, but the thickness of the drift along it is much greater than on either side, and boulders are conspicuous. Northeast of this submerged part of the moraine, in the northern part of T. 42 N., R. 1 E., there is a prominent limestone strip which was swept bare by lake action, as it stands just below the upper limits of Lake Algonquin. There is a similar prominent limestone strip in the western part of T. 42 N., R. 2 E.

LES CHENEAUX DRUMLIN DISTRICT

The drumlins on Les Cheneaux Islands and the adjacent part of the mainland are among the most conspicuous features produced by the ice in this part of the northern peninsula. They were studied and described by Russell[7] in 1904. The prevailing trend of the drumlins is about S. 50°-55° E., or very nearly the same as the latest striae on the rock ledges near them. They are much elongated, some of them being about a mile long; the width is ordinarily one-eighth of a mile or less. The height ranges from 10 or 15 feet in the smaller ones to 40 or 50 feet in the larger ones. About 50 of these drumlins were mapped by Russell, and he estimated that nearly as many more may be present in the uncleared land which he did not examine in detail. Those on the mainland are within about 2 miles of the shore of Lake Huron and are present from Hessel eastward a short distance beyond Cedarville. Some of the islands consist of single drumlins; others of groups of drumlins. The till in the drumlins is rather compact and clayey and has a reddish color. Part of the large stones embedded in it are local limestone, and part are crystalline rocks brought in from Canada. Russel reported that a highway cut through a drumlin in Cedarville, showed the till to be distinctly laminated in the upper 5 or 6 feet, but the lamination is less evident at greater depth. The laminae are concentric with the convex surface of the hill. Russell suggested that lamination of this sort may be produced either by the pressure of the ice or by a plastering or surface accretion by the ice in its passage over the hill. On the surface of many of the drumlins boulders are very numerous. Russell suggested that a concentration of boulders may have been produced by lake waves and currents working on the drumlins and removing the fine material from their surface. In their present condition they are thus washed drumlins. There are also notches and terraces on the slopes which are especially conspicuous at the level of the highest Nipissing beach, about 40 feet above Lake Huron.

[7]Russell, I. C, Michigan Geol. Survey Ann. Rept. for 1904, pp. 69-71, 1905.

MORAINES AND OTHER FEATURES OF EASTERN CHIPPEWA COUNTY, MICH.

In the eastern part of Chippewa County there are several bouldery ridges which trend in general from northwest to southeast and appear to have been formed by ice moving southwestward across St. Marys River. The direction of ice movement changed to southward toward Drummond Island. The ice movement that formed these morainic ridges differed strikingly from that which formed the drumlins in Les Cheneaux Islands, though those islands lie directly south of these moraines. In forming these moraines the ice appears to have made a more vigorous movement from the uplands at the east end of the Lake Superior Basin and advanced into an area that had been in the path of a movement southeastward from this end of the basin. These moraines are considered in order from south to north in what appears to have been their order of development.

KINROSS MORAINE

The Kinross moraine, here named by the writer from Kinross station, on the Soo Line, which stands on it, becomes a definite feature at the northwest in sec. 11, T. 45 N., R. 1 E., and leads southeastward for about 20 miles, passing by Stalwart and Gatesville and coming to the Lake Huron shore about 6 miles southeast of Gatesville, in T. 41 N., R. 3 E. Its general width is between 1 and 2 miles, but for a few miles southeast from Kinross it expands into a boulder-strewn tableland about 4 miles wide. In the vicinity of Gatesville and southward to Lake Huron the moraine and a gravelly plain on the southwest, which seems to be outwash from it, occupy a strip about 4 miles in width.

In altitude the moraine ranges from 700 to 800 feet or more above sea level, except near its southeast end, where it drops below 700 feet. It is highest between Kinross and the Munuscong Valley, where it stands about 100 feet above the bordering plains. This highest part is deeply indented by basins and has a nearly plane surface, like an outwash apron. It is underlain to a considerable depth by cobble and gravel beds, but its surface is thickly strewn with boulders. Perhaps this occurrence of surface boulders is due to an advance of the ice over its outwash of such a character as to cause

but little change in the topography of the outwash plain. The moraine and the outwash plain were eroded and terraced to a marked degree by the waves of Lake Algonquin as it was dropping to lower and lower levels. The crest also carries an Algonquin beach in the vicinity of Gatesville. The highest level of the Algonquin waters was nearly 100 feet higher than the highest part of this moraine. It is therefore somewhat surprising to find that the moraine has so much relief. The relief was probably somewhat greater than now when the ice sheet melted away, for the plains bordering the moraine have received a deposit of clay from the waters of Lake Algonquin.

Wells along the ridge generally penetrate about to the level of the base of the loose-textured deposits to strike water, as there appears to be no clay or impervious bed to check downward percolation. The boulders on the ridge are largely crystalline rocks from Canada, there being only a few limestone and sandstone slabs from the local formations. The cobblestones and small pebbles include a larger percentage of local rocks.

On the south side of the Kinross moraine, from its northwest end to the Niagara escarpment at Stalwart, there is a heavy filling of laminated red clay; but southeastward from Stalwart the outer border district is rough and broken, with bare limestone hills separated by swampy lowlands. From Stalwart northwestward the main settlement has been on the plain south of the moraine, and only a few farms have been cleared along the moraine. But from Stalwart southeastward the moraine is largely under cultivation, and but few farms have been opened south of it.

On the north side of the Kinross moraine there is a belt of sand and swamp land 2 or 3 miles wide extending from the west end to Mud Lake, at the mouth of Munuscong River. It is largely a barren waste. South of Mud Lake a large cedar swamp lies between the lake and the moraine, but it is diversified by a few limestone hills. From a point opposite Gatesville southeastward to Detour the district between the moraine and St. Marys River includes some fair farm land, mainly in the depressions between limestone ridges. It has a stony clay loam on which surface boulders abound. Several clearings have been made and turned into meadow or pasture.

LATER MORAINES

The part of Chippewa County lying in the bend of St. Marys River, from the head of the river to Neebish Island, is nearly all covered by a deposit of red laminated clay such as occurs south of the Kinross Ridge. A few narrow ridges and small knolls rise a few feet above the level of the clay plain. They do not appear to be superimposed on the plain, but instead they seem to be ridges that were partly buried by the deposition of the red clay. They carry some remnants of the red clay deposit on their crests and slopes. This feature seems to indicate that they were at one time covered more completely with the clay, but owing to the steepness of their slopes much of the clay has been washed down and spread over the bordering plain, or where the ridges are composed of gravel the clay has been carried down into them.

A conspicuous sharp gravelly ridge immediately southwest of Sault Ste. Marie, known as Larke Hill, is about 3 miles long, a quarter of a mile wide, and 15 to 50 feet high. It runs south from a point near the southwestern limits of the city of Sault Ste. Marie about to the line between Tps. 46 and 47 N., R. 1 W. The north end has been opened extensively for road | ballast and to supply a stone crusher. These pits all show gravel with beds dipping sharply westward, on the east slope as well as on the west slope and the crest. On the west side of the ridge is a nearly smooth tract standing 10 to 20 feet or more above the plain east of the ridge, but itself descending westward within a mile to a level as low as the plain east of the ridge. As exposures in this tract show the presence of stony material at a depth of 10 feet or less, it is thought to be a low glacial ridge on the top of which the gravelly ridge has been built. An examination of the matrix or fine material of the gravel beds shows a notable amount of red clay, which it is thought may have worked down into the deposit from a capping of clay that has now nearly all disappeared from the surface. The material in the gravel ridge is rather coarse, cobblestones and small boulders being abundant wherever pits have been opened, and the surface is strewn with stones 6 to 10 inches or more in diameter. The ridge has a range in altitude amounting to about 100 feet, the highest point being at the Larke Lake Survey station, which is 800 feet above sea level, and the lowest near the south end, where, according to an aneroid determination, its altitude scarcely reaches 700 feet. The residents commonly regard this ridge as an old lake beach, or bar, but its great size, its range in altitude, and its structure are more consistent with aqueoglacial than with lake action.

A system of small ridges and knolls leads southeastward from Dafter past Barbeau post office to St. Marys River opposite Neebish Island. These ridges rise from 10 to 40 feet or perhaps slightly more above the bordering plains. They are spread over a strip 2 or 3 miles in width but occupy much less than half the surface, there being clay plains of considerable extent among them. They are thickly strewn with boulders, nearly all derived from Canada. The ridges vary greatly in constitution, some being composed of clayey till, some of sandy till, and some apparently of gravel. There are a few sandy ridges, but they are perhaps the result of subsequent lake action. The usual trend of individual ridges is northwest to southeast, or in harmony with the trend of the system as a whole. In the vicinity of a church and schoolhouse about 3 miles south of Rosedale, in secs. 4 and 5, T. 45 N., R. 1 E., there is a plexus of gravelly ridges inclosing basins and giving the surface an exceptionally rough appearance. These ridges are probably of fluvio-glacial origin in stagnant ice and are similar to eskers in mode of development, if not simply a network of eskers. There happens to be an old lake

level at about the same altitude as the highest parts of the system of ridges, but the beaches formed by the lake seem to be confined to small terraces and to spits and small ridges much smaller than the ridges forming this network.

Between the Dafter-Barbeau system of ridges and Charlotte River there is a strip 2 or 3 miles wide in which very few knolls and ridges appear. But on the north side of Charlotte River from the vicinity of Rosedale northwestward for several miles is a practically continuous ridge standing 20 to 30 feet above the bordering plains and having a breadth of nearly a mile. It contains a clayey till, but the surface is in places coated with sand as well as strewn with boulders.

This ridge flattens out 4 or 5 miles south of Sault Ste. Marie, near the meridian line of the land survey. It may, however, continue northward in very flattened form as far as St. Marys River in the western part of Sault Ste. Marie. In the plain that lies south of Sault Ste. Marie there is a barely perceptible westward rise toward this supposed line of continuation. The plain is coated with lake clay to a considerable depth. Exposures in Sault Ste. Marie seem to indicate that its sloping surface is the masked slope of a glacial ridge. Near the tannery in the western part of the city a stony clay is found up to an altitude about 100 feet above Lake Superior, but in exposures farther east, in the southern part of the city, the stony clay is not present, though some of them extend down to a level about 60 feet above the lake. At large clay pits near the tannery the upper 10 feet is a distinctly laminated red clay with very few embedded stones, below which is a somewhat stony clay apparently of glacial origin. In this stony clay are pockets of gravel and sand. There is also some lamination, as if it were till deposited in water. These exposures seem to indicate a close connection between the decidedly stony clay and the nearly pebbleless laminated clay that overlies it, as if the latter followed immediately upon the former. It is probable that on the plain south of Sault Ste. Marie a change from the lake clay to the stony and sandy glacial deposit occurs at about the level where water is obtained in wells, which is at a depth of 30 to 50 feet.

There are two ridges of morainic aspect in the northern part of Sugar Island, in St. Marys River. One on the west side of the island is about a mile in average width and 6 miles in length. Its crest ranges from about 785 to 844 feet above sea level, or 200 to 260 feet above St. Marys River, and is generally distant but a mile from the river. It therefore appears very prominent when viewed from the west side. It rises, how ever, only 50 to 60 feet above a plain east of it, but that plain has a clay coating 20 feet or more in general depth. The Mirron Lake Survey station stands on the highest point, 844 feet, and this is occupied by a lake beach. Lake beaches also occur on the slopes of the ridge. The surface of this ridge is thickly strewn with boulders and smaller stones, some of which may have been stranded on it during the lake occupancy.

In the northeastern part of Sugar Island is another ridged belt about 3 miles long and 1 to 2 miles wide. Its west border is about 11/2 miles from the east edge of the ridge just described. It rises somewhat abruptly about 60 to 75 feet above the plain that lies between the two ridges, the highest points reaching an altitude of more than 860 feet above sea level. Lake beaches occur on its crest and slopes. It is very thickly strewn with boulders and smaller stones, and the drift is a sandy till.

On the plain between these ridges farms have been opened, but the ridges are scarcely at all cleared. At the farms wells usually obtain water at depths of 20 to 25 feet in sandy and stony deposits that underlie the lake clay. Some of the ravines have cut down through the lake clay and exposed a stony surface under it, with some very large boulders. The contrast here between the glacial and lake deposits is much more striking than in the exposures in the western part of Sault Ste. Marie noted above.

MORAINES AND ACCOMPANYING FEATURES OF THE EASTERN PART OF THE NORTHERN PENINSULA OF MICHIGAN

In the eastern part of the northern peninsula of Michigan there is a complex system of moraines which are in some places crowded together and in others separated by plains or swamps several miles in width. There are generally two strong moraines and associated with them some weaker ones. At the beginning of the development of this system of moraines the ice appears to have melted away from the Huron and Michigan lake basins to the south, or if it persisted in any part of these basins it probably became an inactive or stagnant mass, disconnected from the moving ice to the north of the basins.

This morainic system is in part above and in part below the level reached by the waters of Lake Algonquin. The part below that level has a much stronger morainic expression than is commonly exhibited by moraines laid down in water, such as those of the Saginaw and Erie Basins. The effect of the lake has been remarkably slight in toning down the morainic features. The basins are only partly filled and the knolls bear only slight notches cut by the lake waves.

Sandy ridges on the slopes of the moraines add considerably to their roughness. These ridges seem to be different from ordinary dunes, as they support heavy growths of hardwood timber, yet excavations in them show only fine sand with no clayey mixture. Nor are there pebbles or rocks that would require water or glacial action. The moraines are bordered in places by plains of sandy gravel, which by their situation as well as the character of their material appear to be outwash aprons, yet most of them are considerably lower than the highest level of Lake Algonquin. These will be considered in connection with the description of the moraines.

The southernmost member of this morainic system in general lies a few miles from the shore of Lake Michigan. The outlying district is largely a tract of limestone with very thin drift cover. Its highest parts are fully 200 feet above Lake Michigan, and in a few places—for example, in a limestone tract west of Indian Lake in southwestern Schoolcraft County—they stand above the upper limits of Lake Algonquin. There are gaps in the limestone which are generally occupied by low sandy plains, but in places are filled to the general level of the limestone surface.

MORAINES SOUTH OF THE MANISTIQUE AND TAQUAMENAW SWAMPS

From the reentrant angle in the ice border in northeastern Delta County and neighboring parts of Schoolcraft and Alger Counties, described on page 43, the ice border seems to have had a slight lobation in the Manistique drainage basin and crossed Manistique River about 10 miles northeast of Manistique, in the northwestern part of T. 42 N., R. 14 W. Morainic features are prominent along the Schoolcraft-Delta county line and along the Manistique & Lake Superior Railroad for several miles eastward from the morainic complex. Low sandy plains and swamps then interrupt the moraines for several miles, but in the northern part of T. 43 N., R. 16 W., moraines reappear and a definite moraine runs southeastward for about 12 miles. This morainic tract is about 150 feet above Lake Michigan, and along part of its south border there is a table-land of sandy gravel, which seems to be an outwash apron. This table-land is nearly free from boulders, but the morainic strip has numerous boulders and smaller stones scattered over its surface. It also has a more productive soil than the outwash plain. In this strip is the farming community known as Hiawatha Settlement.

On the east side of Manistique River for several miles above its mouth there is a sandy table-land standing 120 feet or more above the level of Lake Michigan. Where the highway rises to this tableland about 2 miles east of Manistique, near the corner of secs. 4, 5, 8, and 9, T. 41 N., R. 15 W., there is a great depth of sand exposed, in which pebbles are very rare, but at the top of the deposit is a more pebbly sand a few feet thick. The upland is a sandy plain thence northward to the westward-flowing part of Manistique River in T. 42 N., R. 15 W. On this plain there are scattered boulders. The deep filling with sand appears to extend eastward only to a small stream that runs north through secs. 27 and 22, T. 42 N., R. 15 W. East of that stream rock is near the surface, and a few boulders and coarse stones are about all there is of definite glacial material. There seems to be very little morainic material in T. 42 N., Rs. 14 and 15 W., but in eastern Schoolcraft County, in Tps. 43 and 44 N., R. 13 W., there is strong morainic development, apparently in the line of continuation of the moraines west of Manistique River. From the southeast border of this morainic area, in the southern part of T. 43 N., R. 12 W., a plain of sandy gravel extends northeastward as well as eastward into western Mackinac County over the greater part of T. 43 N., R. 12 W., and the northwestern part of T. 43 N., R. 11 W. The morainic belt also bears northeastward across the northwestern part of Mackinac County into the southern part of Luce County. The Manistique Lakes lie in it, and its north edge is near the Duluth, South Shore & Atlantic Railway across the entire width of southern Luce County. There is a sandy outwash plain outside of the moraine in the headwaters of Mille Coquins River and east of Mille Coquins Lake which runs southeastward to the shore of Lake Michigan near Naubinway. The outer part of the morainic system turns southeastward and runs past Gilchrist to Lake Michigan. This part carries sandy ridges, which conceal much of the surface of the moraine. A plain of sandy gravel sets in on the north shore of Lake Michigan a few miles farther east, but morainic features are weak to the north of it. This outer member of the morainic system is a definite feature as far east as the southwestern part of T. 43 N., R. 7 W. There are scattered morainic knolls a few miles farther back from Lake Michigan along or near the Soo Line from Gilchrist nearly to Trout Lake.

The main part of this morainic system lies still farther north and runs eastward across southern Luce County into Chippewa County, keeping south of the great Taquamenaw Swamp. There are two conspicuous recesses in the north border of the moraine in Luce County, one from 1 to 4 miles west of Newberry and the other from 4 to 10 miles east of that town. In the first recess a low clay plain extends about 3 miles south of the Duluth, South Shore & Atlantic Railway, and in the second about 5 miles. Along the St. Ignace branch of this railroad there is a low sandy plain rising gently southward to the divide between Lake Superior and Lake Huron, 3 miles northwest of Trout Lake. Near the line of Luce and Schoolcraft Counties the moraine is greatly interrupted by swamps for about 6 miles south of the railroad. These swamps appear to be underlain by sand, and so does the great swamp that occupies much of the drainage area of Manistique River in Schoolcraft County. Near Eckerman the moraine under discussion becomes merged with a later one, which continues northeastward nearly to the head of the outlet of Lake Superior at Point Iroquois.

There are few places where this morainic system is developed at a level less than 150 feet above Lake Michigan. Where the land stands lower along its course there are usually sandy plains and swamps. Some of the highest points are found at the west end, in the interlobate tract in western Schoolcraft County, where the altitude reaches fully 950 feet above sea level, or about 370 feet above Lake Michigan. A single knoll near Rexton is also 950 feet above sea level, and a knoll a mile south of McMillan reaches about 1,000 feet. The altitude of the greater part of the moraine is between 800 and 900 feet. The highest level of Algonquin waters in this district is not far from 900 feet above the sea, being a little above that level in western Schoolcraft County and a little below in southern Luce and Chippewa

Counties and in Mackinac County. The islands rose but little above the lake and were of slight extent.

The relief of the moraines on the outer or south border is generally very slight, being ordinarily only 20 to 30 feet. The inner-border relief is much greater, as a low swamp lies along the border in Schoolcraft and Luce Counties and western Chippewa County. The lowest part of the swamp in southern Manistique County is less than 650 feet above sea level, and the altitude is only 720 ‘feet at the divide between the Manistique and Taquamenaw drainage basins. The altitude is low as far east as Soo Junction. Eastward from that point the swamp rises to 800 feet at Eckerman and about 825 feet at Strong station. In places a narrow plain lies along the south side of the swamp in Luce County, and the morainic features set in at 750 to 800 feet above sea level, or 20 to 70 feet above the level of the swamp. The village of Newberry stands on this plain.

Throughout much of its course the moraine has a strong expression. The basins are especially conspicuous. The swells have usually rather gentle slopes, but a few of them are steep and rise high above the surrounding part of the moraine. Thus the highest points of a chain of knolls about 11/2 miles north of Garner are about 100 feet above the rest of the moraine, and a knoll north of Rexton rises 90 feet. The moraine in western Schoolcraft County has many sharp knolls and ridges 60 to 75 feet high. Some of the basins are very large. The one occupied by Manistique Lake has an area of about 15 square miles. The neighboring morainic knolls and ridges rise 60 to 80 feet above the lake. Some small basins are very deep. Those in the Hiawatha Settlement which contain small lakes have rims about 40 feet above the lakes, and the lakes are said to be 60 to 75 feet in depth. As a rule, however, the lakes along this morainic system are shallow, and there are many basins that are occupied by swamps or have dry bottoms. The basins are nearly all in the part of the morainic system that was covered by the waters of Lake Algonquin. The basins are preserved where they lie near the level at which strong wave action seems likely to have occurred, as well as where they were deeply submerged.

A considerable part of this morainic system has been built up to about the level of the highest part of the Niagara escarpment where it lies along the crest of the escarpment. The drift is thus rather thin where the rock stands high and thick where it stands low. The drift is very thick to the north of the escarpment. The moraine lies mainly north of the escarpment, though its outer part extends to and in places beyond the escarpment from the vicinity of Hendrie westward to Manistique River. The rock has been struck north of the escarpment in only a few borings, as shown in the following list:

Deep borings along or near the moraine north of the Niagara escarpment

Location	Altitude	Depth	Remarks
	Feet	*Feet*	
Van Leuven estate, sec. 25, T. 47 N., R. 4 W.	825	140	No rock struck.
Strong (Turner's mill)	840	220	Rock at bottom. Drift mainly clay to 175 feet; gravelly hardpan, quicksand, and sandy gravel below.
Strong (Turner's boarding house)	845	203	Sand 7 feet at top, then clay to 175 feet, below which is gravelly hardpan and quicksand
Near Soo Junction	720	172	Rock at bottom. Drift largely a gummy clay. Thin bed of gravel on the rock.
Newberry asylum	870	186 245 457	One well, 245 feet, from gravel. Four wells, 186 feet. Rock at 320 feet. Drift entirely sandy or gravelly material. Water obtained from upper part of limestone, drift water being cased out. Shale in lower 70 feet.
Newberry waterworks	775	110	Three wells. Entirely in sand to gravel at 90 feet.
Newberry chemical works	765	92–128	Ten wells, 92 to 108 feet; test well, 128 feet; sand, 5 feet; clay, 16 to 18 feet; fine sand extending to 90 feet, coarser sand to bottom of wells, and in test well to rock at 126 feet.
Newberry Furnace	765	80	Section as in well at chemical works.
Ryberg well, ½ mile east of Newberry	760	140	Black muck, 5 feet; clay, 80 feet; quicksand and gravel to bottom.
Dollarville, Danaher Lumber Co.	725	120–140	Four wells; rock struck at 130 to 140 feet. Flowing wells.
J. Watson, sec. 4, T. 45 N., R. 12 W.	760	106	Hardpan and clay, 120 feet; sand and gravel at bottom.
School house sec. 9, T. 45 N., R. 12 W.	850	192	Largely through sandy drift.
J. Templeton, sec. 10, T. 45 N., R. 12 W.	850	196	Do.
A. Carlson, sec. 10, T. 45 N., R. 12 W.	850	150	Do.
J. Hunter, sec. 9, T. 45 N., R. 12 W.	740	103	Red clay, 40 feet; sandy slush to gravel at bottom. Flowing well.
A. Pentland, sec. 10, T. 45 N., R. 12 W.	740	103	Largely red clay to sand at 90 feet. Flowing well.
J. Swanson, sec. 2, T. 45 N., R. 12 W.	750	84	Entirely through sand. Flowing well.
J. Peterson, sec. 11, T. 45 N., R. 12 W.	740	53	Mainly red clay to sandy slush at bottom. Flowing well.
About 3 miles southeast of Newberry	860	170	Well at a wood camp penetrated sandy drift 100 feet; blue hardpan, 65 feet; sand, 5 feet.
McMillan (at schoolhouse)	785	80	Water from sand under clay.
Helmer post office, by Manistique Lake	705	70	Water from gravel below clay. Flowing well.
Schoolhouse, sec. 29, T. 45 N., R. 12 W.	775	96	Limestone at 40 feet.
Charles McKenna, sec. 29, T. 45 N., R. 12 W.	765	86	Do.
Jerry Holland, sec. 30, T. 45 N., R. 12 W.	730	85	Limestone at 18 feet.
J. Richards, sec. 21, T. 45 N., R. 12 W.	775	76	Rock at bottom.
Mr. Stafford, west of Manistique Lake	770	80	No rock struck.
Blaney, Wm. Mueller Lumber Co.	750	214	Drift 113 feet, shale 101 feet. Drift was as follows: Clay loam and sand, 15 feet; quicksand, 26 feet; gravel, 4 feet; blue clay with sand streaks, 65 feet.

On the long stretch of moraine between Iroquois Point and Manistique River the only notable amounts of clay or clayey till are found either on the inner border or in a few townships in southwestern Luce County, northwestern Mackinac County, and eastern Schoolcraft County. The clay on the inner border beneath swamps is reported to have very few pebbles. It is commonly red at the surface but is said to become blue in some places at considerable depth. The red color may be due to the incorporation of material from the red layers of sandstone. The red color is pronounced in the vicinity of Manistique and Whitefish Lakes and westward to Manistique River. Considerable coarse material is incorporated with the sandy material that forms the great bulk of the moraine, which should be classed ordinarily as a sandy till rather than as assorted material (sand and gravel). Boulders are not usually conspicuous on the surface either between Point Iroquois and Manistique River or west of the Manistique Swamp. There are places, however, where cobblestones from 4 to 10 inches in diameter abound.

In the Hiawatha Settlement, north of Manistique, the hardwood tracts are in places thickly strewn with cobblestones, and small boulders are not rare. Cobblestones are very numerous also on a table-land east of Scotts Camp, in the southern part of T. 45 N., R. 17 W. The ridges in western Schoolcraft County and southern Alger County are only in places thickly strewn with boulders.

The most extensive farming district on this moraine is found in the tract of clayey till in southwestern Luce County, northwestern Mackinac County, and eastern Schoolcraft County, though a fair-sized area has been developed in the Hiawatha Settlement, and there are some good farms on the inner slope of the moraine in the vicinity of Newberry. In all these farming districts, except the Hiawatha Settlement, there is more or less clay, but the soil in that settlement is a gravelly loam.

MORAINES NORTH OF THE MANISTIQUE AND TAQUAMENAW SWAMPS

There is a strong morainic system north of the Manistique and Taquamenaw Swamps which is combined with the one south of these swamps from the east end of the swamp near Strong station eastward to Iroquois Point. It runs westward along the north side of the Taquamenaw Swamp through Luce County and the north side of the Manistique Swamp in Alger County and northern Schoolcraft County. It continues westward about to the meridian of Munising and then swings around to the south on the east side of the Au Train-Whitefish Valley and dies out about 3 miles north of the Alger-Delta county line. Its general width from Munising eastward is 5 or 6 miles, but here and there it expands to 10 miles or more. It lies near the Lake Superior shore from Munising to Grand Marais, but in the part between Grand Marais and Emerson the inner border of the main moraine is 5 to 10 miles from the shore and a small inner member fills part of the space between it and the lake. Eastward from Emerson it again borders the lake shore closely.

In the portion of the moraine east of Munising the crest generally stands not far from 900 feet above sea level but ranges from less than 800 feet up to about 1,000 feet. Along the inner slope, on the south shore of Whitefish Bay, the morainic contours extend down within 50 feet of the Lake Superior level, or 650 feet above the sea, but farther west they rarely reach so low a level, and the inner border is generally at an altitude between 700 and 800 feet. The outer border is only 700 to 720 feet above sea level in the lowest part of Taquamenaw Swamp but reaches about 840 feet near Strong station, at the point of divergence from the outer morainic belt. The altitude is still higher along the outer border in the Manistique drainage basin, being usually not far from 900 feet. The edge next an outwash apron south of Munising stands at 1,000 to 1,020 feet for a few miles, but it falls to about 850 feet at the border of the Whitefish Valley.

This morainic belt, like the outer one, has a rolling surface, with numerous basins inclosed among the knolls. The larger basins contain lakes or swamps, but many of the smaller ones are dry, the water table being below the level of their bottoms. The most prominent knolls rise 100 feet or more above neighboring sags and basins, and a height of 40 to 60 feet is common along the moraine from Iroquois Point to Au Train River. The prominent knolls occur commonly in clusters, which tower above neighboring parts of the moraine. Although the moraine is several miles wide, it does not seem to admit of separation into two or more constituent ridges but is a great and intricate mass of rolling drift.

The portion of this moraine east of Munising is composed very largely of sandy till, the clayey till and laminated clay being almost entirely confined to its inner border and present even there only in a few places. Indeed, the writer observed clayey till in only two localities, one between Taquamenaw River and Salt Point, west and south of Emerson, and the other in the vicinity of Munising. Clayey till occurs on the inner border of the moraine east of Munising, and a laminated clay near Hallston, south of Munising. It is not unlikely, however, that clayey till occurs elsewhere along the moraine at points not found by the writer.

In the district east of Au Train River the drift has considerable thickness except on the border of Lake Superior along the Pictured Rocks, or for 18 to 20 miles northeast from Munising. Thin drift is present north of the moraine on Train Point, west of Munising, and also on Grand Island, north of Munising.

The only rock outcrops east of Grand Marais appear to be those along Taquamenaw River between the upper and lower falls, near the line between Luce and Chippewa Counties. There are a few small outcrops near Grand Marais, but none of much consequence occur east of the Pictured Rocks, whose east end is in T. 48 N., R. 17 W. Outcrops are nearly continuous along the Lake Superior shore from this township westward to T. 43 N., R. 23 W.

But few well records were obtained along this moraine. A well at Stillman station, on the Munising, Marquette & Northeastern Railway, is 90 feet in depth. It penetrated some clayey hardpan, but at the surface there is a sandy drift. The soil in this region is clay loam, and the well is thought to have penetrated some clay as well as sand. A well at Robert Gogarn's farm, about 2 miles northeast of Munising, in sec. 6, T. 46 N., R. 18 W., is about 20 feet deep. It is only half a mile from the shore of Lake Superior and about 135 feet higher. A well in sec. 33, T. 47 N., R. 18 W., put down by Henry Russell, of Munising, entered rock at only 12 feet, though at an altitude more than 200 feet above Lake Superior. A well near the outer border of the moraine east of Mud Lake, in sec. 31, T. 45 N., R. 20 W., is 72 feet deep and is entirely in sandy drift. Two miles farther south, on slightly lower ground, rock was struck at 20 feet. A well at a lumber camp on the outwash apron south of Wetmore, in sec. 36, T. 46 N., R. 19 W., is 104 feet deep and is entirely in sandy drift. The altitude is about 965 feet above sea level.

From Iroquois Point southwestward nearly to Trout Lake a plain of sandy gravel lies along the southeast border of this morainic system. It is 880 to 930 feet above sea level next to the moraine but slopes rapidly to the southeast.

From its point of separation from the outer morainic belt near Strong station westward as far as the meridian of Newberry there is a swamp on the immediate outer border of this moraine. An outwash apron of gravelly sand appears in a recess of the moraine 6 to 12 miles west of the meridian of Newberry, chiefly in T. 47 N., R. 11 W., but extending southward into T. 46 N., R. 11 W. This outwash apron appears to have been built in successive steps from south to north as the ice border receded, there being more than one plain of filling. The ice contact at the north edge of each plain is marked by

a low blufflike rise, the northern edge of each plain being a little higher than the southern edge of the next one and being trenched in places by the passage of streams across it from the next later plain.

West of this outwash apron a morainic spur extends as far south as the southern edge of the apron, and from both there is a steep descent over a bluff to the Taquamenaw Swamp, which is there only 2 or 3 miles wide and was traversed by a strait of Lake Algonquin.

West of this spur, on the west edge of Luce County, an outwash apron of gravelly sand sets in which borders the moraine entirely across the north end of Schoolcraft County, though broken up more or less by swamps at the west in T. 47 N., R. 16 W. The outwash apron extends southward from the moraine for several miles and gradually drops down to the marsh drained by Manistique River and its tributaries.

For the next 18 or 20 miles, or nearly to the meridian of Munising, swamps are conspicuous on the outer border of the moraine, and dry sandy plains are of very slight extent. But about 2 miles east of Wetmore, or 5 miles southeast of Munising, there is a high outwash apron of gravelly sand with an abrupt border on the east, next to the swamp, having a relief of 100 feet or more. From this point west and south to the Whitefish Valley there is a continuous outwash apron. The absence of the filling of outwash in the district to the east may be attributable to the ponded condition along that part of the ice border. The parts where outwash plains occur were high enough to stand above Lake Algonquin or were very close to the upper level of the Algonquin waters.

In the district west of the Au Train-Whitefish Valley there does not appear to be a definite morainic belt in continuation of the one under discussion. Most of the surface is gently undulating, like ground moraine. In a few places groups of sharp knolls are present, but these do not seem to line up into a definite morainic belt. It seems likely, therefore, that in the district west of the Au Train-Whitefish Valley the ice border did not hold any position long enough to build up a definite moraine. The drift is very thin in the part covered by the waters of Lake Algonquin from Au Train River westward about to Chocolate River. This is a strip from 6 to 10 miles in width next to the Lake Superior shore. In places the surface is strewn with slabs of the local rock formations in such numbers as to render the soil difficult to till. There are, however, small farming settlements on this lake-washed land where conditions for cultivation are better.

In the district east of Grand Marais there is a rather weak moraine which farther west is combined with the stronger one but which is here separated from it by a space of 2 to 6 miles. It runs eastward across northern Luce County and comes out to the Lake Superior shore near the Luce-Chippewa county line. Its width is 1 to 2 miles and its inner border is only 1 to 4 miles back from the shore of Lake Superior. Its altitude is 75 to 150 feet above the level of Lake Superior, and it stands 15 to 30 feet above the plain at its south edge. The plain, however, rises southward within a short distance to an altitude higher than any part of the moraine. This moraine has a subdued swell and sag topography, and there are very few basins on it. It carries more boulders than are commonly present on the bordering plains. It is on the whole very loose textured. The more clayey parts of the moraine carry maple and other hardwood forest; the lighter or sandy parts are timbered with pine.

The trend of this moraine compared with that of the strong moraine outside of it suggests a northwestward recession of the ice border from the southeast end of Lake Superior. It is the latest moraine developed in the district under investigation, and the further history of the ice retreat must be looked for in Canadian territory. It is probable that a study of the eastern shore of Lake Superior will throw considerable light upon the method of retreat of the ice from the Lake Superior Basin.

THE LAKE FEATURES

PREDECESSORS OF GLACIAL LAKE DULUTH

In the course of the melting and shrinking of the Superior lobe within the area that now drains to Lake Superior water became ponded along the ice border in several independent small lakes, to which names have been applied that correspond usually to the drainage districts in which they stood. Thus glacial Lake Nemadji occupied much of the headwater part of the Nemadji River drainage basin, glacial Lake Brule occupied a part of the Brule River drainage basin, and glacial Lake Ontonagon part of the Ontonagon River drainage basin. These lakes were all in the district west of the Keweenaw Peninsula. East of that peninsula the ice drained to the basins of Green Bay or Lake Michigan along the glacial drainage channels noted above in the description of the moraines of the western part of the northern peninsula of Michigan. Glacial Lake Duluth, however, extended a few miles farther east than the Keweenaw Peninsula, to the border of the Huron Mountains, east of Keweenaw Bay. In the early part of the recession of the ice front Lake Duluth, with an outlet from the Brule River Valley through the St. Croix River Valley, was present in the western part of the Lake Superior Basin. A little later the ice border retreated sufficiently to allow the small independent lakes to become a part of Lake Duluth or to be drained by the lowering of the water level, for in general the water level was lowered as these lakes became merged with Lake Duluth.

GLACIAL LAKE ST. LOUIS

One of the bordering lakes was present when the Superior ice lobe was at its full extent. It stood in the part of the St. Louis River drainage basin northwest of the border of the Superior lobe. (See pl. 2.) It was held

between that ice lobe and the Keewatin ice that came in from the northwest to a position a little to the east of Mississippi River. This lake was briefly described by N. H. Winchell,[8] and its highest stage was named Lake Upham and a lower stage Lake St. Louis. As it preceded the other small lakes on the border of the Superior ice lobe, it will be discussed first.

[8]Glacial lakes of Minnesota: Geol. Soc. America Bull., vol. 12, pp. 109-128, 1901.

This lake, which occupied the central part of the St. Louis River drainage basin, was thought by Winchell to have had at its highest stage a westward discharge to the Mississippi and at a lower stage a discharge down the St. Louis Valley to Scanlon, Minn., where it came to the ice edge and was deflected southwestward in a course along or near the edge of the ice lobe into tributaries of St. Croix River. Winchell had no idea that at the highest stage of this lake the Keewatin ice from the northwest was still occupying the Mississippi Valley along the west side of the lake, and so he assumed that there was free discharge from the lake to the Mississippi. It is a question, therefore, whether two names are neccessary and whether the early and highest stage of the lake should be called Lake Upham. The name Lake St. Louis is self-explanatory and seems in every way suitable for all stages.[9] There is still some uncertainty as to the course of drainage while the ice border retreated to a position in which the outlet could take the course past Scanlon, above noted. It is likely to have been through some of the many swampy depressions along or near the edge of the ice lobe in southern St. Louis County and neighboring parts of Carlton and Aitkin Counties. Data are not available as to the relative altitude of these swamps, and the course of the drainage may remain unsettled until such data are available.

The head of the outlet that leads down St. Louis River is near Mirbat, about 3 miles below Floodwood. A well-defined beach comes to this outlet from the west along the south side of East Savanna River. Its altitude is about 1,275 feet above sea level. This is nearly as high as the divide between East Savanna and West Savanna Rivers at the place where Winchell supposed the lake had a westward discharge. A survey for a canal from St. Louis River to the Mississippi crossed this divide at an altitude of 1,282 feet.[10] This does not give quite so low a passage across the divide as is found along the line of the railroad that runs from Swan River station on the Great Northern Railway southwestward to the Mississippi at Jacobson, the summit there being about 1,275 feet above sea level. There may be places on the divide with still lower altitudes. The divide is occupied by a great muskeg swamp, which so far as the writer is aware has not been surveyed except along the two lines just noted. West of the divide there is a complex system of glacial knolls and ridges, many of which rise to a greater height than the divide, but among them are low tracts through which water now drains from the western part of the muskeg swamp westward to the Mississippi. The east front of the Keewatin ice is thought to have been standing near these ridges while the glacial lake was forming its beach south of the East Savanna and to have persisted during the recession of the west front of the Superior ice lobe to Scanlon and the opening of the St. Louis Valley outlet. Differential uplift has raised the northern part of the district covered by this glacial lake to more than 1,300 feet above sea level. There may be some significance in the fact that a change from silt to sand occurs on that border at about 1,300 feet. It is thought that the sand may indicate only a shallow depth of water. The silt, on the other hand, seems to have been laid down in deeper water, where waves and currents did not have a disturbing influence. The banks of streams traversing this old lake bed show thick deposits of nearly pebbleless silt. Silt-laden water may have come partly from the neighboring ice sheet on the west. Probably there was also a large amount of silt brought down St. Louis River from a great recess in the ice at the headwaters of its drainage basin. The lake became so filled with silt that it was very shallow in the final stage of its history. Only a few feet of deepening in the outlet would have been required to drain it completely. It is therefore an open question whether the lake persisted long enough for the ice barrier at the west to have given way and thus opened a passage into the Mississippi.

[9]The writer and Sardeson have used the name Lake Upham for the most expanded stage in their discussion of the features of this lake in Bulletin 13 of the Minnesota Geological Survey. This was done because the water body had an extent similar to Winchell's conceptions, whereas Lake St. Louis, as conceived by Winchell, was much smaller water body.

[10]54th Cong., H. Doc. 330, p. 13, 1896.

It has not been feasible to trace the shore of this lake in the district east of St. Louis River or, indeed, anywhere except for the few miles along the south side of East Savanna River, for that is the only place on the whole circuit of the shore of the lake where the country has been cleared and drained. The northward differential uplift suggested above is an inference from the observed northward rise of the shore lines of glacial Lake Aitkin, in the Mississippi Valley (pl. 2), as well as of glacial Lake Duluth, in the neighboring part of the Lake Superior Basin.

The outlet stream followed down the course of the present St. Louis River to Scanlon, near Carlton. But there it was turned aside by the front of the Superior ice lobe, took a southward course to Kettle River, in northern Pine County, and followed down that stream to the St. Croix and thence to the Mississippi. After turning away from the St Louis Valley the outlet soon crossed the present divide between the Great Lakes and Mississippi drainage systems. This crossing was near Atkinson, at an altitude of 1,170 feet, or about 100 feet lower than the head of the outlet near Floodwood. Later, when the border of the Superior ice lobe had been melted back to the line of the Thomson moraine, a slightly lower passage became available south of Atkinson between the Thomson and Cloquet moraines. Thiswas stated by N. H. Winchell[11] to be 1,125 feet

above sea level at the divide. Still later there was discharge to a small marginal glacial lake in the Lake Superior Basin at Wrenshall. A thick deposit of calcareous clay in the vicinity of Wrenshall may have been brought in by drainage from the Keewatin ice and its calcareous drift.

The bed of the outlet in its course along St. Louis River is one-third of a mile or less in width and has the appearance of a scourway, for in places it is literally paved with boulders. On leaving St. Louis River at Scanlon the stream entered a line of glacial drainage in which deposits of sand and gravel had been laid down. It cut into these deposits and near Barnum reached the underlying rock at an altitude of about 1,100 feet above sea level.

[11]Geology of Minnesota, vol. 4, p. 19, 1899.

GLACIAL LAKE NEMADJI

In his report on Carlton County in volume 4 of the "Geology of Minnesota" Winchell called attention to the channel that leads westward from the west end of the Lake Superior Basin to Moose Lake, where it joined the outlet of Lake St. Louis. Later he applied the name Lake Nemadji to the small body of water that stood between the receding ice border and the head of this outlet, for its bed is now largely drained by Nemadji River.[12] The head of the outlet is about 1,070 feet above sea level, and there is a moderate fall in the 5 miles to Moose Lake, where it joins the Lake St. Louis outlet. The width of the outlet averages only about one-sixth of a mile and where greatest is scarcely one-fourth of a mile. The channel was cut to a depth of 10 to 20 feet. The small size of the outlet indicates that the lake which discharged through it was rather small.

The Thomson moraine marks the position held by the ice edge for a considerable part of the time when this outlet was in operation. The area of the lake bed outside this moraine is only about 20 square miles. The part of the melting ice lobe that discharged into this lake may also have been very small. A few miles to the east of the Moose Lake outlet the Brule-St. Croix outlet received the discharge from the ice border. It is probable that the transfer of the entire drainage of the west end of the Lake Superior Basin to the Brule-St. Croix outlet and the beginning of Lake Duluth did not take place until after the Fond du Lac moraine had been formed and the ice edge began to recede from its inner slope. In that case the area of Lake Nemadji may have reached a maximum of about 50 square miles.

The part of the lake bed outside the Thomson moraine is nearly all coated with a thin deposit of fine sand and there is sand on part of the bed between the Thomson and Fond du Lac moraines. It is thus in contrast with the district inside the Fond du Lac moraine, which has a stiff red-clay soil with only a few small sand-covered spots. This sand was probably laid down in part as outwash from the ice, though some was due to wave action on the shores of the lake.

Lake Nemadji formed a well-defined sandy beach along its northwest shore, which traverses a farming district and is thus open to study. In places there are two small ridges, the inner 5 to 10 feet below the outer. The south shore, on which there has been very little clearing of forest and brush, can not be followed so readily. It was possible to determine the lake border easily, however, by the abrupt change to strong moraine. The lake seems to have cut into the morainic ridges in places and thus formed steep bluffs 20 feet or more in height. These cuts, as well as the well-defined beaches of the northwest shore, indicate that the lake endured for a considerable time.

[12]Geol. Soc. America Bull., vol. 12, p. 121, 1901.

GLACIAL LAKE BRULE

There was a small lake in the part of the Brule River drainage basin south of the copper range that seems to have preceded Lake Duluth and used the outlet to the St. Croix Valley before the waters of the larger lake had been turned into this outlet. The ice at this time was resting on the copper range in eastern Douglas County, Wis., and also covering the northern part of the Bayfield Peninsula in Bayfield County. Lake Brule received not only the waters escaping directly from the part of the ice border crossing its drainage basin but also the discharge from the melting ice for many miles to the east, probably from as far as Baraga County, Mich. It is not improbable, therefore, that the outlet was measurably deepened by this discharge before the waters of Lake Duluth began their work.

Lake Brule covered an area of about 20 square miles between the copper range and the Duluth, South Shore & Atlantic Railway. A large part of this lake bed is swamp land, but drift hills occur in and around the swamps and give the impression of roughness of surface that at first seems inconsistent with a lake bed. Some of the hills were completely submerged, so that no wave work was done on them. Others stood a little above lake level and bear marks of wave cutting on the slopes. A conspicuous hill of this sort is to be seen east of Brule River south of the village of Brule. Traces of lake action reach there an altitude of 1,125 to 1,130 feet above sea level as determined by a line of hand levels run from the railway near by. Evidence of a similar altitude was found in the northwestern part of the lake bed in the vicinity of Bellwood and Blueberry stations. Lake deposits are inconspicuous on the borders of this little lake basin. The silt seems to have settled in its deeper part along Brule River at a level 100 feet or more below the highest shore. The features of the Brule outlet are taken up in the discussion of Lake, Duluth. The head is near the line of the Duluth, South Shore & Atlantic Railway, although the present divide between the Great Lakes and Mississippi drainage basins is some 14 miles to the southwest, or immediately north of upper St. Croix Lake. The open waters of Lake Duluth had their southern limit 6 miles farther north, where Brule River breaks through the copper range, or about 20

miles by direct line northeast from the present divide. (See fig. 7.)

GLACIAL LAKE ASHLAND

Glacial Lake Ashland occupied several townships in northwestern Ashland County, Wis., and extended west in Bayfield County to the eastern slope of the Bayfield Peninsula. It discharged across the peninsula along the line of the Duluth, South Shore & Atlantic Railway as far as Pike Lake and then took a westward course to Muskeg, passing south of Iron River village. From Muskeg it followed the course of the Northern Pacific Railway westward into the Brule Valley.

The highest shore line is crossed about 3 miles north of Mellen by the Soo Line. It has a storm beach at 1,128 feet above sea level and an ordinary beach at 1,123 feet. The head of the outlet at Pike Lake is at very nearly the same altitude, being about 1,125 feet above sea level on a terrace and 1,110 to 1,115 feet in a narrower channel cut into the terrace. The valley, including the terrace, is about one-third of a mile wide, and between Pike Lake and Iron River the valley is in places nearly 50 feet deep. The deeper inner channel is scarcely half as wide as the outer channel. It is not entirely certain that the lake outlet excavated the broader channel, for that may have been cut by glacial drainage while the ice border was pressing against the eastern slope of the peninsula close to the head of the outlet. Moreover, the smaller channel seems consistent with the small size of the lake.

The limits of the lake on the northeast seem to have been at a moraine that runs northward to the Lake Superior shore at Clinton Point, about 18 miles east of Ashland. The ice seems to have covered the Bayfield Peninsula about as far south as the ridge west of the fish hatchery, 3 to 4 miles southwest of Bayfield, and to have stood at the north edge of the sandy pine plain or outwash apron in the northern part of T. 49 N., R. 6 W., and the southwestern part of T. 50 N., R. 5 W. It appears to have held its position here long enough for a marked deepening of the Brule-St. Croix outlet, for the highest beach formed to the north of the moraine above noted is lower than the highest one in the Lake Ashland and Lake Brule areas. It is about 1,115 feet above sea level at Saxon, Wis., or 8 feet lower than at Coria, on the south side of Lake Ashland. This figure, however, does not measure the full amount of difference in lake level, for this district has been subjected to northward differential uplift. Saxon is about 15 miles northeast of Coria, and the uplift in that direction is likely to be not less than 15 feet, for in the 40 miles from Saxon northeast to the Porcupine Mountains it amounts to 48 feet, or from 1,115 to 1,163 feet above sea level. It is probable, therefore, that the Brule-St. Croix outlet was deepened about 20 feet while Lake Ashland was an independent lake.

The bed of Lake Ashland consists very largely of red clay. There is a sandy coating in parts of the border of the lake at levels a little below the highest beach. The soil on glacial ridges in the lake is also of looser texture than that on the plains between them. It is doubtful if this red clay was wholly the deposit of Lake Ashland and its successor, Lake Duluth. It may be glacial in large part and may even be older than the latest ice invasion, though this is an open question. Lake Ashland gave place to Lake Duluth when the ice had receded from the Bayfield Peninsula far enough to open water communication there.

GLACIAL LAKE ONTONAGON

Glacial Lake Ontonagon occupied much of the Ontonagon drainage basin in the northern peninsula of Michigan south of the copper range, the position of the ice border for a considerable part of its existence being along the copper range. The south shore is easily traceable across northeastern Gogebic County, southern Ontonagon County, and southern Houghton County. This shore is about 1,320 feet above sea level at the west end of the lake and 1,335 to 1,340 feet at the east end; the greater height at the east is due to the eastward component of the differential uplift. As the north shore was an ice wall, there is no record preserved to give a measure of the northward component of the uplift, but it is greater than the westward component, for the direction of tilting was about south-southwest. It is not improbable that the ice sheet had some attraction and raised the lake waters higher at the east end of the lake than at the west end, for the east end of the lake extended into a recess in the ice sheet where it was bordered by thicker ice.

Over the bed of this lake there is generally a thin coating of fine loamy material on a red clayey till. In the eastern part of the lake bed from Trout Creek village northward to Pori there are sandy deposits, and at its northeastern limits, in southern Houghton County, there is a gravel plain which extends from Frost Junction to Sidnaw. This great gravel plain seems to have been formed as an outwash from the ice into the edge of this lake. There are high rolling tracts within this lake area that rose about to the level of the surface of the lake. They have a looser-textured soil than the bordering plane tracts.

The outlet of this lake is a small shallow channel one-eighth to one-fourth mile wide and 20 to 40 feet deep. The outflow crossed from Gogebic Lake to the Presque Isle River Valley near the line of the Duluth, South Shore & Atlantic Railway. It then followed the course of the present river northward a few miles but was turned back southward in a sharp loop by the ice front and came to the line of the railroad again a short distance west of Thomaston. From this point the railroad runs in the outlet channel much of the way westward to Saxon, Wis. The fall in the outlet is rapid, being 200 feet in 40 miles from Gogebic Lake to the Wisconsin State line. The fail is not uniform, stretches .of gentle gradient alternating with those of steep gradient, but precise data as to the differences in the rate of fall have not been obtained. The fall is especially rapid from the meridian of

Thomaston westward to North Bessemer, being about 100 foot in 6 miles (from 1,270 to 1,170 feet above sea level).

The ice border was only a few miles north of this outlet, probably at a moraine that lies within 2 to 5 miles of the shore of Lake Superior from the Porcupine Mountains westward to Clinton Point in Wisconsin. In that case Lake Ontonagon was a contemporary of Lake Ashland, and its outlet led to Lake Ashland in the northwestern part of Iron County, Wis. The Brule outlet received at this time not only the drainage from land areas tributary to Lake Ashland and Lake Ontonagon and the lake areas themselves but also the waters coming from the melting ice front from the Keweenaw Peninsula westward past the Bayfield Peninsula.

From Baraga County eastward the waters from the melting ice were discharged toward the Lake Michigan Basin into Lake Chicago down to the time when the waters of Lake Duluth were admitted to the district bordering Keweenaw Bay. In Marquette County there was ice-border drainage southward to the Lake Michigan Basin down to the time of the greatest expansion of Lake Duluth. Lake Chicago, however, appears to have given place to Lake Algonquin before the waters of Lake Duluth were drawn down to the Algonquin level.

GLACIAL LAKE DULUTH

LIMITS OF THE LAKE

The lake which had been discussed by Upham[13] as the "Western Superior Glacial Lake" was later, through a suggestion of F. B. Taylor,[14] named Lake Duluth. Its beaches are especially prominent in the city of Duluth and have long been recognized as old shores. As already indicated, it was preceded by a string of small lakes on the border of the Superior ice lobe. With the shrinking of the ice lobe these independent lakes became confluent at a level in harmony with the outlet to the St. Croix Valley. It is probable that several small glacial lakes, Nemadji, Ashland, and Ontonagon, became lowered to the level of Lake Brule and its outlet in the order named. In Lake Nemadji and Lake Ashland the lowering was very slight, probably somewhat less than 20 feet. But Lake Ontonagon was lowered nearly 200 feet and much of its bed became a land surface. Narrow bays of Lake Duluth, however, extended a few miles up each of the tributaries of Ontonagon River south of the copper range.

[13]Upham, Warren, Minnesota Geol. Survey Twenty-second Ann. Rept., pp. 54-66, 1894.

[14]A short history of the Great Lakes, in Dryer, C. R., Studies in Indiana geography, 1st ser., p. 10, fig. 1, 1897.

On the north side of the Lake Superior Basin Lake Duluth extended eastward step by step with the recession of the ice border. This recession seems to have taken so long a time that the outlet became materially deepened. As a result the highest beach of the eastern part of the north shore does not correspond with the highest beach of the western part but is the continuation of one of the lower beaches. The same is true of the beaches on the south shore, the highest beach in Michigan being too young and too low to be correlated with the highest beach west of the Bayfield Peninsula. In the present state of the country, with few roads and much of the surface still in brush, it has not been feasible to map in detail each of the higher shore lines and clear up its relation to the moraines. But there seems no question that a correlation such as has been worked out on other glacial lakes will some day be established here.

The eastern limits of Lake Duluth on the south shore have been found to be at the Huron Mountains, in northwestern Marquette County, Mich. When the ice melted away from the northern and eastern slopes of these mountains border drainage channels were opened, which took not only the discharge from the melting ice but also the waters of Lake Duluth and carried them into the Lake Michigan Basin. Lake Duluth was thus lowered step by step as lower and lower lines of border drainage were opened by continued recession of the ice border. Eventually the waters were lowered to the level of Lake Algonquin, and that body of water occupied the western part of the Lake Superior Basin as well as the basins of Lake Michigan and Lake Huron and finally the eastern part of the Lake Superior Basin. The eastern limits of Lake Duluth on the north coast of Lake Superior have not been determined. It is known, however, that the lake extended at least to the Kaministikwia River Basin back of Fort William, Ontario, and it may have extended considerably farther. It is probable that there was a protrusion of the ice into Keweenaw Bay at the time of greatest expansion of Lake Duluth, and the east end of the Keweenaw Peninsula may have been beneath the ice down to the time the Lake Duluth waters were drained eastward. (See fig. 7.) This idea was suggested by observations on the southeastern slope of the peninsula near Gratiot Lake, where the moraines fail to show strong lake action at the high levels at which it is displayed around Calumet, a few miles to the west. Whether the ice protruded into the lake between the Keweenaw Peninsula and Isle Royal or between Isle Royal and the Canadian shore depends upon the amount of iceberg formation that took place. The depth of water was in places more than 1,000 feet, or sufficient to favor the breaking off of icebergs. Whether the ice persisted on Isle Royal to the end of Lake Duluth time is not known. No part of the island rises high enough to record Lake Duluth shore lines.

BEACHES NEAR THE OUTLET

Lake Duluth formed several beaches in the vicinity of its outlet in Douglas County, Wis., which show little or no splitting of beaches as a result of differential uplift. These beaches, therefore, owe their difference in level mainly to the deepening of the outlet. The altitudes of

beaches crossed by the Duluth & Minneapolis branch of the Soo Line in western Douglas County, a few miles west-northwest from the head of the outlet, were determined on the ground with the railroad profile in hand. The upper limit of wave action, with a rather indefinite beach, is 1,100 feet above sea level, and strong gravelly beaches occur at 1,070-1,076, 1,040-1,044, and 1,017-1,022 feet. The floor of the outlet at the present divide north of upper St. Croix Lake in T. 45 N., R. 11 W., is 1,022 feet above sea level as determined by a canal survey by United States Army Engineers.[15] Here the floor has but a thin cover, scarcely 5 feet, of muck and peat. It is evident, therefore, that the beach at 1,017-1,022 feet is the lowest that could have opened into this outlet. It is possible that the faint shore at 1,100 feet is older than Lake Duluth and represents the work of Lake Nemadji. The gravelly beach at 1,070-1,076 feet is evidently the product of Lake Duluth, and this is 50 feet above the bed of the outlet. It is certain, therefore, that the outlet was deepened 40 to 50 feet during the life of Lake Duluth. If the weak shore at 1,100 feet pertains to Lake Duluth the deepening of the outlet was about 75 feet.

The present divide in the outlet is in a part of the channel that was cut in an outwash gravel plain just outside the limits of the outer morainic system of the Superior lobe. The gravel plain was built up to an altitude of about 1,140 feet in the vicinity of this divide north of Upper St. Croix Lake. This is higher than any of the shore work of Lake Duluth or of its small forerunners (if due allowance is made for subsequent differential uplift). Some trenching of the gravel plain, therefore, seems to have preceded the discharge of lake waters across it. Streams flowing direct from the melting ice edge might easily have produced the amount of trenching here displayed. It was not more than 40 feet at the time Lake Brule began its discharge. It may have reached 60 to 65 feet before Lake Brule gave place to Lake Duluth, and it was 110 to 120 feet at the end of the Lake Duluth discharge. There was markedly deeper excavation just south of the present divide in the part of the channel occupied by Upper St. Croix Lake. The bed of this lake is in places only 993 to 995 feet above sea level, and the lake may have been filled to some extent by wash into the basin since the Lake Duluth waters ceased flowing through the channel. The bed is 18 to 20 feet lower than the floor of the valley immediately south of Upper St. Croix Lake. The overdeepening here is, therefore, at least 20 feet. It occurs at a place where the outlet is only one-fourth to one-third mile wide, or scarcely more than half the usual width. It is but natural, therefore, that the outlet should have been scoured deeply when a stream of such great volume as was discharged by the expanded Lake Duluth was thus restricted.

[15] 54th Cong., H. Doc. 330, 1896.

BEACHES OF THE NORTH SHORE

Around the west end of the Lake Superior Basin there are usually three strong beaches with intervals of about 25 feet between them. They seem to correspond with the three observed on the Soo Line in western Douglas County, Wis. In the central part of the city of Duluth the highest of these beaches is about 1,135 feet above sea level and the lowest is not more than 1,085 feet. The series have an altitude here about 60 feet greater than on the south side of the basin, though the intervening distance is only about 24 miles. There thus appears to have been a northward differential uplift of 2.5 feet to the mile. A weak shore line is found at 1,160 feet above sea level in Duluth, which may be correlated with the weak shore at 1,100 feet on the south side of the basin in western Douglas County.

Near the west line of Lake County, Minn., the Duluth & Northern Minnesota Railroad crosses the highest well-defined beach of Lake Duluth at Higgins station at 1,165 feet above sea level, whereas the lowest of the Duluth series of beaches stands at about 1,110 to 1,115 feet. There is evidence of faint shore action at 1,190 feet. A similar series was noted east of Waldo, but only barometric readings were taken there. The same is true on a line from Beaver Bay westward to Beaver station, where the beaches are present west of a rock range as well as on its eastern slope. This full series does not seem to extend much farther northeast, and probably the highest strong line as well as the faint shore line above it terminated west of the moraine that runs into the Lake Superior Basin in eastern Lake County. To the east of this moraine, in the southwest end of Cook County, a road survey crosses the highest beach at 1,191 feet and one just below it at 1,175 feet. The next definite beach is at 1,126 feet, but it is doubtful if this beach belongs in the series made by the lake that discharged through the Brule-St. Croix outlet. The outlet may thus have been cut within 20 feet of its full depth before the ice had receded to this district east of the moraine.

Definite levels farther east are available on two lines. One is the survey of Poplar River, which reaches the highest shore at about the level of the dam, at 1,224 feet above sea level. The other line was run from Grand Marais by Axel Berglund, surveyor of Cook County, under the writer's direction, and reached the highest shore at 1,275 feet. There are strong gravelly beaches on the line by Grand Marais at 1,250 feet and at 1,206-1,209 feet. Beaches are faint from 1,200 feet down to 1,006 feet, where one thought to be the highest beach of glacial Lake Algonquin occurs. Barometric observations were taken on a prominent hill northwest of Hovland, in sec. 6, T. 62 N., R. 4 E., which made the upper limit of lake action fully 1,300 feet. There were beaches at short intervals on the slope below this level.

Observations were also made with aneroid barometer on McKay Mountain, south of Fort William, Ontario, which indicate lake action up to 1,350 feet above sea level, or about 200 feet below the top of the mountain. A beach was noted near milepost 57 on the Canadian Northern Railway, in the Kaministikwia River Basin, at an altitude of about 1,370 feet, and another west of Shabakwa station at about 1,300 feet, as well as lower beaches that

probably pertain to Lake Algonquin. The upper limits of Lake Algonquin here probably reach at least 1,100 feet above sea level. It is probable that the highest beach of Lake Duluth in Cook County, Minn., and in the Kaministikwia Basin in Ontario was formed after the outlet had been cut nearly to its full depth, or to what is now about 1,020 to 1,025 feet above sea level. In that case the amount of differential uplift between the isobase of the head of the outlet near Upper St. Croix Lake and Kaministikwia River is not far from 350 feet. This does not measure the total uplift, for the head of the outlet itself has suffered an uplift of perhaps 250 feet, the precise amount being as yet undetermined.

BEACHES OF THE SOUTH SHORE

At the extreme west end of the lake, in Carlton County, Minn., beaches of Lake Duluth are crossed by the Duluth & Moose Lake branch of the Soo Line at 1,062, 1,052, and 1,027 feet above sea level. The inner slope of the lowest beach drops down rapidly to 1,018 feet, and at that level the sand rests on a clayey till.

At Holyoke the Great Northern Railway profile shows the altitude of the highest beach as about 1,065 feet, with a bluff back of it rising to 1,075 feet. Other beaches are crossed at 1,050 feet and at 1,021-1,025 feet. The next railway to the east is the Soo Line, running south in western Douglas County, Wis. Along this line there is evidence of wave action up to 1,100 feet, but, as noted above, the definite beaches are at 1,070 to 1,076, 1,040 to 1,044, and 1,017 to 1,022 feet. The Duluth & Chicago branch of the Soo Line runs out of the Lake area in Douglas County in a valley, and the limit was not accurately determined. But on the Chicago, St. Paul, Minneapolis & Omaha Railway, which runs only about 2 miles farther east where it leaves the lake area, the upper limit of lake action seems to be at 1,118 feet. As a faint beach at Hines is 1,113 feet above sea level, the limit of 1,118 feet may mark storm levels rather than the ordinary stage. A strong beach at 1,085 feet is crossed by the Northern Pacific Railway at Wiehe, 10 miles farther east. Above this are notches on the slope of a moraine near Maple at 1,106 and 1,128 feet. There are beaches at about 1,060 and 1,040 feet just south of this railroad near Poplar. The Chicago, St. Paul, Minneapolis & Omaha Railway from Ashland to St. Paul crosses the Duluth beaches near Grandview (Pratt post office), Bayfield County, and reaches the highest gravelly beach at 1,080 feet. There are notches higher up, on morainic knolls, at 1,100 and 1,120 feet. In the village of Grandview the Duluth beaches are finely exhibited at 1,055 to 1,060 feet and at 1,075 to 1,080 feet. The Soo Line from Ashland to Milwaukee crossess the Duluth beaches between Highbridge and Coria, Ashland County. These beaches were examined by the writer after the new survey of this line had been made and while the figures that had been painted on posts along the right of way to show the altitudes were still preserved. A beach that is referred to glacial Lake Ashland was noted at 1,123 feet, with a storm beach at 1,128 feet. The highest gravel beach of Lake Duluth is at 1,102 feet and the base of the cut bank back of it at 1,107 feet. A sandy ridge at the southeast end of Coria switch is at 1,091 feet. The next strongly marked shore line below this is at 1,038-1,040 feet near Davis switch. There is a beach at 1,015 feet nearly a mile east of Highbridge, but this seems rather low to belong to the Duluth series. It is, however, well defined. The main street in Highbridge is on a beach ridge at 990 feet. There are no definite beaches between this one and the highest shore line of Lake Algonquin, near South York, at 860 feet, though there are faint shore lines in this interval.

At Bayfield the exhibit of beaches is especially full because of the exposed situation. The highest beach of Lake Duluth, as determined by F. T. Thwaites, who ran a line of spirit levels up to it along the main highway from the Lake Superior shore, is 1,148 feet above sea level. It is a gravelly bar at that place, but usually it is a cut bluff, as are also lower shores. The present writer ran a line of hand levels across the series farther east in private roads and through fields and found the upper limit at 1,153 feet and lower beaches at 1,130, 1,075, 1,055, 1,035, 995, 972, and 915 feet (the last the highest beach of Lake Algonquin). Thwaites noted beaches at 1,148, 1,119, 1,067, 1,042, 1,012, 993, 962, and 915 feet (the last the highest of Lake Algonquin). The error in hand levels is very slight, amounting to less than the variation usually displayed by a single beach. Some lack of correspondence is due to the development of a cut bank in one place at a level where one was not developed in the other.

On the inner or north slope of the moraine north of Saxon, Wis., the highest beach of Lake Duluth, is at about 1,115 feet above sea level. There is a second beach at about 1,104 feet. Lower beaches are very indefinite and probably lower than the Brule-St. Croix outlet. In the northern peninsula of Michigan the level of the highest beach has been determined at several points west of the Keweenaw Peninsula, and the topographic maps of the Houghton and Calumet quadrangles serve to show the limits on part of that peninsula. A line of levels by the Michigan Geological Survey in the Porcupine Mountains, as reported by A. C. Lane, makes the highest beach at 1,163 feet in sec. 15, T. 51 N., R. 43 W. The highest beach has the same altitude where crossed by the Chicago, Milwaukee & St. Paul Railway 1 mile south of Pori. An isobase connecting these places trends about N. 74° W., thus making the tilt line N. 16° E. in this part of the Lake Superior Basin. The upper limit of Lake Duluth is somewhat definitely known at Bruce Crossing and Ewen, 1,134 feet; Rockland, 1,178 feet; Greenland, 1,192 feet; Twin Lakes, near the Winona mine, 1,215 feet; the Taylor mine switch, south of L'Anse, 1,215 feet; near Toivola, 1,240 feet; near Mill Mine Junction, 1,250 feet; and on Centennial Hill, in Calumet, 1,305 feet. An isobase for 1,215 feet connecting the Taylor mine switch and Twin Lakes bears N. 58° W., thus giving the tilt line a bearing N. 32° E. This isobase projected across Lake Superior strikes the

north shore near Lutzen, where the highest beach is at 1,224 feet. It is also about in harmony with the isobase of the Nipissing Great Lakes for this same district.

In numerous places lower shores of the Lake Duluth series and of the transition to Lake Algonquin are well displayed. It is only in the Calumet and Houghton quadrangles, however, that much effort was made to determine their altitudes. The facts that these beaches have been tilted 2 feet or more to the mile and that shores are found at slightly different altitudes in neighboring places, as shown above in the Bayfield records, make it difficult to establish correlation except by continuous tracing. Such work is impracticable in much of the area because of its brushy conditions In exposed situations, as on the northwest slope of the Keweenaw Peninsula, there is a beach for about every 20-foot interval, and in places the interval is but 10 or 15 feet. But in protected situations there is only here and there a shore feature distinct enough to be easily recognized or followed.

GENERAL CHARACTER OF THE LAKE BED

Wherever the bed of Lake Duluth has a plane surface the prevailing soil is a heavy red clay with few pebbles, covered by remarkably little sand or loose-textured material. The clay is sufficiently calcareous for the development of numerous calcareous nodules, and there are a few limestone pebbles embedded in it. Were there no limestone pebbles the nature of the clay might seem to be due entirely to the precipitation of calcium carbonate from the lake. But their presence indicates that some of it is due to glacial agencies that brought in calcareous material from limestone areas. The source of the limestone pebbles is not fully determined. They may have been brought in wholly or in part from the northwest at a pre-Wisconsin glacial stage. Or they may have been brought in from the James Bay region by a movement in the Illinoian or the Wisconsin stage. There is also a possibility, if not a probability, that some limestone outliers, such as the one west of Baraga in the Keweenaw Basin, were distributed here and there over the region and that they have supplied calcareous material. Chert derived from limestone is a common feature in the drift over nearly the whole of the area bordering Lake Superior on the south. Some of the calcareous material is probably due to the precipitation of calcareous sediment on the lake bed during the period of lake occupancy. On rough areas that were covered by the lake, such as the slopes of the Bayfield and Keweenaw Peninsulas and much of the north shore, the soil is largely stony till, with only a small amount of the red clayey till at the surface. The stony till in places rests on a red clayey till somewhat similar to the red clay in the lake bed. The beaches of Lake Duluth on the entire circuit of the lake are developed on this stony till, the red clayey till generally not being conspicuous above the lowest of the beaches that open into the Brule-St. Croix outlet. For this reason they are gravelly and sandy ridges, with only here and there a cut bank. In very exposed situations, however, as in the Bayfield and Keweenaw Peninsulas, cut banks are common features, and they connect with bars built out into the recesses of the old shore.

At a few places the shores were of bare rock with-insufficient drift cover to be shaped by the waves. Such places, however, embrace scarcely 1 per cent of the old coast. It is usually not difficult to trace the limits of lake action across these, rock areas by pebbly deposits built in the coves and by the clearing out of earthy material from cracks and openings in the rock surface as a result of wave action. On the whole, the shore records are clear, and it is only because of the brushy condition of the land surface that they have not been traced through continuously.

THE DIFFERENTIAL UPLIFT

The entire area of Lake Duluth was subject to tilting in late Pleistocene time, and it seems probable that the head of the outlet now stands about 250 feet higher than at the time the lake discharged through it. It was hoped that the study would clear up definitely the part of Pleistocene time embraced in this uplift, expressed in terms of lake history, as has been done in the basins of the lower Great Lakes. The complexity of the shore lines of the western part of the Lake Superior Basin, which are coupled partly with the shore lines of the forerunners of Lake Duluth and partly with the recession of the ice step by step while the outlet was in process of deepening, makes it difficult even to set off by themselves the beaches that open into the Brule-St. Croix outlet, much less to determine whether uplift and splitting of beaches had begun before the outlet had shifted to the east. As indicated in the description of the shore lines, the full series of the Lake Duluth features seems not to extend on the north shore to the east edge of Lake County, Minn., and on the south it may not pass around the north end of the Bayfield Peninsula. It seems advisable, therefore, to take only this restricted district into consideration in the first step toward the determination of the tilting of the shore lines. In part of this district the shores of Lake Nemadji have to be separated from those of Lake Duluth.

The uplift of the Lake Duluth beaches on the north shore may be determined by considering the rise of the lowest member as well as the rise of the highest. In some respects the lowest is of chief importance, for it is sure to be related to a definite height of the outlet—namely, the height at the time when it came to be abandoned. The highest shore line is not so easily correlated with a given altitude of the head of the outlet.

If, then, we take the lowest of the Lake Duluth shore lines we find it rising from about 1,022 feet above sea level at the southwest end of the lake in Carlton County, Minn., to about 1,115 feet on the meridian of Two Harbors, near Higgins, in western Lake County, a distance of 55 miles in a direction N. 50° E., or 20.4 inches to the mile. The direction of maximum tilting,

however, in the highest well-defined beach in the part of the Lake Superior Basin west of the Bayfield Peninsula seems to be about N. 20° E., or at a right angle with the 1,135-foot isobase connecting Duluth, Minn., and Bena, Wis. (See fig. 8.) In a direction N. 20° E. from the isobase of 1,022 feet in the lowest beach opening into the St. Croix outlet to the 1,115-foot or corresponding beach near Higgins the distance is 44 miles, which makes the rate of tilting 25.63 inches to the mile. The isobase of 1,022 feet, like that of 1,070 feet for the highest beach, runs near the head of the outlet. There is a rise in this lowest beach of 55 feet (to 1,077 feet) in the first 22 miles from the isobase of the outlet to the isobase running from Duluth to Bena, or 30 inches to the mile, and only 38 feet (to 1,115 feet) in the 22 miles from that isobase to Higgins, or 20.73 inches to the mile. From this isobase opposite Higgins to one passing through the beach on the highway west of Schroeder at 1,175 feet there is a rise of 60 feet in 42 miles, or 17 inches to the mile. In Cook County, as shown by Figure 8, the tilt line trends about N. 30° E. From the highway west of Sehroeder to Grand Marais on a tilt line of N. 30° E. the rise of 34 feet to 1,209 feet is made in 30 miles, or at a rate of 13.6 inches to the mile.

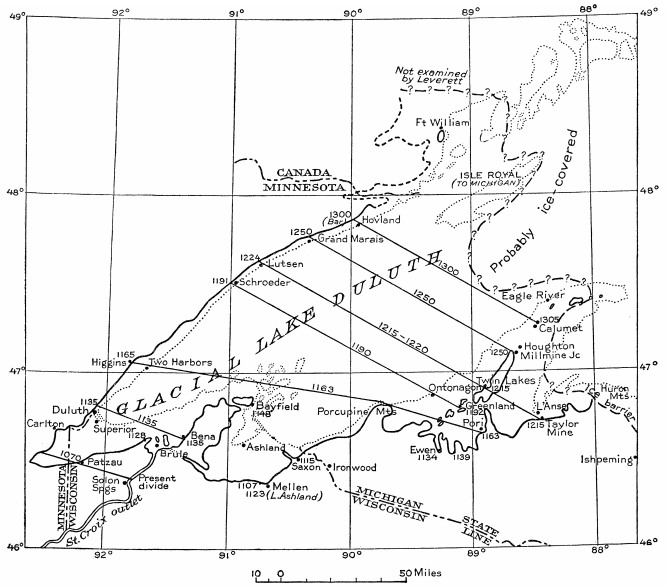


FIGURE 8.—Map showing isobases of the highest beach of glacial Lake Duluth. Figures indicate altitude above sea level.

The highest beach in Cook County, Minn., and that on the part of the northern peninsula of Michigan with corresponding isobases (fig. 8) probably represent one of the intermediate beaches of the west end of the lake basin, but they show a markedly higher rate of rise toward the north-northeast than the lowest Lake Duluth beach in this part of the Lake Superior Basin. Uplift was thus in progress there before the lowest beach was formed. At the highest beach in Cook County, Minn., the rise from the beach at 1,191 feet on the highway west of Schroeder to that on Poplar River is 33 feet in 13.3 miles, or 30 inches to the mile along the course of the beach. The rate would be about 3 feet to the mile if calculated along the tilt line. The rate is nearly as great from Lutsen to Grand Marais and to a hill northwest of Hovland, where the highest beach is about 1,300 feet above sea level by barometric measurement. The available data suggest that the rate of uplift is not so high in the adjacent part of Canada. If the tilting were continued at this rate to the Canadian Pacific Railway the highest beach at the railway should be about 1,450 feet above sea level, but the highest one noted there is at 1,370 feet. The highest beach there may, however, be a lower member of the series than the highest beach in Cook county, for it stands in the direction of the recession of the ice border and may have been covered with ice at the time the highest beach in Cook County was forming.

The amount of the uplift at the head of the Brule-St. Croix outlet is roughly calculated by determining the amount of uplift of the neighboring Lake Algonquin beach. Near the isobase of the Brule outlet the Lake Algonquin beach stands at about 850 feet. The altitude of the Port Huron outlet of Lake Algonquin is 605 feet. The uplift of the Algonquin beach on the isobase of the outlet of Lake Duluth is therefore about 245 feet. The uplift of the head of the Brule-St. Croix outlet is at least that much, and if some uplift took place before the Algonquin beach was formed it is that much more. It is doubtful, however, whether much uplift took place until the time of Lake Algonquin. We may therefore provisionally leave the amount at about 245 feet. Deducting this from 1,022 feet, the present altitude of the head of the outlet, we have 777 feet as the altitude of the outlet when it was in operation. It is probable that the uplift affects St. Croix River at least as far down as St. Croix Falls, but with diminishing amount downstream. The river below the falls is now 687 feet above sea level. At the mouth of Trade River, 12 miles upstream, it is at 753 feet. The distance by stream from the outlet of Upper St. Croix Lake to the mouth of Trade River is 101 miles and that from the divide north of the lake is about 105 miles. There may have been only 24 feet of fall in that distance before the uplift occurred. The Kettle River rapids head 33 miles above the mouth of Trade River and now stand 850 feet above sea level. It is not unlikely that a considerable part of the estimated fall of 24 feet took place at these rapids and that the outlet was cut to a very low grade down to that point. The rapids may have been as high as 770 feet, or within 80 feet of their present altitude. By whatever amount the St. Croix Falls have been uplifted the fall of the stream must have been greater than 24 feet. There is now a descent of 15 feet in the 20 miles from the foot of the falls to the mouth of Apple River. This may be largely a result of uplift. If we assume an uplift of 15 feet in 20 miles and extend the estimate up to the mouth of Trade River, 12 miles farther, we have not less than 25 feet of uplift there. In that case the fall would have been 49 feet instead of 24 feet between the head of the outlet and Trade River. This would give room for the rapids at Kettle River to have had some prominence during the operation of the outlet.

On the Keweenaw Peninsula and in Keweenaw Bay and on its eastern border the trend of the tilt line seems to be about N. 30° E. The rate of tilting seems to be somewhat uniform at about 2.7 feet to the mile from Ewen or Bruce Crossing to Calumet, a distance of 63 miles. Intermediate points, such as Greenland, Twin Lakes, and Toivola, fall into the plane almost exactly.

To the west, between the Porcupine Mountains and Keweenaw Peninsula, the tilt line seems to trend about N. 17° E., and it is similar in the district westward from the Porcupine Mountains to the Bayfield Peninsula and as noted above about N. 20° E., between the Bayfield Peninsula and the northwest shore of the lake. The axis of tilting appears to curve toward the south in passing to the southwest end of the basin. Thus the southeast shore appears to have experienced a more rapid rate of uplift than the northwest shore, and the isobases converge in passing from the northwest shore to the southeast, as indicated in Figure 8.

It will be a matter of much interest to determine whether this differential uplift is in correspondence with ice weighting, the greater resilience being where depression by ice weighting was greater. It is very probable that the district northwest of Lake Superior, being at the west edge of the Labrador ice field and at the east edge of the Keewatin ice field, was subject to very slight ice weighting in the part of the Wisconsin stage under discussion, which followed the withdrawal of the Patrician ice sheet. On the other hand, the southeast shore of the lake was subject to converging ice movements and a resulting heaping of ice. The ice was moving southward in the district west of the Keweenaw Peninsula and southwestward to westward in the district east of the peninsula. There is thus enough correspondence between the ice accumulation and the degree of uplift at least to suggest causal relationship.

TRANSITION FROM LAKE DULUTH TO LAKE ALGONQUIN

The strong movement of the ice up the slope to the Huron Mountains and the district to the southeast prevented the lowering of the waters in one single drop to the level of Lake Algonquin. Instead there was at first border drainage at levels but little below the Brule-St. Croix outlet. Lower and lower passages for border drainage were opened from time to time as the ice melted back. But we may infer from the strength of the beaches formed in the western part of the Lake Superior Basin at levels between the Lake Duluth and Lake Algonquin shores and controlled by the level of the heads of border drainage channels that the ice margin may have held a given position for considerable time.

The water reached the Lake Michigan Basin and swelled the lake in that basin. It is probable that at first the water was poured into Lake Chicago, for it is doubtful if the ice had melted away from the district south of the Straits of Mackinac sufficiently to allow the waters of Lake Algonquin of the Lake Huron Basin to become confluent with Lake Chicago and thus initiate the greater Lake Algonquin. Eventually, however, this connection was opened and Lake Algonquin took possession of the Lake Michigan Basin as well as the Lake Huron Basin. The part of the northern peninsula between Lake Michigan and Lake Superior and the eastern part of the Lake Superior Basin were still occupied by the ice when this occurred.

There seems to have been a brief period when the flow from the Lake Superior Basin went southward through the Au Train-Whitefish Valley while the ice was still occupying the part of the south shore of Lake Superior to the east. It is probable that the waters were not brought to the level of Lake Algonquin in the Lake Superior Basin until the withdrawal of the ice from that part of the Lake Superior shore.

The courses of the border drainage channels have been followed for short stretches and crossed at frequent intervals, but a complete tracing has not been attempted. Contour maps and careful leveling in the district traversed by these channels are needed to serve as a basis for definite correlation of channels.

In places near Marquette there are faint shore lines that were formed at levels higher than the Algonquin water plane. One of these at 985 to 990 feet was traced from Dead River in sec. 7, T. 48 N., R. 25 W., southeastward to the Mount Mesnard Range, south of Marquette. Its precise altitude was determined on some knolls in the southern part of section 21 by reference to the United States Geological Survey bench mark near by and found to be 985 feet. The altitude seems to increase slightly toward the north-northwest and to be not less than 990 feet in section 7, where tracing began. The same shore line was noted also north of Dead River, where a road running west in the southern part of section 6 crosses it just below the 1,000-foot level. It can be traced but little farther, as rock hills set in on whose slopes there was scarcely enough drift material to allow the waves to form a beach. The only direction in which the body of water that formed this shore line could have discharged was eastward, and the outlet must have been north of the "Calciferous" escarpment in eastern Marquette County and western Alger County, for the escarpment rises above 1,000 feet. On the Marquette-Alger county line it could not have been farther south than the north edge of secs. 11 and 12, T. 46 N., R. 23 W., or about 6 miles from the shore of Lake Superior. The course was probably eastward from that point across the northern part of T. 46 N., R. 22 W., and thence southeastward into the Au Train-Whitefish lowland to the lake in the Lake Michigan basin. These lake features above the Lake Algonquin plane near Marquette seem to show that the ice was still occupying part of the south shore of Lake Superior farther east. Otherwise the Lake Algonquin water level would have extended to Marquette.

Below the shore line just noted near Marquette there is a slight wave-cut notch near the 940-foot level, but the first strong well-defined shore line in the Marquette

quadrangle is 20 feet lower, or near 920 feet. This may be the highest Lake Algonquin beach.

To the east of the Au Train-Whitefish lowland, in the vicinity of Munising and Wetmore, lake features were noted at levels that seem to be higher than the Lake Algonquin plane. Accurate levels were run to these lake features north and south from Wetmore station by L. G. Hornby under the writer's direction. To the south, on the north slope of a table-land known as Scaffold Hill, there seems to have been wave action up to an altitude of 960 feet. This may, however, mark the storm beach, and the low-water level may be represented in a beach 10 or 12 feet lower, or 948 to 950 feet above sea level. North of Wetmore, in section 12, about a mile from the railroad station, a weak gravelly bar was found at 950 feet and another at 946 feet. Gravelly bars at 929 feet, at 903-904 feet, and at 879 feet were crossed in running northward from Wetmore station. The surface has a wave-washed appearance up to fully 950 feet in the district between Wetmore and the Lake Superior shore at Munising. In the southern part of Munising, less than a mile from the shore of Lake Superior, levels run by the Cleveland Cliffs Iron Co., showed that a ridge with an altitude of 966 feet is notched on its north slope about 5 or 6 feet lower, or about 960 feet above sea level. Morainic hills within 1 or 2 miles southwest of Munising rise to fully 1,000 feet and others east and southeast equally near the shore to about 1,000 feet. They are hummocky and irregular from the crests down to an altitude of about 950 or 960 feet, below which the surface is much smoother and seems to have been wave-washed.

The highest points on Grand Island, which stands in the bay north of Munising, are about 950 feet above sea level and consist of nearly bare limestone. The scarcity of drift seems likely to be due to removal by wave action, as the ledges are subject to attack from all directions. A beach of gravelly material is crossed by the Cleveland Cliffs driveway in the northern part of the west shore of the island at an altitude of 885 feet. This fits in well with the altitude of the highest Lake Algonquin beach farther east, whereas the higher beaches just noted seem to be above the Lake Algonquin water plane. A beach at 875 to 880 feet both north and south of Anna River at Wetmore may be the highest one of Lake Algonquin there.

In order to account for a water body being held up to the high level of 950 to 960 feet near Wetmore and Munising, it seems necessary to assume that the ice was still present in the great Manistique Swamp, to the east and southeast. It also seems probable, as already indicated, that the Scaffold Hill table-land stands in a recess in the ice border, the ice having been on the east as well as the north when this table-land was formed as an outwash plain. If the ice on the north disappeared earlier than that on the east the waters would have been ponded where these lake features occur. The most probable line of discharge would have been through the Au Train-Whitefish lowland. This lowland may thus have been a line of discharge for ponded waters over the whole interval from Marquette to Munising. The beach at 985 to 990 feet above sea level in the vicinity of Marquette may pertain to a lake that had a narrow line of discharge between the ice and the "Calciferous" escarpment in eastern Marquette County and western Alger County, with enough fall in this line of discharge to bring it down to the level of a lake at 950 to 960 feet around Munising. Or this lake near Marquette may have slightly antedated the melting of the ice from the Munising region.

GLACIAL LAKE ALGONQUIN

The name Lake Algonquin was first applied by J. W. Spencer[16] to a lake occupying the southern part of the basin of Lake Huron and the tributary Saginaw Basin. The lake, as shown in Plate 7, discharged southward past Port Huron through St. Clair River, Lake St. Clair, and Detroit River to Lake Erie. The northern part of the Lake Huron Basin and Georgian Bay were still occupied by the ice sheet, and the ice covered the northern part of the southern peninsula of Michigan between this lake and Lake Chicago, in the Lake Michigan Basin. With the melting away of this ice barrier the two water bodies came to the same level. At about the same time the ice front was melted back sufficiently in the Georgian Bay Basin to open an eastward outlet past Kirkfield, Ontario (pl. 7 and fig. 9), and down Trent River to the Lake Ontario Basin, which was somewhat lower than the outlet past Port Huron, but how much lower has not been determined. This change of outlet appears to have drawn down the waters of the Lake Michigan Basin as well as the Lake Huron Basin. The eastward outlet was maintained for a long time, perhaps until the ice had disappeared from the northern peninsula of Michigan and the waters of the western part of the Lake Superior Basin had been brought to the level of the lake in the Huron and Michigan Basins. An uplift that raised this eastward outlet and returned the discharge to the southward outlet appears to have occurred in the midst of the Lake Algonquin stage rather than near its beginning.

[16]Am. Assoc. Adv. Sci. Proc, vol. 37, p. 199, 1889.

The highest shore line of Lake Algonquin to the south of the Kirkfield outlet and its isobase is not the one that opens into that outlet, for this shore became submerged when the tilting raised the water to the level of the Port Huron outlet. The waters to the north of the Kirkfield outlet probably dropped away from the highest shore of that region at the same time they were rising from the Kirkfield outlet to the Port Huron outlet. In the absence of definite data as to the amount of uplift that was necessary to raise the water from the Kirkfield to the Port Huron outlet it is not possible to determine which shore line to the north of the Kirkfield outlet is to be correlated with the beginning of the discharge through the Port Huron outlet.

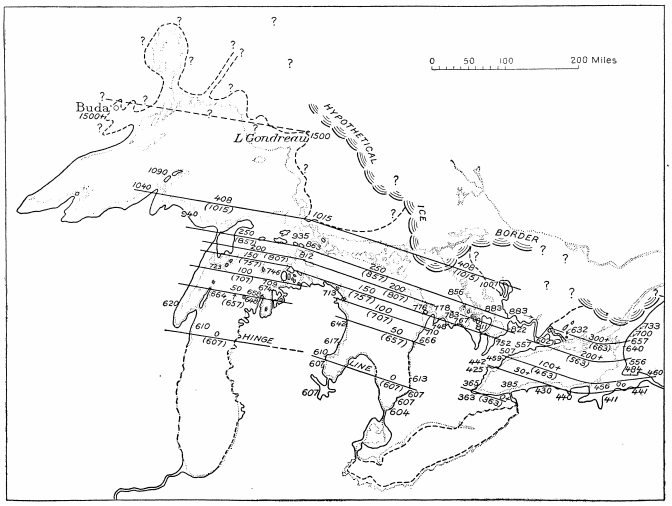


FIGURE 9.—Map showing isobases of glacial Lake Algonquin at its highest stage and isobases of glacial Lake Iroquois as represented by Goldthwait. The figures above the isobases indicate altitude above the horizontal or unaffected part of the beach south of the hinge line; the figures in parentheses below the isobases and the scattered figures elsewhere indicate altitude above sea level.

It is probable that when the waters were raised from the Kirkfield outlet to the level of the Port Huron outlet they were also raised sufficiently at the south end of the Lake Michigan Basin to cause some outflow through the Chicago outlet. The main discharge, however, seems to have been through the Port Huron outlet, and this became deepened to a level below that of the head of the Chicago outlet.

The part of Lake Algonquin in the Lake Huron and Lake Michigan Basins has been discussed in Monograph 53. Attention is therefore given here to the part that encroached upon the northern peninsula of Michigan and the border of the Lake Superior Basin in Michigan, Wisconsin, and Minnesota. There are so few data available on the Lake Algonquin shore lines in the Canadian part of the Lake Superior Basin that it can not be adequately treated at this time. It was shown in Monograph 53 that the Lake Algonquin beach is a single strong line in the Saginaw Basin, in the part of the Lake Huron Basin between the Saginaw Basin and Port Huron, and in the Lake Michigan Basin as far north as Manistee, Mich., and Two Rivers, Wis. North of the Saginaw Basin and the points named in the Lake Michigan Basin the shore features become more and more complex. Within a short distance three or four distinct ridges become traceable, which at first differ but little in altitude but which become more widely separated toward the north and also more numerous. In the northern part of the northern peninsula there are half a dozen or more distinct shore lines, all referable to Lake Algonquin.

At the top of the series are usually two or three ridges that are especially strong and continuous which are separated by intervals of but 5 to 10 feet. Below this strong series the ridges are more widely spaced and usually weaker and less continuous. They appear to have been formed while uplift was going on most rapidly, whereas the ridges at the top were developed before rapid uplift had set in, and their separation may be due in part to the cutting down of the outlet. The lowest member of this upper series may be the one that should be correlated with the single strong beach that leads to the Port Huron outlet and to the Chicago outlet. It seems probable, also, that the western part of the Lake Superior Basin had become connected with Lake Algonquin by the time this strong series was completed. On the whole, the Lake Algonquin beaches in the western part of the Lake Superior Basin are weak and widely spaced, as if they might have been formed during the time of rapid uplift. On the south border of this part of the basin there is a stiff clay on which sandy and gravelly material is very scanty, and the shores there are generally marked by slight notches in the clayey slope. On the north side of the Lake there was a large amount of gravel and cobble to be worked into beaches, and the beaches are more distinct than those on the south shore, yet even there they are in general widely spaced and appear to have been developed while rapid uplift was in progress.

From the west end of the Lake Superior Basin eastward to the Au Train-Whitefish outlet the limits of Lake Algonquin are found to lie only a short distance from the present Lake Superior shore. The lake extended into the Nemadji Basin only about to the Wisconsin-Minnesota State line, or scarcely 20 miles beyond the present head of Lake Superior. Its north shore throughout its course in Minnesota stood but 1 to 3 miles back from the present Lake Superior shore. From Superior, Wis., eastward around the Bajmeld Peninsula to Ashland, Wis., the distance of Algonquin limits from the present lake shore ranges from a mile or less at Bayfield up to 6 or 7 miles. In the Bad River drainage basin, southeast of Ashland, the lake reached back in places 18 or 20 miles from Lake Superior. The limits were very close to the Superior shore from the Wisconsin-Michigan line eastward past the Porcupine Mountains. From these mountains northeastward to the Portage Canal the lake limits are 6 to 12 miles back, but from the canal eastward to the end of the peninsula they are closer. The lake covered the entire width of the peninsula at the Portage Channel and also at the Allouez Gap. On the east side of Keweenaw Peninsula the greatest extension was at the head of Keweenaw Bay, where it reached 20 miles to the southwest. From Keweenaw Bay eastward to the Au Train-Whitefish lowland the limits were from 1 to 6 miles back from the Lake Superior shore.

The limits of Lake Algonquin are less definitely known in the uninhabited districts of northeastern Delta County and adjacent parts of Alger and Schoolcraft Counties, Mich., but it is thought that an aggregate area of about 200 square miles in this region may have stood above the Algonquin level. From Munising eastward across eastern Alger County and northern Schoolcraft County into Luce County the amount of land standing above Lake Algonquin has not been determined. In this district

there are extensive outwash plains which are slightly below 900 feet at their northern edge, and they may be not far from the Algonquin level.

In Schoocraft, Luce, Mackinac, and Chippewa Counties there was only a few square miles that stood above the level of Lake Algonquin. There were small islands south of McMillan, south of Newberry, between the Hendricks quarry and Rexton, and along the high escarpment in northern Mackinac County and east of Trout Lake in Chippewa County. At the highest stage of Lake Algonquin there may have been an island of considerable extent in the high area south of Whitefish Bay. There certainty was a large island there when the lake level had been lowered a few feet.

The shore lines of Lake Algonquin show a rapid rise northward in the area between the Huron and Michigan Basins and the Lake Superior Basin. Thus the upper limit of lake action on Mackinac Island is at 809 feet above sea level; on St. Joseph Island, at 934 feet, with a storm beach at 940 feet; and about 5 miles north of Sault Ste. Marie, Ontario, at 1,015 feet. This gives a rise of 206 feet in a distance of about 52 miles or practically 4 feet to the mile. The altitude is about 930 feet near Rexford station, or practically the same as on St. Joseph Island. An isobase drawn from Rexford to St. Joseph Island bears about 15° south of east, thus making the trend of the tilt line N. 15° E. This isobase is 32 miles from Mackinac Island, there being thus a rise of about 125 feet in that distance, or nearly 4 feet to the mile. In the district north of the isobase the rise is 85 feet in 20 miles to the shore lines north of Sault Ste. Marie. The rate of tilting is thus but little greater to the north of the Rexford-St. Joseph isobase than to the south. The line from Mackinac Island to the shore north of Sault Ste. Marie falls very close to the direction of maximum tilting, N. 15° E.

The tilt line appears to trend nearly north in the part of the northern peninsula of Michigan from Marquette eastward about to Whitefish Bay. There are, however, places in which the shore lines fail to come up to the general plane. For example, in the vicinity of Rexton there is definite shore work up to nearly 900 feet above sea level, but at McMillan, about 30 miles to the northwest, the highest shore work seems to be about 30 feet lower, or between 860 and 870 feet. To fit the plane it should be well above 900 feet. The shore work east of Trout Lake is also about 30 feet too low to fit the plane. This discrepancy might be accounted for if the ice covered the district around McMillan and Trout Lake to a later time than at Rexton, so that the highest beach at Rexton is not represented at these other places, but it is difficult to find anything to support this explanation unless the ice persisted as stagnant ice in the low areas immediately north of McMillan and along the Soo Line east from Trout Lake. A few miles farther northwest than McMillan on the road leading from Seney to Grand Marais shore features are found to come up about to the general plane, or to more than 900 feet.

The most remarkable rise in the upper shore line that has yet come to notice is found along the border of the Au Train-Whitefish Valley. From a point near the Delta-Alger county line northward to Chatham there is a rise of 93 feet in a distance of 13.5 miles, or about 7 feet to the mile. In the southern 8 miles of this line the rise is 65.5 feet, or slightly more than 8 feet to the mile, and in the northern 5.5 miles the rise is 27.5 feet, or 5 feet to the mile. This most rapid rate of tilting is in a narrow passage only 1 to 11/2 miles wide. Farther north, where the rate is lower, the waters had greater width.

The rate is still lower in Delta County south of this narrow strip. The rate of rise from Brampton to the Delta-Alger county line is about 3 feet to the mile. It is possible that the highest shore action in this narrow strip and the district to the north occured at a transition stage in the course of the lowering of the waters from Lake Duluth to the Lake Algonquin level, for this lowland seems likely to have carried the discharge from such a transition lake southward to the Lake Michigan Basin. The passage may at first have been obstructed by drift deposits in southern Alger County, so that in cutting through this barrier there may have been considerable descent. In that case the uplift may turn out to be consistent with that shown to the north and to the south of this narrow part and to be between 3 and 5 feet to the mile.

The rise of the highest Algonquin shore along the west side of the Green Bay Basin increases in rate from south to north. In the 50 miles from Menominee to Ford River at Newhall the rise is 75 to 80 feet, or about 11/2 feet to the mile. From Newhall to the north line of Delta County there is a rise of about 95 feet in 32 miles, or practically 3 feet to the mile. The trend of the shore is very nearly in the direction of the tilt line, as determined by drawing isobases from the highest Algonquin shore west of Green Bay to the highest shore on the peninsulas and islands east of the bay. The altitudes on the Wisconsin islands and peninsula were determined by J. W. Goldthwait by wye level, and those on the Michigan slope by W. H. Hobbs,but those on the west side of Green Bay, by the present writer, are chiefly from railroad surveys.

The altitudes of the Lake Algonquin shores are accurately determined in the Marquette, Houghton, and Calumet quadrangles. In the Marquette quadrangle Algonquin shore action and corresponding stream deltas are conspicuous at 920 feet, but shore action is more obscure at higher altitudes. There is, however, a shore at about 940 feet and one at about 990 feet, each traceable for several miles in the southwestern part of the quadrangle. The shore at 990 feet is evidently above the Algonquin plane, and the one at 940 feet may be also.

The highest Algonquin beach is between the 1,000 and 1,020 foot levels at the south edge of the Houghton quadrangle but rises to 1,042 feet at the Isle Royale mine, a mile south of Houghton, and to 1,080 feet directly west of Calumet. It is at 1,095 to 1,100 feet near

Mohawk and at 1,110 feet at the north edge of the Calumet quadrangle, west of Cliff. Near the Central mine it is above 1,120 feet. Throughout its course in the Houghton and Calumet quadrangles it is an exceptionally strong beach. Where cut into steep slopes the bluff back of it is in places 15 to 20 feet high, but more commonly it is a gravelly ridge with a deposit several feet in depth. The highest Lake Duluth beach developed on this peninsula stands 200 to 220 feet above the highest Lake Algonquin beach. These beaches seem to run nearly parallel across these quadrangles, and the interval between them is no greater at the north than at the south edge. Each shows a rise of about 100 feet in 33 miles in a north-northeast direction.

There are but few accurate measurements of the highest Algonquin beach in the western part of the Lake Superior Basin. The Soo Line, running southeastward from Ashland, Wis., crosses it near North York at 860 feet above sea level. At Bayfield, Wis., a line of levels run by F. T. Thwaites crosses the beach at 915 feet and levels on Oak Island, also run by Thwaites, cross it at 926 feet. Oak Island is about 40 miles nearly due north of North York, and the northward component of uplift, 66 feet in 40 miles, is thus about 20 inches to the mile. The rate of rise is slightly higher across Lake Superior from Oak Island to Grand Marais, Minn., a distance of about 60 miles in a course slightly east of north. The measured altitude of the highest Algonquin beach at Grand Marais is 1,042 feet, and there is thus a rise of 116 feet in 60 miles, or a little less than 2 feet to the mile. Near the west end of the lake the altitude on the south shore is 850 to 855 feet. On the north shore it rises from about 860 feet near Fond du Lac to 880 feet in the main part of Duluth and 910 feet near Knife River. At Amnicon Falls, which is about 28 miles nearly south of Knife River, the altitude of the highest Algonquin shore is 855 feet, or 35 feet lower than near Knife River. The rate of tilting here is thus very similar to that between Oak Island and Grand Marais, or slightly less than 2 feet to the mile. The data are not sufficient to determine the precise direction of the tilt line, but such as are available suggest that it is but little east of north and about the same as that of the shores of Lake Duluth. (See figs. 7 and 8.)

TRANSITION FROM LAKE ALGONQUIN TO THE NIPISSING GREAT LAKES

BATTLEFIELD BEACH

The expansion of Lake Algonquin continued as the ice front was gradually melted back until it reached eastward beyond Georgian Bay as well as northward over much if not all of the Lake Superior Basin. From the east end of Georgian Bay a lowland extends past North Bay into the Ottawa Valley. It is 600 to 800 feet lower than the bordering uplands and several miles in width. On its north side are large tributary valleys, which may have served as passages for ice tongues extending southward from the main ice sheet after its border had receded a few miles on the uplands north of the Ottawa Valley. It has been suggested by F. B. Taylor[17] that the Ottawa Valley may have afforded an outlet eastward around the south ends of these ice tongues by which the waters of Lake Algonquin were drawn down below the level of the Port Huron outlet, and that the Battlefield and Fort Brady beaches, which stand a few feet above the level of the Nipissing beach, may have been formed while the discharge was eastward past these ice tongues. With the complete withdrawal of the ice from the Ottawa Valley the water was drawn down to the Nipissing level.

The name Battlefield was applied by F. B. Taylor to a beach on Mackinac Island that traverses an old battlefield. This beach stands 130 to 135 feet above Lake Huron, or 710 to 715 feet above sea level. It is about 70 feet above the Nipissing beach and 30 to 35 feet below the lowest Algonquin beach. When traced southward on the borders of the southern peninsula it is found to drop less rapidly than the Algonquin beaches as far south as Norwood, on the east side of Lake Michigan, and Ossineke, in the west side of Lake Huron. At Norwood it is about 650 feet above sea level, and at Ossineke 640 feet. The highest Algonquin beach at these points is only 22 to 24 feet above the Battlefield beach.

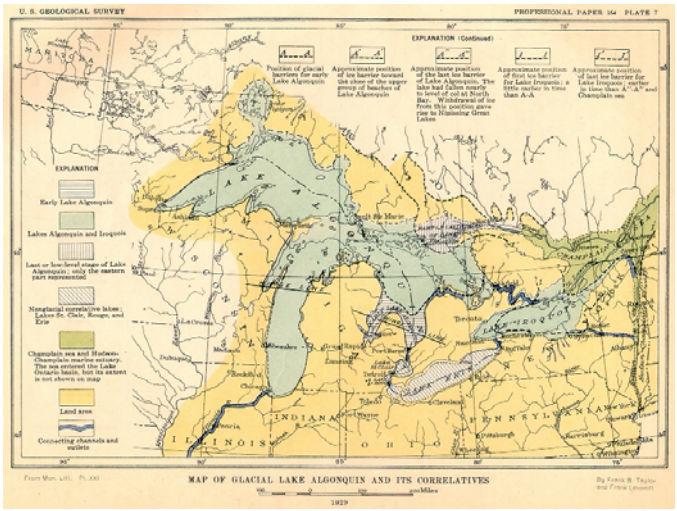
[17]U. S. Geol. Survey Mon. 53, p. 440, 1915.

The Battlefield beach is well defined on the islands along St. Marys River from Drummond Island to Sugar Island and is present back of Sault Ste. Marie, where its altitude is 790 feet. This beach is also well defined on the borders of the Lake Superior Basin in Michigan, Wisconsin, and Minnesota. It becomes complex on the borders of this basin and is split into two or three members, whose altitude, as determined by hand level near Grand Marais Mich., is 785 feet, 760 feet, and 725 feet above sea level. Above these beaches at Grand Marais are five Lake Algonquin beaches, of which the highest is 895 feet and the lowest 820 feet above sea level. The highest beach here may not be the highest of the Algonquin series. Back of Sault Ste. Marie, Ontario, beaches that seem referable to the Battlefield series are found at intervals of 10 to 15 feet from 740 feet up to 790 feet above sea level. Nine Lake Algonquin beaches ranging in altitude from 820 feet to 1,015 feet are found in that locality. The Battlefield beach is especially well displayed on the Keweenaw Peninsula and the east face of the Bayfield Peninsula and at many places along the north side of Lake Superior in northeastern Minnesota. In all these places it is usually represented by two or more members separated by narrow spaces.

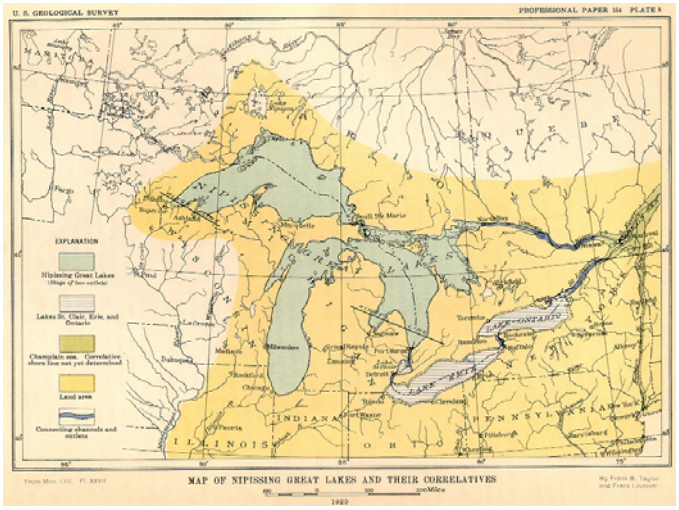
FORT BRADY BEACH

The Fort Brady beach stands between the Battlefield beach and the Nipissing beach. It seems to have been first brought to notice in the writer's studies in 1905. It is named from the fort at Sault Ste. Marie that stands on it.

At the fort there is a cut bank, in front of which is a boulder-strewn terrace. The beach is relatively weak, being about like the weaker members of the Algonquin series. At Fort Brady the beach is slightly below 700 feet above sea level, but a few miles to the east, at the north end of Sugar Island, it reaches 704 feet. It declines to about 660 feet at St. Ignace and is exceptionally well developed in that vicinity. At Grand Marais and in the vicinity of Marquette it is 670 feet above sea level. It is well displayed on the Keweenaw and Bayfield Peninsulas and on the Apostle Islands, as well as along most of the north shore of Lake Superior in Minnesota.



[PLATE 7. Map of glacial Lake Algonquin and its correlatives]



[PLATE 8. Map of Nipissing Great Lakes and correlatives]

The lake that formed this beach was probably merely a lower stage of the one that formed the Battlefield beach and discharged eastward through the Ottawa Valley while it was still partly obstructed by the ice.

PASSAGES BETWEEN THE LAKE SUPERIOR AND LAKE MICHIGAN BASINS

Reference has already been made to the Au Train-Whitefish lowland, which runs southward from the Lake Superior coast at Au Train to the head of little Bay de Noc, an arm of Green Bay, at Rapid River. The divide on this lowland is in a swamp between Mud Lake and Trout Lake at 768 feet above sea level, or 166 feet above Lake Superior. This lowland has a rock floor exposed along much of its length, and Au Train River falls about 100 feet in less than a mile directly north of the crossing of the Munising, Marquette & Southeastern Railway. This lowland has been under consideration by Government officials and others interested in the development of navigation between the Lakes as a shortcut between Lake Superior and Lake Michigan. But the expense of developing a waterway has been found to be so great that it overbalances the advantages in shipping. The amount of shipping between the ports on Lake Superior and Lake Michigan is relatively small when compared with the shipping toward the Atlantic seaboard.

Another passage between the Lake Superior and Lake Michigan drainage basins is found near Wetmore station on the Duluth, South Shore & Atlantic Railway. Here a swamp connects the head of Anna River with one of the tributaries of Manistique River. Its altitude is 838 feet. It is a relatively narrow passage, and the land close by on either side is nearly 900 feet above sea level.

A passage east of Sency connects headwaters of Taquamenaw River with one of the tributaries of Manistique River. This is the lowest passage into the Manistique drainage area from the Lake Superior Basin, being only 720 feet above sea level. It is about 2 miles in general width in its narrowest part, from a point near McMillan westward into the Manistique drainage basin, but there widens out into an extensive marsh through which several of the tributaries of the Manistique take their courses. East of McMillan in places the swamp is widened to 5 or 6 miles or more and is bordered by morainic ridges. A sandstone formation is crossed by Taquamenaw River at the northeast end of the swamp, and a descent is made in a short distance over the sandstone ledges to the level of Lake Superior. The effect of the northward differential uplift has been to increase the swampy conditions in the Taquamenaw by reducing the gradient of the stream. But in the Manistique drainage system, which leads southward, the gradient has been increased. As a result, the streams are cutting trenches and have narrow strips of dry land on their immediate borders.

The Manistique drainage basin is bordered on the north by extensive outwash plains next to the morainic belt that lies along the south edge of the Lake Superior Basin which are at a much higher level than the marshy plains to the south or the swampy passage connecting the Taquamenaw and Manistique drainage areas. There is generally an abrupt blufflike rise of 50 feet or more from

the marshy sandy plains to these outwash plains. The higher plain consists usually of gravel and cobbles; the low plain and marshes are underlain by sand. It seems probable that the low plain was covered with lake waters to the height of the high plain at the time the high plain was built up as an outwash from the ice into this lake. If so, the abrupt border marks an old shore line or the place to which the outwash into the lake reached.

There are two table-lands of cobbly and gravelly outwash farther south in the Manistique drainage basin which stand somewhat higher than the bordering swamps and sandy plains. One of these is in the Hiawatha Settlement and is described on page 51 in connection with the moraine of which it is an outwash. It is fully 50 feet above the bordering sandy land and probably was built up at the edge of a lake, though it stands lower than the highest Algonquin shore. The other table-land lies about 6 miles southeast of Shingleton. It is covered with cobbles and gravel, but the surrounding lower land is sandy. It is about 60 feet higher than the sandy plain and covers about 4 square miles. It seems to be somewhat lower than the highest Algonquin level.

NIPISSING GREAT LAKES

The next stage in the geologic history of this region is represented by the Nipissing Great Lakes. These lakes occupied the basins of the upper three Great Lakes, Superior, Michigan, and Huron, and were almost as distinctly separated as those of to-day. (See pl. 8.) They were, however, all at a single level, for their waters covered the present rapids at Sault Ste. Marie to a depth of about 50 feet. The water also stood about 50 feet above the Strait of Mackinac, and there was a strait farther south leading from the head of Little Traverse Bay past Burt and Mullet Lakes to Cheboygan. On most of the borders of Lakes Superior, Michigan, and Huron the Nipissing shore line is less than a mile from the present water's edge. For a short distance near the west end of Lake Superior the present lake, as indicated in Figure 10, covers and extends beyond the Nipissing shore line. The water was about 2 miles in width at Sault Ste. Marie but expanded to a width of 10 to 12 miles a few miles to the southeast, in the vicinity of Mud Lake. The outlet of the Nipissing Great Lakes, as determined by F. B. Taylor in 1893, had its head at North Bay, Ontario, on the northeast shore of the present Lake Nipissing. The discharge passed down Mattawa River to the Ottawa and thence to an arm of the sea in the St. Lawrence Valley. (See pl. 8.) Later the differential uplift raised the outlet at North Bay so high that the lake waters were brought up to the St. Clair outlet at Port Huron. By this rise any shore work done by the Nipissing Great Lakes south of the isobase that runs through the North Bay outlet would have been submerged and to a large degree obliterated. The original Nipissing beach is to be seen, if anywhere, only in the extreme northeastern part of the Lake Superior Basin. The visible Nipissing beach is therefore, in the main, the product of the shore work after this rise, at a time when both the North Bay and the St. Clair outlet were in use. The Nipissing beach is a strong shore line throughout nearly all its course around the Nipissing Great Lakes. In places it is marked by a steep bluff 25 to 30 feet or more in height, and in others by strong gravel bars. To cut back far enough to give this height the lake probably encroached on the land a considerable part of a mile. The headlands or projections and exposed points on this old shore are generally marked by cut banks showing removal or encroachment, and the recesses along the shore are generally marked by ridges of sandy gravel which tend to fill them and thus straighten the shore.

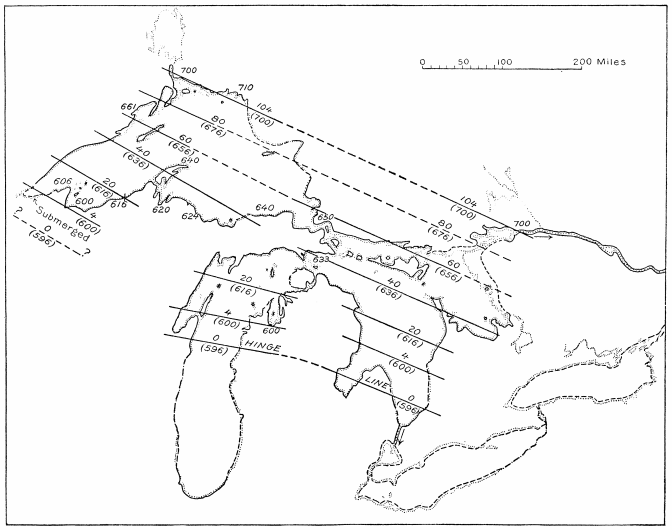


FIGURE 10.—Map showing isobases of the Nipissing Great Lakes at the two-outlet stage. The figures above the isobases indicate altitude above the horizontal or unaffected part of the beach south of the hinge line; the figures in parentheses below the isobases and the scattered figures elsewhere indicate altitude above sea level.

On Whitefish Point a large number of ridges of sandy gravel were developed by the Nipissing Great Lakes, which extended the point several miles beyond its former limits. The area occupied by these sand ridges is indicated on Plate 1. At the city of Escanaba the currents of this lake stage and a slightly higher lake stage gathered up the sandy material laid down at the mouth of Escanaba River and strung it out in a long ridge that reaches from the mouth of the river beyond the city and has a width of about a mile and a length of 5 or 6 miles. The city thus stands on a sand bar, and the swamp back of the city represents a bay that separated it from the mainland. At Au Train there is a great accumulation of sandy and gravelly material filling in the space between Au Train Lake and the shore of Lake Superior. There are also very extensive sandy bars along the shore of Lake Michigan immediately west of the Strait of Mackinac, filling the space between Brevoort Lake and the Lake Michigan shore. They cover a space 1 to 2 miles in width and 8 to 10 miles in length. These several places afford some of the most striking examples of the development of sand ridges in connection with the

Nipissing Great Lakes, but the wave work along the shore is a conspicuous feature throughout almost the entire borders of Lakes Superior, Michigan, and Huron. Many of the land-survey plats made by the Government surveyors indicate the position of the Nipissing shore as the "former coast line," its features being so strikingly similar to that of the present shore and its separation so slight both in altitude and in distance as to leave no doubt concerning the interpretation.

The main Nipissing beach is at the level where the waters stood when the outlet past Port Huron came into use. In the course of the cutting down of the Port Huron outlet to the present level, a cut of about 15 feet, the waves have formed beaches below the main one. In the part of the shore where no uplift has occurred these lower beaches are less than 596 feet above sea level. This part embraces most of the Saginaw Basin, the part of the Lake Huron Basin east of the Thumb of Michigan, and the part of the Lake Michigan Basin south of Manistee, Mich., and Algoma, Wis. The northern parts of the Lake Huron and Lake Michigan Basins, including much of Georgian Bay and Green Bay, have suffered uplift, and so has the entire Lake Superior Basin. As a result of this uplift the main Nipissing beach has been carried up to about 700 feet above sea level in the vicinity of the North Bay outlet and in the northeastern part of the Lake Superior Basin. The lower beaches appear at several lower levels, but are relatively weak features, and indicate that uplift was going on at such a rate that the lowering waters had not time to build strong shores at any given level.

The altitudes and tilting of the highest Nipissing beach have been set forth in Monograph 53 for the Lake Superior Basin, as well as for the Lake Michigan and Lake Huron Basins. Plate 8 and Figure 10 are taken from that report. It was shown that on the east side of Lake Huron the beach rises from an altitude of 596 or 597 feet at the south end to 698 feet at North Bay. On the west side of Lake Huron it rises from 595 feet at Port Huron to 626 feet at Cheboygan and 631 feet on Mackinac Island. On the east side of Lake Michigan it is at 595 to 597 feet as far north as Herring Lake, a few miles south of Frankfort, Mich., and on the west side as far north as a point 4 miles north of Algoma, Wis. Between that point and Rapid River, at the head of Little Bay de Noc, it rises to 613 feet. It is also at 612 to 613 feet on the Garden Peninsula at Fayette Bay.

On the south side of Lake Superior the Nipissing beach declines from about 650 feet at Sault Ste. Marie to 635 feet at Grand Marais, Mich., 628 feet at Marquette, 620 feet at L'Anse, 616 feet at Ontonagon, and 606 feet near Bayfield, Wis.; west of the Bayfield Peninsula it is either combined with or falls below the present shore of Lake Superior. As the Keweenaw Peninsula is farther north than neighboring parts of the south shore of Lake Superior the Nipissing beach is somewhat higher there, being 640 feet above sea level at Eagle Harbor and Copper Harbor, 635 feet at Lac la Belle, and 630 feet at the north end of the Portage Canal. On the north shore of Lake Superior the Nipissing beach is combined with or below the present shore of the lake as far northeast as Beaver Bay. At Little Marais it is only 10 feet above Lake Superior, or 612 feet above sea level. It reaches 623 feet at Lutzen, 630 feet at Grand Marais, 638 feet at Chicago Bay, and 661 feet at Port Arthur. In the northeastern part of the Lake Superior coast, at Jackfish Bay and Peninsula Harbor, it is slightly above 700 feet. The accompanying map (fig. 10), taken from Monograph 53, sets forth the trend of isobases for each 20 feet of uplift in the three basins occupied by the Nipissing Great Lakes.

FEATURES OF THE PRESENT SHORES

The features of the present shores of the Great Lakes have on the whole a stronger expression than those of the glacial lakes, the lake cliffs reach greater heights, and the beaches and bars are more pronounced. The shores of the Nipissing Great Lakes come nearer than those of any of the glacial lakes in rivaling the strength of the present shores. From this it should not necessarily be inferred that the glacial lakes were of correspondingly shorter duration, for it seems not unlikely that shore work was hampered to a greater extent by a frozen condition in the glacial lakes than it is in the present lakes.

The present lakes have encroached on the land along the greater part of their shores, and in places cliffs over 100 feet in height rise abruptly from the water's edge. The islands especially show prominent cliffs. The building of barrier bars across bays is conspicuously illustrated in Minnesota Bar, at the head of Lake Superior, and in the bar across Chequamegon Bay opposite Ashland, Wis. At Gladstone, Escanaba, and Menominee, Mich., there has been a marked growth of sandy points lakeward. In the vicinity of Marquette, Mich., rocky islands have been joined to the mainland by the filling in of the channels that once separated them.

The northward differential uplift has caused a rise of water at the southwest end of the Lake Superior Basin, so that the Nipissing shore is submerged for a short distance from the head of the lake. There are features which suggest that this uplift may still be in progress. George R. Stuntz,[18] a land surveyor, found stumps in places beneath the water of St. Louis River near its mouth, which seem to indicate a relatively recent rise of the water on the land. G. L. Collie[19] in his studies of the Apostle Islands has found evidence of a rise of water that has caused the removal of the ends of spits that extend out from the islands into Chequamegon Bay. One at the south end of Madeline Island, "according to well-authenticated tradition," once extended 5,000 feet from the island. A shoal now marks its former position and shows that the extent is not exaggerated. It is a destructional feature, not constructional. Old residents of Madeline Island state that the spit has been cut away 2,000 feet in the last 50 years. It remains to be determined whether this recent rise is independent of the uplift that tilted the Nipissing and earlier beaches or is part of a movement that has continued to the present

time. Its rate seems to be more rapid than is consistent with a continuous uplift dating back to the time of the Nipissing beach.

[18]On some recent geological changes in northeastern Wisconsin: Am. Assoc. Adv. Sci. Proc, vol. 18, pp. 205-210, 1870.

[19]The Wisconsin shore line of Lake Superior: Geol. Soc. America Bull. vol. 12, 197-216, 1901.